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The Impact of Bilingualism on the Communicative Skills of Autistic and Neurotypical Children



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THE IMPACT OF BILINGUALISM ON THE COMMUNICATIVE SKILLS OF AUTISTIC AND NEUROTYPICAL CHILDREN

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A mon papa, mon étoile la plus brillante.
Et à ma maman, la plus fiable des boussoles.

ABSTRACT

Communication – the exchange of information through verbal and non-verbal means – relies on several key abilities, including (1) co-speech gesture comprehension, which facilitates spoken language understanding; (2) metalinguistic awareness, which enables reflection on language structure and meaning; and (3) narrative macrostructure, which ensures coherent and structured discourse. These skills are interwoven with cognitive and linguistic skills, making them particularly relevant for studying communication in both typical and atypical development. They are also known to be affected in Autism Spectrum Disorder (ASD), yet enhanced by bilingualism in neurotypical populations. However, the impact of bilingualism on communicative abilities in autism remains underexplored, raising questions among educators and caregivers about whether bilingual exposure might exacerbate communication challenges for autistic individuals.

Autism is characterized by differences in communication and social interactions, often manifesting as difficulties in integrating gesture with speech, interpreting ambiguous linguistic structures, and constructing well-organized narratives. Yet, variability in these abilities suggests that cognitive, linguistic, and environmental factors may influence communicative outcomes in autism. Bilingualism, a dynamic experience that shapes language and cognition, has been associated with communicative advantages in neurotypical children, such as heightened sensitivity to non-verbal cues and greater metalinguistic awareness. Understanding whether similar benefits extend to autistic individuals is critical for informing evidence-based recommendations.

This thesis examines the effects of bilingualism on gesture comprehension, metalinguistic awareness, and narrative macrostructure in autistic and neurotypical children aged 3 to 12 years. The research comprises sixth experimental studies conducted within the ABCCD project, using digitalized and gamified tasks to enhance accessibility, particularly for autistic participants. Gesture comprehension was assessed through pointing, iconic, and conventional gestures, both in isolation and in combination with speech. Metalinguistic awareness was assessed through a grammaticality judgment task, requiring participants to evaluate sentences based on grammar rather than meaning. Narrative macrostructure was examined through a storytelling task particularly suited for multilingual populations. Crucially, this research moved beyond binary monolingual-bilingual comparisons by incorporating continuous bilingual variables and controlling for participants' language and cognitive skills.

Findings revealed bilingual-related advantages in neurotypical children across two domains: gesture comprehension, and narrative macrostructure. Autistic children benefited from bilingualism particularly in metalinguistic awareness, but no significant effects were found in gesture comprehension or narrative macrostructure. These results suggest a

differential impact of bilingualism on communicative abilities in neurotypical and autistic populations. Importantly, bilingualism had no adverse effect on any communicative domain in autistic participants. These findings alleviate concerns that bilingual exposure may pose additional challenges for autistic children, instead supporting the recommendation that they maintain use of all their languages.

A key strength of this thesis lies in its international reach, inclusion of five language versions, and careful operationalization of bilingualism. The findings provide a foundation for future research on how specific bilingual variables (e.g., relative exposure, language proficiency) influence communicative skills in autistic and neurotypical children. This work has important clinical and educational implications, advocating for evidence-based support strategies that recognize bilingualism as a viable and non-detrimental experience for autistic children.

RÉSUMÉ

La communication, à savoir l'échange d'informations par des moyens verbaux et non verbaux, repose sur plusieurs compétences clés, telles que (1) la compréhension des gestes co-verbaux, facilitant l'interprétation du langage parlé ; (2) la conscience métalinguistique, permettant de réfléchir à la structure et au sens du langage ; et (3) la macrostructure narrative, garantissant un discours cohérent et structuré. Ces compétences sont étroitement liées aux habiletés cognitives et linguistiques, les rendant particulièrement pertinentes pour l'étude de la communication dans le développement typique et atypique. De plus, elles sont connues pour être altérées dans le trouble du spectre de l'autisme (TSA), mais renforcées par le bilinguisme chez les personnes neurotypiques. Toutefois, l'impact du bilinguisme sur les compétences communicatives des personnes autistes reste peu étudié, soulevant des interrogations parmi les éducateur·rice·s, et les aidant·e·s quant à une éventuelle exacerbation des difficultés de communication chez ces individus.

L'autisme se caractérise par des différences dans la communication et les interactions sociales, qui se manifestent notamment par des difficultés à intégrer les gestes avec la parole, à interpréter des structures linguistiques ambigües et à organiser des récits de manière cohérente. Cependant, ces compétences varient d'une personne à l'autre, suggérant que des facteurs cognitifs, linguistiques et environnementaux peuvent influencer les compétences communicatives. Le bilinguisme, une expérience dynamique qui façonne le développement linguistique et cognitif, est associé à des avantages communicatifs chez les enfants neurotypiques – telle qu'une sensibilité accrue aux indices non-verbaux et une conscience métalinguistique plus développée. Il est donc essentiel de comprendre si ces bénéfices s'étendent aux enfants autistes, afin d'élaborer des recommandations fondées sur des preuves scientifiques.

Cette thèse examine les effets du bilinguisme sur la compréhension des gestes, la conscience métalinguistique et la macrostructure narrative chez les enfants autistes et neurotypiques âgés de 3 à 12 ans. Cette recherche repose sur six études expérimentales menées dans le cadre du projet ABCCD, utilisant des tâches informatisées et ludiques afin d'améliorer leur accessibilité auprès des participant·e·s autistes. La compréhension des gestes a été évaluée au travers des gestes de pointage, iconiques et conventionnels, seuls ou accompagnés de parole. La conscience métalinguistique a été mesurée à l'aide d'une tâche de jugement de grammaticalité, dans laquelle les participants devaient évaluer des phrases sur la base de leur grammaticalité et non de leur sens. Enfin, la macrostructure narrative a été étudiée au travers d'une tâche de narration particulièrement adaptée aux populations multilingues. Ce travail va au-delà des comparaisons binaires monolingue-bilingue traditionnelles en intégrant des variables continues de l'expérience bilingue et en tenant compte des compétences linguistiques et cognitives des participant·e·s.

Les résultats révèlent des avantages liés au bilinguisme chez les enfants neurotypiques dans deux domaines étudiés : la compréhension de gestes et la macrostructure narrative. Les enfants autistes ont bénéficié du bilinguisme, en particulier au niveau de la conscience métalinguistique, mais aucun effet significatif n'a été observé sur la compréhension des gestes ou la macrostructure narrative. Ces résultats suggèrent un impact différentiel du bilinguisme sur les compétences communicatives des populations neurotypiques et autistes. Il est important de souligner que le bilinguisme n'a eu aucun effet néfaste sur les compétences communicatives des participants autistes. Ainsi, ces résultats participent à dissiper les craintes selon lesquelles l'exposition bilingue pourrait conférer des difficultés supplémentaires pour les enfants autistes, et soutiennent au contraire la recommandation de maintenir l'usage de toutes leurs langues.

L'un des points forts de ce travail de thèse réside dans son envergure internationale, la déclinaison de son protocole en cinq langues, et l'opérationnalisation rigoureuse du bilinguisme. Les résultats obtenus ouvrent la voie à de futures recherches sur l'influence de variables spécifiques du bilinguisme (e.g., l'exposition relative aux langues, leur niveau de maitrise), sur les compétences communicatives des enfants autistes et neurotypiques. Enfin, ce travail apporte des implications cliniques et éducatives importantes, en plaidant pour des stratégies d'accompagnement fondées sur des données empiriques robustes, reconnaissant le bilinguisme comme une expérience viable et non préjudiciable pour les enfants autistes.

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First and foremost, I would like to express my gratitude to the esteemed experts who have agreed to be part of my jury and evaluate my work. To Jean-Marie Annoni, who set me on the path of this ambitious project four years ago – without you, I would not be writing these lines today. To Ianthi Tsimpli, thank you for accepting to evaluate this work. I am also grateful to the jury members who have been actively involved in different phases of the project: Inge-Marie, thank you for your invaluable input during our meeting at the conceptualization phase. David, many thanks for your warm welcome at la Pitié-Salpétrière, and for giving our students the opportunity to access and test participants within your team. Letty, thank you for your dedication to this project, from conceptualization and data collection to the submission of abstracts for conferences and journal articles. Your input was always very valuable. It is a great honor for me to have such a distinguished jury. I am truly grateful to each of you for being part of it, and I extend my special thanks to Stephanie for bringing you all together.

Stephanie, my thesis supervisor, I am deeply grateful to you for giving me the opportunity to undertake this thesis and carry out the ABCCD project. Thank you for being present at every stage – always available, enthusiastic, and demonstrating unwavering determination. You examplify problem-solving and dedication to your work.

I also extend my gratitude to the *Swiss National Science Foundation*, whose funding, awarded through Stephanie Durrleman's grant, made this project possible. Thanks to this financial support and its effective management, I was able to carry out my thesis under excellent conditions. I feel privileged and grateful to have had access to high-quality equipment, to be able to compensate families for their participation, and to travel to conferences to disseminate our research and connect with other scholars.

I would also like to thank the students and interns who took an interest in our research topics and supported us at various stages of the project, including preparing assessment materials, recruiting participants, testing children, preparing and coding data, among others.

A special thanks as well to *Human Tech* at the *Haute-école d'ingénieurerie et d'architecture* of Fribourg, and particularly to Marine Capallera and Robin Cherix, for implementing our tasks as a tablet-based game using the stimuli and procedure we had designed.

A heartfelt thank you to the families and children who participated in this study. I am aware of the commitment it represents, and I am deeply grateful for the time and energy you dedicated to us. My gratitude also goes to the associations, schools, and hospital services that helped us recruit participants and welcomed us into their spaces.

A special *thank you* to my dear colleagues: Anna, I am grateful for our discussions and for your thoughtful proofreading, which greatly helped me refine the writing. Ehsan, thank you for your expertise and support. Though our time working together was short, I learned a lot from you, and it was a pleasure to collaborate with you. My dear Sarah, thank you for your careful proofreading and for the warm moments we shared during your visits to Switzerland.

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Aline, merci pour ton soutien et ta bonne humeur, qui ont illuminé cette aventure doctorale. Tu rends ce parcours bien plus agréable ! Ton tour arrive bientôt, j'ai hâte de célébrer!

Aux affreux et aux affreuses, ma petite famille suisse, merci d'être là et de diffuser tant de bonheur autour de vous.

Enfin, à ma maman et mon frère, merci pour votre amour et votre confiance en moi. Merci de m'avoir soutenue dans mon choix de reprendre les études. Il y a dix ans, notre vie prenait un tournant, mais je regarde le chemin parcouru depuis avec beaucoup de fierté.

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PREFACE

This dissertation was written as part of my doctoral thesis within the *ABCCD project* (i.e., Autism, Bilingualism, Cognitive and Communicative Development), which began in September 2021. Funded by the *Swiss National Science Foundation* and led by Dr Stephanie Durrleman at the University of Fribourg (Switzerland), this project aimed to examine the impact of bilingualism on the cognitive and communicative abilities of neurotypical and autistic children aged 3 to 12. Given that several cognitive and communicative skills known to be affected in Autism Spectrum Disorder (ASD) have been found to benefit from bilingualism in neurotypical individuals, understanding whether similar effects extend to autistic children is of particular interest. While preliminary studies suggest promising outcomes, research remains scarce, despite the critical need for evidence-based recommendations to support families raising an autistic child.

To address this gap, our team developed tablet-based *serious games* designed to provide a reliable and engaging assessment of the targeted skills. The protocol was developed in five languages (i.e., English, French, German, Italian and Spanish) to enable the inclusion of children with diverse linguistic backgrounds across multiple regions. Thanks to rich international collaborations and the dedication of numerous students, nearly 500 children were tested, a third of whom were diagnosed with ASD. To gather information on the evolution of these skills over time, approximately a third of the participants underwent a follow-up assessment one year later. This project has resulted in several conference presentations, posters and publications, including the articles presented in this dissertation.

The overarching aim of my PhD was to investigate *communicative* skills that are reportedly impaired in autism, but potentially enhanced by bilingualism. This objective was pursued through three key research goals:

1. To confirm whether differences in these communicative abilities were indeed observed between autistic and neurotypical children, while accounting for key developmental factors;
2. To contribute to the growing literature on the effects of bilingualism on communicative abilities of neurotypical children, which has yielded mixed findings, using a novel approach that addresses the limitations of previous research;
3. To determine whether the effects of bilingualism on these communicative skills also extend to autistic children.

Throughout the dissertation, I will use both *identity-first* (i.e., "autistic individual") and *person-first* language (i.e., "individual with autism") interchangeably to refer to individuals diagnosed with ASD. This decision reflects the effort to acknowledge and respect the diverse perspectives and preferences within the autistic community, their families, and stakeholders (Bottema-Beutel et al., 2021; Bureau et al., 2024; Kenny et al., 2016).

STATEMENT OF CONTRIBUTIONS

As the primary researcher of this thesis, I was actively involved in multiple stages of the research process. Specifically:

- **Task conceptualization and design**: The test material was conceptualized and designed with input from Stephanie Durrleman and Franziska Baumeister. I was responsible for developing the Gesture Tasks (**Sections 4.1**, **4.2**, and **4.3**) and the Grammaticality Judgment Task (**Sections 5.1** and **5.2**), which were later implemented on tablets by our collaborators at *Human Tech* (Haute école d'ingénierie et d'architecture – HEIA, Fribourg). I also coordinated the implementation of the narrative task (MAIN; **Section 6**) and a Verbal Fluency Task, which is not included in this dissertation. Task materials and stimuli were initially created in French and then translated into German, English, Italian, and Spanish. I thank Franziska Baumeister, Stephanie Durrleman, Elisabet Vila Borrellas as well as our research assistants for their careful language revisions and material piloting. In collaboration with Franziska Baumeister and the support of students, I implemented standardized language tasks (Peabody Picture Vocabulary Test, PPVT; Test for Reception of Grammar, TROG; Non-Word Repetition, NWR) and parental questionnaires (background information; Social Communication Questionnaire, SCQ; Theory of Mind Inventory, ToMI; Strengths and Weaknesses of ADHD Symptoms and Normal Behaviors, SWAN) on *Gorilla Experiments* platform. I also created the Q-BEx questionnaire in all five languages.
- **Data preparation**: Together with Franziska Baumeister, I conducted and coordinated the regular download of parental questionnaires and data files (PPVT, TROG, NWR). I wrote scripts to calculate scores based on reference norms for the PPVT, TROG, and to retrieve information from the parental questionnaires in each language. Additionally, I prepared and processed data for the Gesture Tasks, the Grammaticality Judgment Task, the MAIN and the Q-BEx questionnaire.
- **Ethical procedures**: Ethical procedures for this project were implemented in collaboration with Stephanie Durrleman and Franziska Baumeister. The study was approved by the Swiss Association of Research Ethics Committees Swissethics (Project-ID 2022-00878). I am grateful to the collaborators who participated in data collection by overseeing the ethical procedures to facilitate the research approval by the Research Ethics Committee of Ethical Review of Unió Catalana Hospitals Foundation (Spain), the Research Ethics Board Office at McGill University (Canada), Psychology Research Ethics Committee of the University of Edinburgh (UK), the Institutional Review Board of Emerson College Boston (US), and the Institutional Review Board at the University of Connecticut (USA).

- **Recruitment and data collection**: Franziska Baumeister and I piloted the ABCCD protocol with approximately 40 adult native speakers of French, German, English, and Italian, recruited via university channels and social media. During the assessment phase with children, I recruited and tested participants in France and the French-speaking region of Switzerland. Alongside Stephanie Durrleman, I coordinated training and data collection with our collaborator Vicky Chondrogianni in Edinburgh. Neurotypical and autistic children were recruited through flyers, clinician and hospital contacts, cantonal administrations, social media, and schools.
  Throughout my PhD, I supervised nine Master's students (across seven research topics, mostly in collaboration with Stephanie Durrleman) and 31 interns who contributed to material preparation, participants recruitment, data preparation, and data collection. For the second testing phase, conducted one year later, I led and supervised testing mainly in France and the French-speaking regions of Switzerland. For the second testing point, I supervised testing in the Swiss German area as well. Stephanie Durrleman supervised all stages of the project.
- **Data analysis**: I conducted all statistical analyses presented in the experimental contributions of this dissertation.
- **Manuscript preparation and dissemination**: I took the lead in writing and revising the manuscripts included in this dissertation, incorporating feedback from co-authors and peer reviewers (when available). Additionally, I presented findings at conferences and engaged in scientific discussions to refine interpretations of the results.

While this dissertation reflects a collaborative effort with my supervisor and co-authors, the work presented here primarily represents my own contributions, from study design to final publication.

LIST OF PUBLICATIONS INCLUDED IN THIS MANUSCRIPT

The research conducted for this PhD has resulted in the following publications, for which I led the phases of conceptualization, material development and validation, data collection and supervision, data curation, formal analyis and visualization, as well as writing, submission and dissemination (see *Statement of Contributions*). I am very grateful to my colleagues, co-authors and supervisor for their valuable contributions at different stages of this process. Their respective roles are duly acknoweldged in the *contribution sections* of each article.

- In **Section 4.1**:

Wolfer, P., Baumeister, F., Cohen, D., Dimitrova, N., Solaimani, E., & Durrleman, S. (2025). Co-speech gesture comprehension in autistic children. *Journal of Child Language*. https://doi.org/10.1017/S0305000925000157

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- In **Section 5.1**:

Wolfer, P., Baumeister, F., Rudelli, N., Corrigan, G., Naigles, L. R., & Durrleman, S. (2024). Exploring Metalinguistic Awareness in School-Aged Autistic Children: Insights from Grammatical Judgment. *Journal of Autism and Developmental Disorders*. https://doi.org/10.1007/s10803-024-06569-y

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- In **Section 6**:

Wolfer, P., Tselekidou, F., Baumeister, F., Gagarina, N., & Durrleman, S. (Manuscript submitted for publication). The impact of exposure to additional languages and cognitive factors on narrative macrostructure in autistic and neurotypical children.

ADDITIONAL CONTRIBUTIONS

- In **Appendix A**:

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LIST OF ABBREVIATIONS

The following abbreviations will be used throughout the manuscript:

ABCCD	Autism, Bilingualism, Cognitive and Communicative Development
ADHD	Attention-deficit with/ or without Hyperactivity Disorder
ASD	Autism Spectrum Disorder
EF	Executive functions
GJT	Grammaticality Judgment Task
IQ	Intelligence quotient
LITMUS	Language Impairment Testing in Multilingual Settings
MA	Metalinguistic awareness
MAIN	Multilingual Assessment Instrument for Narratives (Gagarina et al., 2019)
NT	Neurotypical
Q-BEx	Quantifying Bilingual EXperience (questionnaire; de Cat et al., 2022)
TD	Typical development
WM	Working memory

Concepts

1 COMMUNICATION

1.1 COMMUNICATION: AN ESSENTIAL, MULTIFACETED COMPETENCE

1.1.1 Defining communication

Interpersonal communication (hereafter *communication*) can be defined as "*a dynamic and ongoing process whereby senders and receivers exchange messages*"(Burgoon et al., 1996, p. 10). Messages are bits of information, such as ideas, emotions, intentions, knowledge or cultural symbols. On the one hand, communication is *symbolic* and relies on shared systems of meaning such as language (Saussure, 1983; Tomasello, 2008). On the other hand, communication is *pragmatic* as it adapts to the social and situational context (Grice, 1975). Beyond its primary purpose of information transmission, communication notably enables individuals to coordinate actions and behaviors, build relationships, influence others, create shared understanding and establish cultural and social connections (Hargie, 2019, 2021). As such, the ability to communicate in an effective and socially appropriate manner – also referred to as *communicative competence* (Jensen & Trenholm, 2025) – represents a pivotal skill for human beings. Communicative competence is considered to play a pivotal role in health and overall well-being (Hannawa & Spitzberg, 2015). Research indicates that stronger communicative skills are associated with a higher quality of life, encompassing benefits such as enhanced happiness, resilience to stress and psychosocial challenges, as well as improved academic and professional achievements (Hargie, 2019).

Throughout the years, several models have been developed to best describe, explain, and represent the process of communication. Central to the concept of communication is the interaction between a *sender* and a *receiver*, mediated by a shared *code* – such as language, symbols, or gestures – and influenced by context (Shannon & Weaver, 1949). The context refers to the *communicative situation*, that encompasses the physical, social, and cultural environments in which communication takes place, as well as the personal experiences and perceptions of the individuals involved. Early models of communication, such as the influential *mathematical model of communication* proposed by Shannon and Weaver (1949) emphasized a linear transmission of information from sender to receiver. Over time, more nuanced frameworks emerged, like Schramm's interactive model (1954) or Barnlund's transactional model (1970), to account for the dynamic and reciprocal nature of communication. Schramm (1954) notably emphasized the role of context, in introducing

the notion of *field of experiences* which refers to communicators' background, perceptions, life experiences, values, and beliefs that shape their ability to encode and decode the message. Barnlund (1970) later highlighted the simultaneous nature of communication where all participants are both senders and receivers at the same time, underlying the role of *feedback* in ensuring mutual understanding and co-creation of meaning.

Communication is multimodal by nature: it encompasses both verbal (i.e., spoken language) and non-verbal (e.g., gestures, prosody) modalities to create and share meaning. Communication indeed entails "*any behaviors that are sent with intent or interpreted as meaningful by a receiver*" (Guerrero, 2014, p. 54). Both verbal and non-verbal cues interact to convey abstract and concrete meaning flexibly across contexts. Verbal communication in humans refers to the use of structured signs systems such as spoken, written, and signed languages to convey meaning (Rocci & Saussure, 2016). Language, by its intentionality and complexity, constitutes a unique human faculty (Tomasello, 2008). It plausibly evolved with human thinking and reasoning abilities (Fedorenko et al., 2024). Initially conceived as a system of arbitrary symbols (or signs) joining a concept to a sound image (Saussure, 1983), more recent works aknowledge the *embodied*, *embedded,* and *cognitive* nature of language and communication (Dijkstra & Peeters, 2023): Language users engage their body to communicate and speak (i.e., embodiedeness or embodiment), consider the sociocultural, psychological and physical context they belong to (i.e., embeddedness), and rely on various cognitive processes, such as short-term memory or attention, to interpret meaning and communicate efficiently.

Non-verbal communication represents all other communicative behaviors that are not verbal *per se*. It consists of various parameters such as *kinesics* (e.g., gestures, facial expression, posture, body and eye movements), *vocalics* (e.g., speech prosody, pitch or pace) or *chronemics* (i.e., response time), among others (Guerrero, 2014; Knapp et al., 1978). While often underestimated, non-verbal behaviors are estimated to convey the greatest portion of the message meaning in interpersonal communicative situations, from 93% to 60 - 65% (Guerrero & Floyd, 2006).

1.1.2 Developmental aspects of communication

According to Tomasello (2008; 2005), communication is grounded in humans' ability for *shared intentionality*, namely the capacity to collaborate on joint goals and intentions, establish mutual knowledge, share beliefs, and engage in joint attention with others in cooperative contexts. Tomasello (2005) posits that this capacity for shared intentionality distinguishes humans from other species, and serves as the foundation for uniquely human traits such as language, culture, and complex social cooperation. From a developmental perspective, research indeed highlights the collaborative nature of communication: Both joint attention and turn-taking development are foundational communicative processes (Carpenter et al., 1998; Moore & Dunham, 1995; Snow, 1977).

Communicative development follows a fairly consistent pattern in children (Buckley, 2012): In the prelinguistic stage occurring during the first year of life, infants use gestures

such as pointing, gaze following, and vocalizations to convey needs and share interests. Pointing gestures, used to share interest, are considered a hallmark of human communication (Tomasello et al., 2007). The second year corresponds to a pivotal period for the development of language: From the production of protowords (Bates et al., 1975), children first start producing single words from 12 to 18 months, and experience a *vocabulary spurt* slightly after (Bloom, 1993). Children then start asking questions and commenting (Buckley, 2012 citing Halliday, 1975). In the third year, these communicative behaviors consolidate, and language complexifies in both understanding and expression: Vocabulary continues to grow with the acquisition of 2 to 4 words per day, grammatical skills develop to enable the comprehension and production of more complex sentences (Buckley, 2012 for an overview). Children also grammatically revise their productions and start clarifying their message, two noticeable metalinguistic behaviors (Gallagher, 1977). By age three, children become more capable of maintaining conversational topics and improving their adaptation to the needs of a conversation (Pan & Snow, 1999). As they mature, their communicative skills become more elaborate and attuned to the social and contextual contexts. They notably develop storytelling skills, can engage in extended conversations around a shared topic, and express intentions through varied grammatical structures (Buckley, 2012).

As children's communicative abilities become more sophisticated, their ability to engage in efficient interactions and convey complex ideas relies not only on linguistic skills but also on broader socio-cognitive skills. In particular, the development of communication is intertwined with the maturation of executive functions (EF), such as attention and cognitive flexibility, and Theory of Mind (ToM) abilities, such as perspective-taking (see **Section 2.2.1** for an outline of their acquisition paths and status in children diagnosed with Autism Spectrum Disorder).

1.1.3 Socio-cognitive foundations of communication

EF and ToM are not only essential for effective communication, but also co-develop with communicative abilities. On the one hand, EF supports cognitive control, which is necessary for maintaining attention during interactions, processing language, and adapting to social nuances (Diamond, 2013; Souissi et al., 2022). On the other hand, ToM enables individuals to infer and respond to others' thoughts and emotions (Rivero-Contreras et al., 2023). Research highlights that early EF skills, such as inhibitory control and working memory (WM), are closely linked to better linguistic and conversational abilities (Filipe et al., 2023; Shokrkon & Nicoladis, 2022; Šimleša et al., 2017). Similarly, the development of ToM is associated with exposure to linguistically rich environments and social interactions, helping children understand and engage with the mental states of others (Milligan et al., 2007; Siegal & Surian, 2012).

Not only is communication influenced by these socio-cognitive skills, but it is also fundamentally triggered by social motivation, i.e., a child's intrinsic inclination to engage

in social interactions (Buckley, 2012; Tomasello et al., 2005). Social interactions are essential for children's language development, providing a primary context for both learning and practicing language. Through interactions with caregivers and peers, children receive linguistic input and acquire communicative norms, fostering their language acquisition. For instance, Bruner (1983) highlights how caregiver scaffolding enables children to participate in increasingly complex communicative exchanges. These guided interactions gradually promote the development of their children's linguistic and social skills. Similarly, Bandura's *Social Learning Theory* (1977) and its later revision as *Social Cognitive Theory* (1986) underscore imitation as a key mechanism through which children acquire language and internalize communicative norms. Altogether, these findings demonstrate that communication is not merely a biological capacity, but a multifactorial phenomenon where social, cognitive and linguistic factors are intertwined (Tomasello, 2008; Tomasello et al., 2005). Communication is dynamically influenced by the environments in which individuals interact (Buckley, 2012).

In this dissertation, we will examine three communicative abilities that remain largely underexplored despite their relevance for effective communication. First, we will focus on the comprehension of co-speech gestures as an example of non-verbal behavior that supports semantic integration and enhances the comprehension of spoken messages (**Section 1.2**). Second, we will explore metalinguistic awareness, which represents a higher-order competence that engages cognitive and linguistic factors to support flexible and precise communicative interactions (**Section 1.3**). Finally, we will examine narrative macrostructure (i.e., the overall organization of stories), as it is essential for the delivery of rich and coherent information (**Section 1.4**).

1.2 CO-SPEECH GESTURES

1.2.1 Defining co-speech gestures

Communicative gestures, also referred to as *co-speech gestures*, are body movements that accompany or replace speech in the discourse (McNeill, 1992). They are produced in many communicative situations, such as narrations, conversations, presentations, as well as during instructional activities, explanations, or even collaborative problem-solving. Gestures constitute a universal aspect of human communication, observed across all societies (Cooperrider, 2021) and present throughout the lifespan (Göksun et al., 2022). Gestures generally involve the upper body, including head nodding, shoulder shrugs, and arm movements. Among these, manual gestures are likely the most mundane and complex forms of gesturing. They are also the most extensively studied (Abner et al., 2015). Hand gestures vary widely in their forms, purposes, communicative functions, and developmental acquisition. Importantly, gestures are distinct from *signs* used in signs languages: Gestures are often supplementary to speech and context-dependent, whereas signs belong to structured linguistic systems with established grammar and vocabulary (Goldin-Meadow & Brentari, 2017; Kita & Emmorey, 2023).

Manual gestures generally consist of several phases, which reflect their temporal and functional structure (Kendon, 1975; McNeill, 1992). These phases help organize gestures in alignment with the rhythm and meaning of accompanying speech (Kendon, 2004b). However, not all gestures exhibit every phase, and some may occur independently of speech. First, the *preparation phase* involves moving the hands and arms into position, ready to perform the gesture and marking its onset. Then, the *stroke phase* occurs: It corresponds to the most meaningful and prominent phase of the gesture, aligning temporally with accompanying speech (if present). It conveys the core semantic or pragmatic aspect of the gesture (e.g., index finger placed on the lips to gesture SILENCE). This phase is followed – or preceded – by the *hold phase*, where the hands pause either before or after the stroke. This phase may serve to synchronize with speech, emphasize the gesture, or allow for interpretation. Not all gestures include a hold phase, especially in fluid movements. Finally, the *retraction phase* corresponds to the hands and arms moving back to a resting position or transitioning into another gesture. This phase signals the conclusion of the gesture (Kendon, 1975; McNeill, 1992).

Various taxonomies have been developed to describe gestures (Ekman & Friesen, 1969; Kendon, 2004; Rohrer et al., 2020; see Maricchiolo et al., 2014 for an overview). McNeill's (1992, 2000) pioneering framework suggests classifying gestures based on their semantic function.

Four categories are proposed:

- (a) *iconic gestures* represent the referent to a certain extent, in the sense that they share a resemblance (e.g., in form, manner of execution) with the content of speech and idea being conveyed (e.g., using both hands to create a rounded shape in the air, as if outlining the contours of a ball to gesture BALL);
- (b) *metaphoric gestures* are similar to iconic gestures, but differ in that they depict abstract content, rather than concrete entities (e.g., mimicking grabbing something with the hand, when expressing "grasping an idea");
- (c) *deictic gestures* refer to pointing movements, generally with the index finger – although head or chin might also be sometimes used. They point out to a location in space, and can refer to concrete or conceptual entities (i.e., *abstract pointing*; for instance, in storytelling when referring recurrently to the same protagonist at the same location in space);
- (d) *beat gestures*, also known as *accent-batons* (Ekman & Friesen, 1972), are spontaneous rhythmic hand movements aligning with stress and prosody. Initially considered purely prosodic and relatively meaningless, recent research suggests that they play a positive role in narrative performance (Vilà-Giménez & Prieto, 2020), word recall (Igualada et al., 2017), and focusing on relevant linguistic information (D. Dimitrova et al., 2016).

A fifth category, although not presented in McNeill's early work, refers to *emblems* (also labelled as *conventionalized*, *emblematic*, or *quotable* gestures) (Ekman & Friesen, 1969; Kendon, 2004a). These gestures correspond to arbitrary, culturally shared gestures often used as idiomatic expressions without accompanying speech (e.g., waving a hand to say "goodbye"). Their meaning must be learned to be understood, as they vary across languages, cultures and communities (Gullberg, 2012; Kita, 2009). However, conventional gestures may vary in their degrees of iconicity and arbitrariness, ranging from a completely arbitrary link between the gesture and its referent (e.g., a THUMBS UP[1] gesture to convey approval) to a more iconic representation (e.g., moving fingers like SCISSORS to invite someone to stop talking).

These variations in gesture properties apply to all gesture types, and flexibility in classification is warranted, as gesture categories are not always mutually exclusive (Rohrer et al., 2020). Indeed, some gestures can fall into several categories. For instance, the HEART gesture can be considered iconic, when representing the anatomical organ, yet conventional when conveying love or affection. Similarly, in storytelling, gesturing FALLING at two different locations in space – where two protagonists were previously situated – would represent an overlap of iconic and deictic gestures. Gestures also differ in their levels of *indexicality* (i.e., the extent to which a gesture directly indicates something in its context), *iconicity* (i.e., the degree of resemblance to the referent), and *conventionality* (i.e., the extent to which a gesture's meaning is established through sociocultural agreement). This has led researchers to consider gestures as existing along their multiple dimensions and

[1] By convention, capital letters will be used to refer to gestures.

positioned on a continuum (e.g., *Kendon's continuum* as described by McNeill, 2000), rather than being classified into discrete categories.

Gesture use and processing are influenced by a range of factors related to both the communicative context (i.e., external factors) and individual differences (i.e., internal factors; Nicoladis & Smithson, 2022; Özer & Göksun, 2020). The *content of speech* (e.g., visuospatial information; Alibali, 2005), the *communicative intent* (e.g., Trujillo et al., 2018), the *type* of communicative situation (e.g., narration or conversation; McNeill, 1992), the *audience* and *communicative partners* (e.g., visibility among partners, Alibali et al., 2001; adaptation to interlocutors, Wray & Norbury, 2018) all impact gesture production and comprehension. *Feedback from interlocutors* (e.g., Bavelas et al., 1992) and *task difficulty* (e.g., Chu & Kita, 2011) can further modulate gestural behaviors. Moreover, *age* (e.g., Arslan & Göksun, 2022; Hostetter, 2011), *sex* (e.g., Acredolo & Goodwyn, 1988; Bakker et al., 2015; Özçalışkan & Goldin-Meadow, 2010), and *cultural background* (e.g., Kita, 2009), including *bilingualism* (e.g., Gullberg, 2012; Nicoladis & Smithson, 2022), and *language proficiency* (e.g., Aziz & Nicoladis, 2019; Zvaigzne et al., 2019) contribute to individual differences in gesture production and comprehension. For a more detailed discussion on bilingualism effects on gesture comprehension, we refer to **Section 4.2** and **Section 4.3**.

1.2.2 Developmental milestones

The development of gestures in children follows a consistent trajectory, closely intertwined with language development. While infants initially produce gestures to gain and direct attention, gestures soon become pivotal for the development of their language and communicative skills. Gestures emerge early in development: *showing*, *giving* and *pointing* gestures appear in this order between 9 and 12 months of age (Bates et al., 1975, 1979). At the same time, more primitive gestures, such as those expressing emotions, start to decrease in frequency (Blake & Dolgoy, 1993). During the second year, iconic gestures appear, followed closely by conventional gestures (Acredolo & Goodwyn, 1988; Iverson et al., 1994). At this stage, a shift in modality preference occurs: Children begin relying more on verbal labels than on gestures, as gesture production decreases in favor of spoken language development (Capone & McGregor, 2004). However, gestures are still observable and remain essential to children's communication: Gestures transition from being primary linguistic symbols in infancy to elements that clarify, supplement, and scaffold speech in both receptive and expressive communication (Capirci et al., 1996; Capone & McGregor, 2004; Morford & Goldin-Meadow, 1992). New types of gestures also emerge, such as *beat gestures*, which support speech production (Nicoladis et al., 1999).

Gestures play a crucial role in language development: Studies have indeed demonstrated that the frequency and variety of gestures infants use predict their later vocabulary size (Acredolo & Goodwyn, 1988; Colonnesi et al., 2010; Iverson & Goldin-Meadow, 2005; Rowe et al., 2008). The caregiver's response to gestures, particularly in labeling objects, is also pivotal for language learning (Rowe et al., 2008; Tomasello & Farrar, 1986). Gestures – primarily pointing, but also later iconic ones (Özçalışkan &

Goldin-Meadow, 2005) – both *precede* and *predict* language at the lexical and syntactic levels in children. This has been evidenced in both neurotypical (Capone & McGregor, 2004; Colonnesi et al., 2010) and neuroatypical development (Choi & Rowe, 2024; Kilili-Lesta et al., 2022; Ramos-Cabo et al., 2019). Initially, children produce gestures in isolation, but they gradually begin combining gestures with single words that convey the same meaning. These are often referred to as *reinforcing* or *complementary* combinations, such as nodding the head while saying "yes". Later, children start combining gestures with new information that is not conveyed by the gesture itself, reflecting more advanced cognitive ability: The integration of both verbal and gestural streams are required to reconstruct meaning. These combinations are usually called *supplementary* combination (e.g., pointing to a cup while saying "drink"; Butcher & Goldin-Meadow, 2000). Importantly, these specific supplementary gesture-plus-word combinations reliably predict the onset of two-words sentences (e.g., "baby drink"; Iverson & Goldin-Meadow, 2005), a foundational milestone in syntactic development (Goldin-Meadow & Butcher, 2003).

Gesture *comprehension* appears to follow a similar developmental pattern as gesture production (N. Dimitrova & Özçalışkan, 2022). As children start producing pointing gestures around their first birthday, they also become more able to follow adults' pointing gestures (Carpenter et al., 1998). Furthermore, they better understand the communicative intent behind pointing when used to indicate the location of a hidden toy (Behne et al., 2012). The comprehension of iconic and conventional gestures follows that of deictic gestures, and typically emerges between ages 2 and 3, concomitant to their production (Hodges et al., 2018; Namy et al., 2004). This hand-in-hand development of gesture production and comprehension extends to the different modalities in which gestures are paired with speech: Children first understand gestures presented alone, then gestures accompanied by reinforcing speech, and finally gestures that supplement speech (Morford & Goldin-Meadow, 1992).

1.2.3 Relevance for communication

In addition to their positive impact on language development, growing evidence suggests that gestures provide both communicative and cognitive benefits (see Clough & Duff, 2020 for a narrative review). Gestures have been reliably found to help listeners better understand speech (Dargue et al., 2019; Hostetter, 2011), including in cases of hearing loss (Obermeier et al., 2012), or contexts with degraded speech (Drijvers & Özyürek, 2020). Gestures help clarify and disambiguate speech (Dick et al., 2014), and provide additional information that is not conveyed through speech alone. Furthermore, gestures play a pivotal role in conversational dynamics, facilitating turn-taking by signaling intent to speak or ceding the floor to others, thereby promoting smoother and more coordinated interactions (Bavelas et al., 1992; Holler & Kendrick, 2015).

Beyond their communicative advantages, gestures also support cognitive processes. They assist with speech conceptualization, planning, and organization (Alibali et al., 2000; Kita et al., 2017), while contributing to speech production. Notably, gestures can help speakers access words, as proposed by the *Lexical Retrieval Hypothesis* (Krauss et al., 2001).

They can emphasize key elements in conversation and narration (Beattie & Shovelton, 1999), and simplify complex visuospatial information, allowing speakers to package their thoughts into speech-compatible units, according to the *Information Packaging Hypothesis* (Kita, 2000). The positive impact of gestures on learning is well established (Church et al., 2004; S. W. Cook et al., 2008; Goldin-Meadow, 2011, 2014), particularly in disciplines such as mathematics. Research shows that gestures reduce cognitive load by enhancing working memory (Goldin-Meadow, 2011), and facilitate information retention at short- and long-term (S. W. Cook et al., 2008).

Altogether, gestures not only support internal processes of thinking and learning, but also contribute to rich interpersonal interactions, making communication more effective, nuanced, and engaging. As such, gestures serve as crucial communicative elements that may also be shaped by various experiences, such as bilingualism (see **Section 3.2.2**).

1.3 METALINGUISTIC AWARENESS

1.3.1 Defining metalinguistic awareness

Effective communication also involves higher-order skills, such as Metalinguistic Awareness (MA), which is actively mobilized in interaction: MA refers to an individual's ability to reflect upon, analyze and evaluate the structure and functions of language (Thomas, 1992; Tunmer & Herriman, 1984). According to Jessner (2018), MA can be described as "*the ability to both focus on linguistic form and switch focus between form and meaning*" (Jessner, 2018, p. 35). This metacognitive ability also includes an individual's capacity to *control* and *plan* their own linguistic processing (Gombert, 1990). As such, MA encompasses the ability to *think* about language as a system or an object, rather than merely using it as a communicative tool. According to Sinclair (1986), MA represents an abstract approach to thinking about language, and focusing on understanding its structure and use. MA serves a way to analyze language on a conceptual level, separate from its practical application in communication (see **Section 1.3.3**), thereby providing knowledge distinct from language comprehension and production (Sinclair, 1986). Metalinguistic skills refer to explicit knowledge involving activities consciously controlled by the cognitive system. It encompasses the ability to *identify* and *manipulate* linguistic elements such as phonemes, morphemes, and semantic structures. Thus, MA is not a monolithic construct, but rather a multilayered set of knowledge and skills that can be examined at different levels of language (Scribner & Cole, 1981). For instance, detecting and manipulating phonemes engages *meta-phonological* abilities, identifying and correcting grammatical errors in utterances reflects *meta-morphosyntactic* competence, and tasks requiring word definition may tap into *meta-lexical* and *meta-semantic awareness*.

Due to its multifaceted and complex nature, achieving a clear consensus on the definition of MA has been challenging (Bialystok, 2024; Bialystok & Ryan, 1985; Sinclair, 1986). To address this issue, Bialystok and Ryan (1985) developed a *cognitive framework* that characterizes two fundamental components inherently present in all metalinguistic tasks: *analyzed knowledge* and *cognitive control*. *Analyzed knowledge* refers to the linguistic competence *per se* – namely, the comprehension and reflection on language structures themselves. *Cognitive control*, in contrast, pertains to the control of attentional procedures that enable the selection and processing of this specific linguistic information (Bialystok & Ryan, 1985). While all language use involves these components, metalinguistic tasks typically place a high demand on both dimensions – although the extent varies depending on the specific task considered (Bialystok, 2001a). For example, an increasing level of *analyzed knowledge* is required when asking participants to (1) detect grammatical errors, (2) correct the errors, and (3) explain the errors. Similarly, greater *cognitive control* may be exerted by inserting misleading information that needs to be ignored, or by using tasks requiring to pay attention to non-salient or unexpected content (Bialystok, 2001a). By highlighting the interaction between linguistic knowledge and cognitive processes, this framework accounts for the dual nature of metalinguistic competence.

1.3.2 Developmental milestones

The development of metalinguistic awareness occurs gradually from early childhood through adolescence and into adulthood. This higher-order skill is closely tied to the maturation of both cognitive and linguistic abilities (Bialystok, 2001b; Birdsong, 2012). It is influenced by various factors, such as language exposure (Atagi & Sandhofer, 2020), formal education (Bessy & Knouse, 2020; Krulatz & Christison, 2023), and bilingualism (Adesope et al., 2010; Bialystok, 2001; for a presentation of bilingualism effects on MA, and their exploration in children with and without Autism Spectrum Disorder, see **Section 5.2**).

The first signs of MA can be observed early in the development, in children as young as three years old (Chaney, 1994; Patterson, 2011). Phonological awareness is one of the first dimensions of MA to emerge, with children around this age beginning to recognize rhymes and identify phonemes within words. Recent research suggests that phonemic awareness, particularly in receptive tasks, may develop even earlier than previously thought (Kenner et al., 2017). By ages four to five, children exhibit a broader range of metalinguistic skills: Word awareness begins to develop, allowing children to recognize words as separate linguistic units distinct from their meanings. At the meta-morphosyntactic level, children become able detect simple grammatical mistakes and occasionally correct them, even if they cannot always explicitly articulate the underlying grammatical rules (Gombert, 1990).

Middle childhood, particularly between ages six and eight, marks a critical period for the growth of MA as children enter formal instruction (Edwards & Kirkpatrick, 1999; Melogno et al., 2022; Sinclair, 1986). A significant increase in metalinguistic performance is typically observed around ages seven and eight on metalinguistic tasks, leading researchers to describe this period as an "*age-dependant shift in metalanguage development*" (Edwards & Kirkpatrick, 1999, p. 326; Melogno et al., 2022; Sinclair, 1986). During this period, literacy acquisition not only strengthens phonological awareness but also significantly enhances word awareness (Berthoud-Papandropoulou, 1978; Melogno et al., 2022). In addition, children become more adept at identifying and correcting complex grammatical errors with greater precision. They also develop increased semantic awareness (Gombert, 1990). From this age onward, they can reflect on how words can have multiple meanings or associations, and begin engaging in tasks that require deliberate manipulation of language, such as the production and comprehension of metaphors and puns (Melogno et al., 2012; Nippold, 1998; Petit et al., 2024).

1.3.3 Relevance for communication

While not always explicitly recognized, metalinguistic awareness plays a critical role in effective communication by enabling individuals to reflect on and manipulate language to suit different contexts. Effective communication requires not only understanding the literal content of language, but also its context and underlying meanings. Speakers may also correct and reformulate their messages, comment on their own utterances or on their interlocutors' production, to repair miscommunications and facilitate smooth

communication. MA therefore promotes accurate interpretation, adjustment to communicative partners and situations, and appropriate response delivery in social interactions (Patterson, 2011). MA also enhances communication skills by enabling speakers to adapt their language use based on the audience, communicative purposes and cultural norms. In this sense, *pragmatics* – the appropriate use of language in context – can be seen as a practical application of metalinguistic knowledge. While pragmatics focuses on the contextual and social rules of language use, MA provides the reflective capacity to analyze and consciously apply these rules, enabling individuals to adjust their language deliberately and flexibly to communicative needs (Mertz & Yovel, 2009; Ninio & Snow, 2018).

In addition, MA is fundamental to literacy, as phonological and morphological awareness notably supports reading development (Apel & Masterson, 2001; Hedley et al., 2013). These skills are indeed strong predictors of spelling (Apel et al., 2012), decoding, and reading comprehension (Dong et al., 2020; Tunmer & Herriman, 1984), in both children (Apel et al., 2012; Nagy et al., 2003) and adults (Tighe et al., 2019; Tighe & Schatschneider, 2016).

Research on second language (L2) acquisition also acknowledges the role of MA as an important contributor to L2 reading development (Bialystok, 2007; Ke et al., 2023), L2 achievement in formal instructional settings (Tellier & Roehr-Brackin, 2017) and L2 learning across the lifespan (Roehr-Brackin, 2018). MA may indeed improve pattern recognition and linguistic structures comparisons, thus facilitating the adaptation to the linguistic features of new languages (Jessner, 2017). Conversely, research also suggests that L2 reading and literacy practices may, in turn, enhance MA by promoting explicit attention to language structures and rule-based processing (Sparks et al., 2019). Together, these findings point to a bidirectional relationship between MA and L2 reading abilities. In particular, bilinguals are reported to demonstrate heightened metalinguistic skills as compared to their monolingual peers, as evidenced by a large body of research on different metalinguistic dimensions (Adesope et al., 2010; Barac et al., 2014; Ben-Zeev, 1977; Bialystok, 2009; Cromdal, 1999). It has been claimed that the confrontation and use of multiple linguistic systems would create an early separation between the formal and semantic aspects of language, thereby enhancing abstraction, conceptual manipulation, and attention to formal language features in bilinguals to a greater extent (Cummins, 1978; Hakuta & Diaz, 1985; Ianco-Worrall, 1972). According to Bialystok's research, the positive effect of bilingualism on MA tasks may be driven by the bilingual's better performance in the *cognitive control* dimension, enabling them to efficiently suppress interference, attend to and manipulate the structural aspects of language (i.e., *analyzed knowledge*; Bialystok, 1988, 2001; Bialystok & Ryan, 1985; see **Section 5.2**). Interventions incorporating explicit MA strategies are widely used as educational settings, given their positive impact on academic achievement (Al-Ahdal & Almarshedi, 2022; Spellerberg, 2016).

1.4 NARRATIVE MACROSTRUCTURE

1.4.1 Defining narrative macrostructure

Oral narratives represent structured accounts of events, experiences that form a story, playing a crucial role in communication, social interaction and cultural transmission (Neuhaus, 2010). Effective narrative delivery requires competence at two distinct, yet interconnected levels (see Kupersmitt et al., 2014 for their interrelations): the *microstructural* and *macrostructural* levels (Heilmann et al., 2010; Kintsch & van Dijk, 1978). On the one hand, microstructure refers to the formal linguistic features of the story, including lexical choices, morphosyntactic accuracy, and cohesion devices that connect sentences (e.g., temporal connectors, pronouns, conjunctions, etc.). It reflects both linguistic precision and an individual's proficiency. Macrostructure, on the other hand, pertains to the global organization and thematic coherence of the narrative: It represents the ability to structure and present information cohesively, and is considered more language-independent (Heilmann et al., 2010). Macrostructure is often analyzed through the *story grammar* model (Stein & Glenn, 1979). This theoretical framework delineates common elements present in well-formed narratives, referred to as *story grammar elements*. These notably include providing context by specifying the *setting* (e.g., place and time), introducing the *initiating event* that triggers the story's actions, defining characters' *goals* (e.g., their motivation), describing the protagonists' *attempts* to achieve these goals, and presenting the *outcome* (e.g., characters' reactions, final state; Stein & Glenn, 1979; Trabasso & Nickels, 1992).

The *story grammar* framework is particularly relevant because it reflects an individual's ability to construct a cohesive, causally linked, and contextually appropriate narrative. Critically, producing a coherent story requires not only linguistic competence but also an *understanding* of the depicted events (e.g., in image-based storytelling), and the capacity to *infer* goals, plans, and outcomes (Trabasso & Nickels, 1992). In this sense, narrative macrostructure served as a window into broader cognitive processes, drawing on inferential reasoning, causal understanding, and organizational skills (Liles, 1993).

1.4.2 Developmental milestones

The development of narrative skills follows a gradual progression throughout childhood and adolescence, reflecting increasing cognitive, linguistic, and social abilities. During the preschool years (around 3-4 years of age), narratives are primarily descriptive or event-focused, often centered on isolated actions or sequences of events (Berman, 1988). At this stage, stories are short and include only few *story grammar* elements (e.g., a character's goal). The macrostructure lacks causal or temporal connections, and the narratives are typically fragmented and minimally organized (Nicolopoulou & Richner, 2007; Trabasso et al., 1992). For instance, preschoolers might enumerate events in chronological order without linking them through cause-and-effect relationships. The narratives also rely on adult scaffolding, where adults prompt the child to provide additional information or

clarification, helping to construct a more complete story (Applebee, 1978; Berman & Slobin, 1994).

From age 5 onward, children's narratives gradually include more elements of the *story grammar* (e.g., setting the story in time and place, mentioning the protagonists' reactions). Stories become more elaborated, complex and structured. At this stage, children start to link events causally, and to explicitly describe the protagonists' goals, feelings, reactions and thoughts (Stein & Albro, 1997). While these developments represent a significant step towards organized storytelling, children's narratives in early childhood often remain relatively simple, focusing on straightforward sequences of actions with limited elaboration. For example, children might produce a story with a clear beginning and end, but provide limited detail about the motivations behind the characters' actions or the broader outcomes of these events (C. Peterson & McCabe, 1983). The development of narrative skills continues throughout primary school, and at around 9-10 years old, children produce well-formed narratives integrating most *story grammar* elements (Berman & Slobin, 1994). Children also exhibit an increased capacity to embed subordinate events and motivations and to produce more elaborated stories, with greater attention to character goals and the interrelationships between events (Berman & Slobin, 1994; Stein, 1988; Stein & Albro, 1997). The development of narrative macrostructure during the primary school years is closely tied to the maturation of social-cognitive skills, such as ToM, and broader cognitive abilities like understanding causality, perspective-taking, and justifying actions, all of which are essential for constructing coherent and well-structured narratives (Berman & Slobin, 1994; Nicolopoulou & Richner, 2007; Trabasso & Nickels, 1992).

By adolescence and adulthood, stories become even more complex and elaborated, as individuals can integrate multiple perspectives, manage different timelines, and adjust their speech register and choice of language to suit their audience. Individuals also make more deliberate choices in structuring their narratives, supported by advanced metalinguistic skills and greater control over the storytelling process (Berman & Nir-Sagiv, 2007; del Carmen Perez et al., 2023; Nippold et al., 2015).

1.4.3 Relevance for communication

Narratives represent an interesting means of communication, providing a comprehensive and authentic sample of language production that reflects the underlying cognitive and linguistic competencies. A well-structured narrative ensures effective communication by allowing listeners to follow the story events in a logical and cohesive manner, understand the plot, and grasp its implications through the expression of characters' goals, emotions, and reactions. This skill is particularly important in academic settings, where storytelling supports literacy development, reading comprehension, and the understanding of abstract concepts, such as those encountered in mathematics and science (Bishop & Edmundson, 1987; Bliss et al., 1998; Westby, 2014).

As previously mentioned, the cognitive foundations of narrative macrostructure are closely tied to socio-cognitive areas such as ToM and EF. ToM is believed to underpin

effective storytelling by enabling individuals to articulate characters' mental states such as thoughts, feelings, and motivations, ensuring rich and coherent narratives (Nicolopoulou & Richner, 2007; Pelletier & Astington, 2004; Trabasso et al., 1992). Similarly, EF plays a role in organizing ideas by enabling individuals to link story components coherently, choose the most relevant linguistic elements, and monitor the narrative structure in real-time. Specifically, working memory helps maintain, integrate and update story details across sentences. Inhibition allows for the suppression of irrelevant or redundant information, and shifting facilitates the smooth sequencing of narrative episodes, allowing speakers to transition between events, revisit earlier story elements, and manage multiple character perspectives. These processes contribute to the production of complete narrative episodes and the effective coordination of the story's overall structure (Mozeiko et al., 2011; Scionti et al., 2023; Tselekidou et al., 2024; Veraksa et al., 2020).

The analysis of narratives offers an ecologically valid approach to assessing communicative competence, offering rich insights into a child's cognitive, semantic, and social skills in naturalistic contexts (Botting, 2002; Gagarina et al., 2012; Liles, 1993; Norbury et al., 2014). As noted by Gagarina et al. (2012), narrative analysis is less biased against bilingual children than traditional norm-referenced assessments (Paradis et al., 2011), making it a valuable tool for diverse linguistic populations. Additionally, narrative assessments help identify language development milestones and potential delays (Allen et al., 2012; Botting, 2002), while also supporting academic achievement and social skills (Bishop & Edmundson, 1987; Bliss et al., 1998; Dickinson & McCabe, 2001; Fazio et al., 1996; Griffin et al., 2004; McCabe, 1997; McCabe & Rollins, 1994).

In this first chapter, we defined and examined communication, highlighting key but underexplored communicative skills such as co-speech gestures, metalinguistic awareness, and narrative macrostructure. We emphasized on how these skills contribute to successful communication, facilitating smooth and flexible social interactions.

Interestingly, some individuals, like those diagnosed with Autism Spectrum Disorder (ASD), face challenges with specific aspects of communication. These difficulties, along with related cognitive and social impairments, have concrete implications for their daily functioning. The next chapter will therefore focus on ASD, emphasizing its inherent heterogeneity. We will begin by defining and describing diverse phenotypes observed in autism, followed by an exploration of both well-established research areas and underexamined domains that merit further investigation.

2 Autism Spectrum Disorder (ASD)

2.1 A spectrum of strengths and challenges

2.1.1 What is autism?

Autism Spectrum Disorders (ASD) refers to a neurodevelopmental disorder characterized by persistent challenges in social communication and interactions on the one hand, and the presence of restricted, repetitive interests, behaviors or activities on the other hand (American Psychiatric Association, 2022). Deficits in social communication include difficulties in socio-emotional reciprocity, challenges in developing and understanding relationships – such as adjusting behaviors to social contexts – and atypical approaches to back-and-forth conversation. Individuals with ASD may also exhibit impairments in nonverbal communication, such as reduced or atypical gesture use, atypical eye contact, or difficulties in interpreting facial expressions. Repetitive behaviors and restricted interests manifest as stereotyped movements (e.g., hand flapping) or speech patterns (e.g., echolalia), ritualized verbal and nonverbal behaviors, as well as fixed interests with unusual intensity. These behaviors can have cascading effects, further reinforcing atypical social interactions and communication. They appear early in development (American Psychiatric Association, 2022), even if they may initially be subtle or masked by compensatory behaviors (J. Cook et al., 2021; Zwaigenbaum et al., 2015). Over time, however, they typically become more pronounced, significantly impacting the individual's ability to engage in reciprocal social interactions and adapt to the dynamic demands of everyday communication and relationships (Pellicano, 2012; Seltzer et al., 2004; Shattuck et al., 2007).

These behavioral traits have substantial repercussions on the individual daily social and occupational functionning (American Psychiatric Association, 2022), even if they may vary in diversity and intensity. The *severity* of these characteristics has to be specified for each individual, along with the presence of any associated neurodevelopmental, mental or behavioral disorder (i.e., comorbidities), commonly encountered in autism. Moreover, according to the most recent versions of the *Diagnostic and Statistical Manual of Mental Disorders* (American Psychiatric Association, 2022), specifying the presence or absence of *language* and *intellectual impairment* is required in the autism diagnosis to more accurately describe the profile of strengths and challenges an autistic individual may present. Indeed, the notion of

heterogeneity is a core characteristic of the autistic condition, reflecting the diversity of the profiles of individuals diagnosed with ASD. As is often attributed to Dr. Stephen Shore: "*When you meet one person with autism, you've met one person with autism*". Autistic individuals can vary drastically in the range of the autistic traits that they display, their intensity and repercussions in their daily lives. This heterogeneity has led to the adoption of the term "spectrum", to better reflect and encompass the diverse range of manifestations, abilities and challenges associated with autism (Wing, 1997). Specifiying the nature of the strengths and impairments of autistic individuals may help tailor personalized interventions and enhance the understanding of a child's functioning.

ASD is one of the most prevalent neurodevelopmental disorders in the world: Recent estimates report a world median prevalence of 65 per 10,000 individuals (0.65%), reflecting approximately 1 individual diagnosed with autism in 154 people (Zeidan et al., 2022). In the US, recent work even reports a prevalence of 1 child born in 36 (Maenner, 2023). All racial, ethnic and socioeconomic groups are concerned, even if significant disparities in access to care and potential diagnosis are reported, likely leading to underdiagnosis (Gallin et al., 2024; Wiggins et al., 2020). Moreover, there is a critical lack of information from non-WEIRD (Western, Educated, Industrialized, Rich, Democratic; Henrich et al., 2010) countries. An increase in the number of individuals diagnosed is globally observed over time (Maenner, 2023). This is partly, but not exclusively, explained by enhanced community awareness, improvement in public health campaigns enabling earlier and better identification, as well as diagnostic criteria broadening (Hansen et al., 2015; Zeidan et al., 2022). Males are generally more frequently affected than females. A female-to-male ratio of approximately 4 or 3 to 1 is generally reported (i.e., 3.8, 4.2; Maenner, 2023; Zeidan et al., 2022). Since women often remain underdiagnosed for longer, this rate may vary in the future (Ratto et al., 2018).

The etiology of ASD is multifactorial, considered to result from a combination of both genetic and non-genetic (i.e., environmental) factors (Sauer et al., 2021). Genetic mutations and variations, specifically in genes involved in brain connectivity and synaptic functions, have been associated with ASD (Abrahams & Geschwind, 2008). Familial forms of autism are frequent, with children and siblings of autistic individuals at higher risk for autism (Ronald & Hoekstra, 2011). Environmental factors associated with ASD notably include *prenatal* factors (e.g., advanced paternal age, prenatal stress, exposure to toxins, etc.) and *perinatal* factors (e.g., birth hypoxia, prematurity; Modabbernia et al., 2017; Sauer et al., 2021). It is now established that other factors such as vaccination, maternal smoking or maternal educational style do *not* trigger autism or increase autism susceptibility (Modabbernia et al., 2017). These hypotheses had been previously formulated and have led to dramatic social repercussions (Grinker, 2007).

Several neuroanatomical alterations are associated with autism, including differences in grey and white matter, atypicalities in brain connectivity, as well as developmental changes in brain volume and cortical thickness over time (Donovan & Basson, 2017; Hazlett et al., 2017). However, just as the clinical phenotypes and etiologies of autism are heterogeneous, so too is its neuroanatomy (Amaral et al., 2008; Donovan & Basson, 2017).

Research is underway to better understand how these alterations contribute to the diverse behavioral, sensory, cognitive and linguistic profiles observed in individuals with ASD.

2.1.2 Diversity of linguistic and intellectual profiles in autism

Indeed, although all individuals diagnosed with ASD experience significant difficulties in social communication and present repetitive behaviors – the so-called *autistic dyad* of impairments – they nonetheless vary greatly in the diversity and intensity at which they experience these manifestations. Among the most striking inter-individual differences in autism certainly lies the diversity of the linguistic and cognitive profiles represented.

Autistic individuals vary in their linguistic profiles: while some of them never acquire language, others display language abilities within the norm, or even beyond. About one third of autistic children are considered non-verbal or minimally-speaking (D. K. Anderson et al., 2007; Tager-Flusberg & Kasari, 2013), producing only vocalizations, non-speech sounds or very short sentences. Noticeably, they can vary in their language comprehension skills, as some of them present near average receptive skills (Bal et al., 2016; Rapin et al., 2009). Besides, linguistic abilities, and their development, are far from homogeneous in the remaining 70% of autistic children with functional speech (Tek et al., 2014). Children with ASD can present salient impairments in one or several linguistic domains, or more subtle difficulties (Ambridge et al., 2015; Rapin & Dunn, 2003). Recent reviews indeed highlight the heterogeneity of the linguistic profiles encountered in autism, recalling the non-monolithic nature of language in this condition (Schaeffer et al., 2023; Silleresi, 2023).

Pragmatics, referring to the use of language in social interactions, integrates both linguistic (e.g., speech register selection, use of referential expressions) and non-linguistic functions (e.g., body language and facial expressions; Eigsti et al., 2011). Because pragmatic skills involve adapting to social contexts and interlocutors, they are strongly linked to the first criterion of autism diagnosis. In that respect, pragmatics appears largely affected in children with ASD (Baird & Norbury, 2016; Lam, 2014; Tager-Flusberg et al., 2005), although recent work suggests that not all pragmatic aspects may be concerned (Deliens et al., 2018; Kissine, 2021; Mognon et al., 2021). Difficulties include pronoun reversal (i.e., using "*I*" for "*you*" and the opposite; e.g., Naigles et al., 2016), fewer responses to questions and less informative contributions in conversations (Capps et al., 1998), challenges with figurative language (Kalandadze et al., 2018), including the comprehension and production of metaphors (Morsanyi et al., 2020), jokes, irony and idiomatic language (Saban-Bezalel & Mashal, 2018; Vulchanova et al., 2015), among others (see Silleresi, 2023 for a review).

Prosodic alterations are frequently observed in autism: Prosody, which refers to the rhythm and intonation of speech in terms of pitch, duration and intensity, is atypical in individual with ASD, who tend to show flat, monotonous, singsong or reportedly "pedantic" speech (Diehl & Paul, 2013; Grossman et al., 2010; Peppé et al., 2006). Challenges in the comprehension of prosody to resolve syntactic ambiguity have also been reported (Diehl et al., 2015).

Pertaining to phonology - the detection, manipulation and organization of speech sounds - inconsistent findings are reported (Eigsti et al., 2011; Silleresi, 2023). Generally considered to be a rather intact area, recent reviews and meta-analyses identify atypical and impaired phonological processes such as limited consonant inventories, at least for some subgroups of children on the autism spectrum (Kjelgaard & Tager-Flusberg, 2001; Schaeffer et al., 2023; Tuller et al., 2017; Wolk et al., 2016).

Research has long indicated that autistic individuals exhibit preserved lexical abilities (Arunachalam & Luyster, 2016; Ellawadi et al., 2017; Schaeffer et al., 2023), with vocabulary knowledge even identified as a relative strength (Kjelgaard & Tager-Flusberg, 2001). However, other studies report lexical deficits in children with ASD compared to aged-matched neurotypical peers (Boser et al., 2002; Boucher, 2012; Naigles et al., 2013), making it difficult to draw clear conclusions about their lexical abilities (Sukenik & Tuller, 2023). Evidence also suggests a distinct linguistic profile, in which expressive skills exceed receptive abilities (e.g., Charman et al., 2003; Hudry et al., 2010; Mitchell et al., 2011). However, a growing body of work challenges these findings, with studies showing no discrepancy between expressive and receptive abilities or even reporting the opposite pattern of performance (Ellis Weismer et al., 2010; Loucas et al., 2008; Luyster et al., 2008). While these "*expressive-over-receptive*" profiles may be more prevalent in autistic individuals than in neurotypical populations, they do not appear consistent or frequent enough to constitute a specific language marker for autism (Kwok et al., 2015).

Finally, the heterogeneity of language in autism may be the most visible at the morphosyntactic level, a topic that has received careful attention in the past decades and generated mixed findings. While previous work reports spared morphosyntactic abilities in autistic individuals (Allen et al., 2011; Goodwin et al., 2012; Naigles et al., 2011), evidence for difficulties in the comprehension and production of several morphosyntactic structures are accumulating (Ambridge et al., 2015; Eigsti & Bennetto, 2009; Tek et al., 2014; for reviews, see Boucher, 2012; Schaeffer et al., 2023; Silleresi, 2023). Impairments notably entail difficulties with tense marking (Roberts et al., 2004), the detection of morphological markers (Eigsti & Bennetto, 2009), and the processing of complex syntactic structures such as relative clauses (Durrleman et al., 2015) and passives (Durrleman et al., 2017). Generally, these difficulties were not attributable to lower non-verbal IQ abilities. The challenges observed are often analogous to the linguistic profiles of by children with Developmental Language Disorder (DLD; previously referred to as Specific Language Impairment, SLI), prompting researchers to highlight the overlap in phenotypes (Durrleman & Delage, 2016). This overlap is attributed to complex genetic interactions rather than merely shared genetic causes (Bishop, 2010).

The notion of heterogeneity extends beyond linguistic abilities and is also evident at the intellectual level. Around 30% of autistic individuals present an intellectual impairment (Maenner, 2023; Zeidan et al., 2022), as evidenced by scores below 70 to well-recognized standardized assessments. Full Scale IQ (FSIQ), derived from standardized tools such as the Wechsler Intelligence Scale for Children (WISC; Wechsler, 1949) are often used. They comprise indices for verbal comprehension, perceptual skills (i.e., non-verbal reasoning), processing speed, and working memory abilities. Children with autism are recognized to

often present heterogeneous profiles in *peaks* and *valleys*, reflecting very high performance in some indices – generally non-verbal tasks involving analytical processing – contrasting with lower abilities in other realms (e.g., attention and working memory, processing speed; Audras-Torrent et al., 2021; Stevenson & Gernsbacher, 2013). Because of the high heterogeneity between autistic individuals in their linguistic abilities, and between the linguistic domains within each individual, it is not surprising that uneven performance is found both between children and between subtasks in a single child. This profile of differential *strengths* and *weaknesses* in various domains makes it difficult to conclude on a general score that would accurately reflect the intellectual abilities of autistic minds. Indeed, the FSIQ of the WISC has been shown to underestimate the IQ of autistic children (Nader et al., 2016). As Silleresi (2023) argues, non-verbal tests – such as the well-known Raven's Progressive Matrices (RPM or Raven's 2; Raven et al., 2018) – are better suited than verbal tests for assessing fluid reasoning and general intelligence in autistic children across the spectrum. Indeed, these tools accurately capture visuospatial and abstract reasoning devoid of linguistic compounds, which could negatively impact the performance of autistic individuals (Silleresi, 2023).

Given the important between- and within-subject heterogeneity in autism in both linguistic and intellectual realms, specific, accurate and "pure" assessments of intellectual and linguistic abilities are essential. That is, assessment tools must precisely evaluate the target ability while minimizing the influence of confounding factors in order to provide a reliable indication of the ability under investigation (e.g., assessing non-verbal reasoning without language involvement or evaluating language with minimal cognitive demand). These careful considerations should guide any evaluation. Moreover, they enable researchers to identify *developmental profiles* among autistic individuals, fostering the best possible outcomes by addressing specific needs in a systematic and evidence-based manner (Silleresi, 2023; Vogindroukas et al., 2022). The International Classification of Diseases (ICD-11; World Health Organization, 2018) indeed identifies distinct profiles that autistic individuals may exhibit:

- (1) ASD with neither language nor intellectual impairment (i.e., ASD-LN without intellectual impairment);
- (2) ASD with impaired functional language and impaired intellectual abilities (ASD-LI with intellectual impairment);
- (3) ASD with impaired intellectual abilities and absence of functional language.

These three profiles are considered *homogeneous*. In addition, *discrepant* profiles are also described:

- (4) ASD with impaired language skills but intellectual abilities within the norm (ASD-LI without intellectual impairment);
- (5) ASD with intellectual impairment and mild or no language impairment (ASD-LN with intellectual impairment).

These profiles have been attested with various research designs and appropriate assessment tools (Silleresi, 2023; Silleresi et al., 2020). However, their presence may arguably vary in proportion, and precise estimations are difficult to provide. Indeed, some profiles may be scarcer, harder to detect or to document, partly due to methodological limitations such as selection bias against individuals with intellectual impairment (Russell et al., 2019; Wolfer & Durrleman, 2023).

Overall, the heterogeneity within autism underscores the need for a careful selection of assessment tools to accurately capture each individual's abilities across the spectrum. Moreover, children with ASD experience unique cognitive and communicative challenges encompassed in the autistic dyad, that often relate to the linguistic and intellectual dimensions. For a comprehensive review of the autistic intellectual and linguistic profiles, we refer to Silleresi (2023), a work that we discussed in Wolfer and Durrleman (2023; see Appendix A).

2.2 BEYOND LINGUISTIC AND INTELLECTUAL CHALLENGES

2.2.1 The *known*: Theory of Mind and Executive Functions

As indicated in the previous sections, autistic children exhibit unique cognitive and communicative profiles, wherein their peculiar linguistic and intellectual abilities play substantial roles. Children with ASD also diverge from neurotypical peers on different domains associated with the autistic dyad, such as Theory of Mind and Executive Functions, two domains that have received some attention. While providing a thorough review of these skills would fall outside the scope of the present manuscript, we briefly recall their status in autism because of their relevance to the social and cognitive functioning of autistic individuals. These abilities indeed contribute to a more accurate description of autistic profiles.

Cognitive Theory of Mind (ToM) also referred to as *mentalizing*, is the ability to attribute mental states to others – such as desires, emotions, intentions and beliefs – while recognizing that these states may differ from one's own. This ability enables individuals to predict and interpret other's behavior based on this knowledge (Premack & Woodruff, 1978). ToM typically start emerging around 4-5 years of age and continues to develop gradually throughout middle childhood (Happé & Frith, 2014). These social-cognitive skills are pivotal to social interactions and developing effective social functioning in everyday life (Astington, 2003; Slaughter et al., 2015). ToM has been extensively studied in ASD, with research indicating a delayed acquisition of ToM abilities in autistic children. However, their developmental trajectory appears to follow the same sequence as that of neurotypical peers (Pino et al., 2017). Autistic individuals generally demonstrate higher rates of failures on false beliefs tasks, which require ascribing a mistaken belief to a protagonist, and predicting their subsequent behavior accordingly. For a long-time, a so-called *deficit* in ToM was hypothesized to constitute a core feature of autism (Baron-Cohen, 1990; Tager-Flusberg & Joseph, 2005). However, more recent work challenges the notion of a universal, generalized ToM impairment in autism (Gernsbacher & Yergeau, 2019). Instead, studies suggest that autistic individuals may acquire the components of this complex, non-monolithic construct at different paces, and may attain different levels of mastery (Andreou & Skrimpa, 2020; Marocchini, 2023; C. C. Peterson & Wellman, 2019). In addition, methodological limitations – such as linguistic confounds in ToM measures and inconsistencies in conceptual definitions – have been highlighted in recent reviews (Beaudoin et al., 2020; Fu et al., 2023; Osterhaus & Bosacki, 2022; Quesque & Rossetti, 2020; Ziatabar Ahmadi et al., 2015). These reviews emphasize the need for carefully designed tasks that better capture the underlying ToM concept under study, an endeavor that recent assessment tools have sought to address (Baumeister et al., 2024; Burnel et al., 2018).

Besides, challenges in executive functions (EF; or *cognitive control*) are commonly reported in the autistic population (Craig et al., 2016; Demetriou et al., 2018 for reviews). EF encompasses a set of higher-order top-down cognitive processes that support goal-directed behavior, including inhibition control (i.e., the ability to regulate attention or control thought to override salient information), cognitive flexibility (i.e., the capacity to shift perspective, adapt behavior and adjust to new rules), and working memory (i.e., WM; the ability to hold, manipulate and make use of mental information; Diamond, 2013). Compared to age-matched controls, children with ASD exhibit lower performance in tasks assessing inhibitory control, cognitive flexibility and WM. Autistic individuals also demonstrate a higher prevalence of Attention-Deficit with/or without Hyperactivity Disorder (ADHD), compared to the general population (Craig et al., 2015; Simonoff et al., 2008). However, significant inter-individual variability exists both across individuals on the spectrum, and within the different EF skills of a same individual (Baez et al., 2020; Friedman & Sterling, 2019). As such, while EF challenges are frequently observed in ASD, they are not considered a hallmark of ASD. Instead, they are often associated with core autism manifestations, particularly those affecting social communication and restricted behaviors (Ellis Weismer et al., 2018).

2.2.2 The *unknown*: Gestures, Metalinguistic awareness and Narrative macrostructure

As much as extensive research has helped to better describe and understand the (socio-)cognitive profile of autistic children, several domains related to the communicative sphere, such as co-speech gestures, metalinguistic awareness, and narrative macrostructure, remain largely understudied, despite their relevance to communicative functioning (see **Chapter 1**).

First, as will be outlined in more depth in **Section 4.1**, autistic children present significant quantitative and qualitative differences and delays in their gestural development, as compared to neurotypical children of the same age and developmental level (McKern et al., 2023; Ramos-Cabo et al., 2019). As such, atypical gesture use or the absence of gestures is one of the earliest behavioral indicators of ASD (Stewart et al., 2022; Zwaigenbaum et al., 2015). Early screening markers for autism diagnosis are crucial for identifying children with high likelihood of ASD (Zwaigenbaum et al., 2015). Detecting these early markers increases the chances of timely intervention, which can, in turn, promote more optimal behavioral outcomes (Sullivan et al., 2014). Furthermore, a closer investigation of the gestural profiles of autistic children could be pivotal to help identifying children with ASD at higher risk for ongoing language impairment, given the predictive role of gestures on language acquisition and development, as well as the robust language-gesture association in both neurotypical and autistic populations (Choi & Rowe, 2024; Kilili-Lesta et al., 2022; see **Section 1.2**). However, previous work on autistic children across different ages has largely focused on observing gesture *use*, leaving the question of how autistic children *comprehend* these non-verbal cues relatively unexplored. Studies examining gesture comprehension abilities in children with ASD have yielded mixed findings, with some

reporting impairments (Cossu et al., 2012; Perrault et al., 2019), and others suggesting performance comparable to that of neurotypical children with similar verbal age (N. Dimitrova et al., 2017; for a review of the conflicting findings, see **Section 4.1**). Moreover, while individuals with ASD are known to experience difficulties in integrating iconic gestures with simultaneous speech (Silverman et al., 2010), it remains unclear whether these challenges persist when gestural and verbal streams must be processed sequentially to derive meaning (see **Section 4.1**).

Second, our understanding of metalinguistic awareness in autism remains very limited, as this domain has rarely been explored in autistic populations (see **Chapter 5**). To date, only one study examined metalinguistic ability across multiple metalinguistic subdomains in twenty autistic children aged 9 to 17, comparing their performance to neurotypical peers matched for age, sex and educational level (Lewis et al., 2007). Findings indicated widespread difficulties in these complex cognitive-linguistic tasks among autistic individuals (Lewis et al., 2007). Given the critical role of MA in communication and social interaction (Patterson, 2011), further research in urgently needed (**Section 1.4**). The scarcity of studies on metalinguistic skills in autism is likely due to several factors:

(1) *Conceptual challenges:* The definition of the construct *itself* refers to a large range of abilities, which are not always transparently defined or operationalized in a way that can be tested.

(2) *Methodological constraints:* The inherently *linguistic* nature of the construct (as discussed in **Section 1.4**) poses significant challenges when assessing children on the autism spectrum. On the one hand, evaluating these cognitive-linguistic skills questions the possibility of *non-verbally* testing content which *is* verbal in nature. On the other hand, recruiting a sufficiently large sample of autistic individuals who (a) have developed the higher-order skills under investigation and (b) can effectively participate in such assessments is particularly challenging.

Ultimately, these challenges relate to the developmental profiles in autism as described in the ICD-11 (World Health Organization, 2018; see also **Section 2.2**). They also raise concerns about sample representativeness. Specifically, it begs the question whether these skills *should* and *can realistically* be investigated across the spectrum, or are rather intended to a particular sub-population of autistic children, namely those without significant intellectual or language impairments.

In **Section 5.1**, we will address the question by exploring two dimensions of metalinguistic abilities (i.e., meta-morphosyntactic and meta-semantic skills) in children with ASD, with a task minimizing the linguistic and cognitive demands.

Finally, narrative macrostructure in autism remains relatively underexplored, and sometimes elusive. As will be presented in **Chapter 6**, macrostructural abilities are generally considered restricted in comparison to neurotypical peers (Baixauli et al., 2016), even if some qualitative differences between groups may appear (Stirling et al., 2014). In general, autistic children deliver less coherent and less informative narratives (Baixauli et al., 2016). Interestingly, narrative macrostructure involves several higher-order social-cognitive skills such as ToM, Working Memory and Metalinguistic Awareness (see

Chapter 6), each identified as independently affected in autism (Baron-Cohen, 1990; Craig et al., 2016; Lewis et al., 2007). This has led researchers to hypothesize that the difficulties faced by autistic children in macrostructure may derive from difficulties encountered in these domains, rather than by specific challenges in macrostructure itself (Baixauli et al., 2016). This assumption has not yet been empirically tested, a gap that the study presented in **Chapter 6** seeks to address.

In this chapter, we have seen that ASD is widespread and characterized by diverse clinical manifestations across communicative and cognitive domains. Intellectual and linguistic dimensions are also impacted, albeit to varying extents. The concepts of *spectrum* and *heterogeneity* are thus particularly relevant in understanding autism.

Meanwhile, bilingualism is a prevalent and growing phenomenon, driven by globalization and increasing multiculturalism. Consequently, many children on the autism spectrum are raised in bilingual environments. This sometimes raises concerns among caregivers, who worry that exposure to multiple languages might exacerbate the communicative challenges associated with autism. However, in neurotypical children, bilingualism has been associated with positive cognitive and communicative outcomes. Although existing research, though limited, indicates that bilingualism *does not* hinder the language and communication development of autistic children, further investigation is necessary to establish robust evidence-based recommendations. In the next chapter, we will define bilingualism and discuss the challenges associated with its measurement, before examining how bilingualism has been studied in the context of autism.

3 BILINGUALISM

3.1 A SPECTRUM OF EXPERIENCES

3.1.1 Bilingualism: From despised to desired

Bilingualism, or *Multilingualism*[2], is defined as an individual's ability to use two or more languages in daily life, regardless of their proficiency (Grosjean, 1982, 1985, 2010, 2024a). Although difficult to ascertain, recent estimates converge to indicate that more than half of the world's population is bilingual (Grosjean, 2024b), with significant variations between countries and regions. Bilingualism is increasing in many places in the world due to globalization, migration and immigration, as well as the growing demand for multilingual skills in social, academic, and professional settings.

While today it is considered a positive, even desirable skill, bilingualism has historically been viewed with skepticism and associated with negative appraisal (Bialystok et al., 2022). Specifically, researchers argued that speaking more than one language could hinder cognitive development and generate mental confusion, leading to delays in language acquisition and lower academic achievement (Hakuta, 1986). This view was particularly prominent in the educational systems of North America and Europe, where the use of multiple languages was frequently discouraged and bilingualism stigmatized (Bialystok et al., 2022; Kohnert, 2013; Kohnert et al., 2020).

Over recent decades, however, a dramatic shift in the perception of bilingualism has been observed. This shift, even referred to as "the swerve" (Bialystok et al., 2022), was likely driven by subsequent studies addressing methodological flaws in earlier research. Peal and Lambert (1962) and Darcy (1953, 1963) notably demonstrated that bilinguals and monolinguals did not differ in intelligence measures, as previously claimed (see Bialystok et al., 2022 for a discussion about these findings). Since then, bilingualism is rather seen as an asset for social, professional and even cognitive functioning. In both layman's press and research as well, the term "bilingual advantage," reflecting cognitive and communicative "benefits," has been largely adopted and relayed over decades, to reflect the better performance of bilingual groups over their monolingual peers in a variety of domains.

[2] In the current manucript, no distinction between *Bilingualism* and *Multilingualism* will be made. Both terms refer to multiple-language exposure or use, irrespective of the number of languages considered (e.g., two or three).

Bilingual individuals have notably been shown to outperform monolinguals in tasks involving metalinguistic awareness (see Adesope et al., 2010; Bialystok, 2009 for reviews, and **Section 5.2** for additional information), gesture production (e.g., Nicoladis, 2007), ToM (Schroeder, 2018 for a review), and communicative effectiveness (e.g., Wermelinger et al., 2017). For instance, according to the COMmunicative-Experience perspective (COME; Wermelinger et al., 2024), children's communicative behaviors are shaped by their experiences with varying communicative situations. Bilingual children, who frequently encounter diverse and sometimes non-effective interactions, develop a broader and more flexible communicative repertoire, as compared to monolinguals. Among the most studied – and debated – domains demonstrating a positive impact of bilingualism are executive functions, such as inhibition and WM (e.g., Adesope et al., 2010; Giovannoli et al., 2020; Gunnerud et al., 2020; Lehtonen et al., 2018; Monnier et al., 2021; Yurtsever et al., 2023). However, as Byers-Heinlein and Lew-Williams (2013) and the authors of these meta-analyses themselves note, the effects are generally small, potentially limited to specific ages, demonstrated through laboratory-based methods conducted in highly controlled settings, with limited repercussions in daily life. The cognitive advantages observed in bilinguals are generally attributed to the process of acquiring and managing multiple languages, which engages brain plasticity in ways that enhance task performance (DeLuca et al., 2019; Green, 1998; Pliatsikas et al., 2020). However, more precise and refined theoretical frameworks are needed to better understand the behavioral and neural effects of bilingualism (de Bruin et al., 2021). Conflicting findings persist, particularly in the domain of executive functions, where the debate has led to an *impasse* (Antoniou, 2019, p. 3; see Leivada et al., 2021 for a discussion on the conflicting findings in meta-analyses).

Beyond the debate over whether a bilingual advantage *exists* across different domains, an equally important question is *why* these discrepancies arise, even in well-controlled studies. Furthermore, identifying *which aspects* of bilingualism and *under what conditions* these effects emerge – or fail to emerge – is pivotal. Addressing these factors can help guide future research, refine theoretical models, and mitigate the limitations of previous studies.

3.1.2 Diversity of bilingual profiles

3.1.2.1 No two bilinguals are the same

Just like ASD is heterogeneous (**Chapter 2**), so too is bilingualism. *"No two bilinguals are the same"* (de Bruin, 2019): Bilingual individuals exhibit varying profiles in terms of the combination of languages they speak or are exposed to (e.g., same or different scripts), their proficiency in these languages in expression and comprehension, the age at which they started learning these languages (e.g., simultaneous or sequential bilinguals), their relative exposure to and use of the languages in different settings, among others (e.g., see de Bruin, 2019 for an overview of their impact on cognitive skills; Luk & Bialystok, 2013). Bilinguals also differ in the socio-linguistic contexts in which they acquired their languages, shaping their attitudes and feelings towards them (Bhatia, 2017). As such, bilingualism can hardly

be treated as a single, uniform construct (Bialystok, 2017; Grosjean, 1982), and appears largely multidimensional (Marian & Hayakawa, 2021). Moreover, bilingualism is a dynamic process subject to evolve throughout life, as does brain plasticity (Pliatsikas, 2020).

Traditionally, research on bilingualism has relied on group comparisons opposing monolinguals to bilinguals. While this categorization offers undeniable advantages in terms of statistical approach and outome interpretation, it nevertheless presents theoretical and methodological pitfalls (De Houwer, 2023; Luk, 2022; Marian & Hayakawa, 2021). First, comparing bilinguals and monolinguals is delicate, as bilingualism in not a *binary* variable (Luk & Bialystok, 2013). There is indeed no consensus on who *is* or *is not* bilingual (Luk, 2015): Distinct boundaries delineating bilingual from monolingual experience do not exist. Group comparisons often imply setting an arbitrary cutoff on a specific measure (e.g., bilingual individuals are those with exposure to a second language more than 20% of their life), that inevitably masks inter-individual differences within groups (e.g., an individual with 19% of dual-language exposure would be considered *monolingual*, whereas an individual with 21% would be integrated to the *bilingual* group, just as an individual with 50% of dual-language exposure, despite their arguable difference; Leivada et al., 2023; Luk, 2022). The fact that some participants with similar characteristics are considered, at times, *monolingual* in some studies and *bilingual* in others depending on the selected criterion (Hantman et al., 2023) confirms that the approach is suboptimal to draw clear conclusions about the impact of bilingualism. Second, this approach inherently overlooks the multidimensional nature of bilingualism, as grouping participants on all bilingual measures is impossible (Baker, 2011; Leivada et al., 2023). Socio-linguistic factors, although crucial in explaining outcomes in bilingual studies (Masullo et al., 2023), are also generally disregarded. Third, according to previous literature (Grosjean, 2024a; Leivada et al., 2023), monolingual versus bilingual groups comparisons imply a *monolingual reference norm*, which fails to account for the diversity of bilingual experiences, notably in contexts involving minority languages. This reliance on monolingual comparisons introduces a *monolingual bias* (De Houwer, 2023), and reinforces a narrow view of bilingualism. It has detrimental consequences for bilingual children, notably their psycholinguistic assessment. Indeed, it has been shown that some standardized tasks contain inherent bias against bilingual children (Peña et al., 2016), a pitfall that has motivated the development of more inclusive, unbiased assessment tools suited for bilingual populations such as the Language Impairment Testing in Multilingual Settings instruments (LITMUS; Armon-Lotem et al., 2015). Altogether, these elements concur to an oversimplification of bilingualism that may explain the discrepancies in previous research on bilingualism (Leivada et al., 2021).

3.1.2.2 Associated methodological challenges

Along with the complexity of bilingualism comes the variety of ways in which this construct can be – and has been – measured (Kašćelan et al., 2021). Measuring bilingualism *is* challenging, and, to date, no consensus exists on the best approach to adopt (Marian & Hayakawa, 2021). Several comprehensive tools have been developed throughout the years, both for adults and children (Language and Social Background Questionnaire (LSBQ),

Anderson et al., 2018; Language entropy, Gullifer & Titone, 2020). One such tool is the Quantifying Bilingual EXperience (Q-BEx; De Cat et al., 2022), an open-source parental questionnaire available in twenty-seven languages, which targets key dimensions of the bilingual experience: language exposure and use, proficiency, input quality, language mixing practices, attitudes towards languages and language mixing, for instance. The questionnaire enables a fine-grained description of the bilingual experience of the participants and allows the researchers to derive measures and scores of interests (e.g., relative exposure to language X, richness of the input in language Y, etc.).

Given the multitude of ways to operationalize bilingualism, it can become challenging to cross-compare studies in view of the interpretation of their findings. While no tool or specific measure may be ultimately better over another, scholars urge researchers to provide more detailed and explicit descriptions of the sample, the selected bilingual measures and models used (de Bruin, 2019; Kremin & Byers-Heinlein, 2021). In addition, recommendations for future research entail use of consistent terminology, use of hypothesis-driven continuous variables clearly justified in relation with the questions under investigation (de Bruin, 2019; Hantman et al., 2023). Finally, researchers are also invited to share their data to promote transparency and assist in standardization efforts (de Bruin, 2019).

In the experimental contributions conducted as part of this dissertation (**Chapters 4**, **5** and **6**), we sought to comply with these recommendations: First, we used a well-recognized and widely used assessment tool (i.e., the Q-BEx) to accurately describe the bilingual experience. Second, we opted for continuous variables, rather than group comparisons, to decipher the impact of specific dimensions of the bilingual experience on the outcome considered. While a continuum of a single factor cannot account for the whole richness of the bilingual experience, it nevertheless becomes a clear strength as compared to dichotomous groups approach. As Gullifer and Anderson (2023, p. 2) rightfully recall, "the middle of the distribution now contributes signal rather than noise". Third, the selection of the continuous variables indexing bilingualism was evaluated for each contribution, carefully guided by the literature, and explicitly stated.

As we have seen, bilingualism, in all its heterogeneity, is generally considered as having a positive influence on development. While this is true for children with typical development, the impact of bilingualism on children facing communicative challenges, such as autistic children, often raises concerns among caregivers. What does research say about the impact of bilingualism on the communicative development of autistic children?

3.2 BILINGUALISM AND AUTISM: WHERE TWO SPECTRA MEET

3.2.1 A detrimental combination?

Because autistic children experience unique communicative challenges inherent to their diagnosis, there is a widespread (mis)belief that bilingualism would exacerbate the difficulties they encounter, generate confusion or cause additional delays (Hambly & Fombonne, 2012). Due to the scarcity of research in this area, caregivers are often advised by professionals (e.g., therapists, educators, and health providers) to adopt a *monolingual approach* and abandon their home language in favor of the societal language (Hampton et al., 2017; Kay-Raining Bird et al., 2012; Yu, 2013). Regrettably, this recommendation has detrimental consequences for both the child's well-being and family dynamics. These include reduced participation in family interactions and less efficient communication (Kremer-Sadlik, 2005), input of lower quality (Drysdale et al., 2015), and concerns about losing cultural and traditional values (Jegatheesan, 2011). These recommendations are particularly problematic as they often contradict caregivers' perspectives, creating a dilemma that places additional pressure and potential guilt on their decision to maintain bilingualism (Howard et al., 2021). Parents frequently highlight the social benefits of bilingualism as part of their cultural identity (Jegatheesan, 2011), and home language plays an important role in transmitting family values and bonding (Yu, 2013).

Evidence-based recommendations are therefore needed to provide clear and consistent guidance for practitioners and families of bilingually-exposed autistic children (Beauchamp & MacLeod, 2017). While still in its infancy, research on bilingualism effects on the communicative, linguistic and cognitive development of children with ASD seems unequivocal to date: Research shows no detrimental impact of dual-language exposure or use in autism. Recent literature indeed highlights no adverse impact of bilingualism on various aspects of language (Dai et al., 2018; Hambly & Fombonne, 2012; Prévost & Tuller, 2022; Reetzke et al., 2015; see Gilhuber et al., 2023; Lund et al., 2017 for reviews), cognitive functions (Valicenti-McDermott et al., 2013), ToM (Andreou et al., 2020; Peristeri, Baldimtsi, et al., 2021) and executive functions (see Romero & Uddin, 2021 for a review).

Nevertheless, further research is needed to confirm and validate these promising findings. Most studies are indeed conducted on small samples and share similar limitations in the characterization of bilingualism as those observed in research involving neurotypical individuals (see **Section 3.1.2.2**). Arguably, studying autism and bilingualism in conjunction presents significant methodological challenges due to the inherent heterogeneity of both spectrums (Prévost & Tuller, 2022; **Sections 2.1** and **3.1**). These challenges notably include participant sampling, the selection of appropriate assessment tools, the consideration of cognitive and linguistic abilities, and the operationalization of key autism- and bilingualism-related variables (see Prévost & Tuller, 2022 for a comprehensive overview). Addressing these methodological issues is crucial to advancing the field and ensuring that research findings translate into reliable, evidence-based

recommendations for autistic individuals and their families. Moreover, some domains remain largely underexplored, despite their potential to inform practice.

Rather than viewing this dual heterogeneity as a limitation, the present work strives to address its challenges as systematically as possible. Careful efforts have been made to mitigate methodological limitations through detailed sample characterization in both autism and bilingualism. While acknowledging the multifaceted nature of bilingualism, this included focusing on a bilingual dimension operationalized as a continuum, aligned with specific research hypotheses. Cognitive and linguistic factors were assessed using objective and standardized measures, and, where possible, non-verbal assessments were employed to minimize language-related biases.

3.2.2 What remains to be explored

Important gaps remain in our understanding of how bilingualism affects the communicative development of autistic children, particularly in areas such as co-speech gesture comprehension, metalinguistic awareness and narrative macrostructure.

Co-speech gesture for instance, has been shown to be more frequently produced by bilingual speakers as compared to monolingual peers (see Nicoladis & Smithson, 2022 for a review). In autism, a retrospective study investigating the multidisciplinary evaluation reports of eighty toddlers diagnosed with ASD showed that the bilingual participants (i.e., children being exposed to two languages at home) produced more communicative gestures such as pointing, giving, nodding or waving to say *hi* and *bye*, than their monolinguals peers (Valicenti-McDermott et al., 2013). A longitudinal study of bilingual and monolingual families with autistic children aged 12 to 26 months investigated the effects of early intervention targeting social skills development (Zhou et al., 2019). After two years of intervention, children from bilingual homes demonstrated greater gains in gesture use compared to children from monolinguals homes. These preliminary studies suggest that bilingualism increases the use of co-speech gestures, which is encouraging given the crucial role of gestures in language acquisition and development (see **Section 1.2**). However, little is known about how autistic children *understand* gestures (**Section 4.1**), and whether differences exist between children with different dual-language exposure. Recent research on neurotypical children suggests that bilingual individuals may develop greater sensitivity to communicative contexts due to their dual-language exposure (e.g., Yow & Markman, 2011, 2016; **Section 4.2**). Notably, bilingual preschoolers have been shown to better interpret pointing gestures than monolingual peers (Yow & Markman, 2011). It remains to be determined whether this effect extends to other communicative gestures - such as iconic or conventional gestures - and whether it is also visible in children with ASD (for an exploration in NT children, see **Section 4.2**; for an exploration in ASD, see **Section 4.3**).

For decades, the effects of bilingualism on metalinguistic awareness have been widely documented in neurotypical children. Bilingual children are largely reported to outperform their monolingual peers on a variety of metalinguistic tasks, such as those involving form-meaning distinction, grammatical mistakes identification and correction (Bialystok, 2001b; Cummins, 1978). Noticeably, the better performance displayed by bilinguals over

monolinguals is reported to be the most prominent in tasks involving additional cognitive demand or misleading information that needs to be ignored (Adesope et al., 2010; Bialystok, 2001a, 2001b, 2024). For instance, bilingual children have been shown to consistently exhibit better performance than monolingual peers in adequately judging sentences as grammatically correct, when they contained a distracting inappropriate meaning (e.g., Bialystok, 1986, 1987, 1988, 2001). This advantage is hypothesized to stem from the acquisition and management of two distinct languages, each characterized by its own unique forms and structures. Exposure to multiple linguistic systems may enhance bilingual individuals' ability to develop a more explicit and nuanced understanding of linguistic principles. The constant need to monitor and select the appropriate language for a given context is believed to strengthen their attentional control, the ability to focus on relevant linguistic features while ignoring irrelevant ones, therefore fostering their metalinguistic competence (e.g., Adesope et al., 2010; Bialystok, 2001). In autistic children, no study to date has examined whether these effects are also present. Autistic children generally present difficulties with EF (Craig et al., 2016; Demetriou et al., 2018; **Section 2.2.1**). Interestingly, these EF skills are largely involved in metalinguistic tasks, and precisely hypothesized to be boosted by bilingualism in the neurotypical population (e.g., Adesope et al., 2010; Bialystok, 2009) and autistic children (e.g., Peristeri et al., 2020, 2021; Sharaan et al., 2021). Future research is warranted to shed light on the metalinguistic abilities of children with ASD as compared to NT peers irrespective of their linguistic background (see **Section 5.1**), and to examine whether the impact of bilingualism on metalinguistic awareness tasks that is found in NT children is also present in autistic children (see **Section 5.2** for a preliminary investigation).

Finally, only a handful of studies have explored the impact of dual-language exposure on narrative macrostructure in autistic children (Baldimtsi et al., 2020; Beauchamp et al., 2023; Hoang et al., 2018; Peristeri et al., 2020). These studies reveal no significant differences between monolingual and bilingual children on the autism spectrum. While offering insightful indications, they are nevertheless limited by their small sample sizes and their dichotomous approach comparing a monolingual to a bilingual group (i.e., *four*, *five* and *twenty* children per groups; except for the study by Beauchamp et al. (2023) comparing $N = 54$ bilinguals to $N = 80$ monolinguals). In **Chapter 6**, we expand this research by examining the impact of multilingual exposure, operationalized as a continuum, on the narrative macrostructure of $N = 168$ neurotypical and $N = 90$ autistic children aged 6 to 12. In addition, we will explore the impact of cognitive factors such as ToM, MA and EF, suspected to be involved in narrative production, to provide a wider picture on how these skills relate to macrostructural abilities.

FROM THEORETICAL INSIGHTS TO EXPERIMENTAL EXPLORATION

The previous chapters have outlined the theoretical concepts relative to *communication*, *autism*, and *bilingualism*.

Chapter 1 presented *communication* as an essential, multimodal and multifactorial competence. I explored in more depth three examples of communicative skills, each contributing to successful communication in children: co-speech gestures, as an example of non-verbal communication; *metalinguistic awareness*, as an example of a higher-order skill bridging language and cognition; and *narrative macrostructure*, as an example of verbal production indexing higher-order abilities.

In **Chapter 2**, I examined the communicative phenotypes observed in ASD more closely, while acknowledging the heterogeneity of the linguistic, intellectual and cognitive profiles contributing to the richness of the spectrum. I described broader cognitive challenges associated with ToM and EF, while mentioning less well understood sets of skills such as *co-speech gestures*, *metalinguistic awareness*, and *narrative macrostructure*. This discussion emphasized the necessity to investigate these dimensions in autistic children to fully understand the communicative profiles of autistic individuals. These research gaps will be addressed in the experimental contributions of this manuscript.

Because children with ASD are naturally raised in a multilingual world, I mentioned that some parents have expressed concerns regarding the impact of dual-language exposure on their child's communicative development, sometimes already vulnerable. **Chapter 3** therefore introduced bilingualism, acknowledged its complexity and multidimensionality, and exposed the challenges associated with its measurement and study. This chapter finally highlighted the gaps in our knowledge of the impact of bilingualism on *gesture comprehension*, *metalinguistic awareness* and *narrative macrostructure* in autistic children.

In the experimental part if this work, I will present empirical studies seeking to address these gaps in the literature:

In **Chapter 4**, I will focus on co-speech gesture comprehension, exploring how autistic and neurotypical children, both monolingual and bilingual, *understand* gestures. First, in **Section 4.1**, I will examine how autistic children integrate speech with gesture, when gestures are embedded in a narrative context. Then, in **Section 4.2**, I will investigate whether a multilingual exposure may influence the comprehension of gestures presented with different types of verbal information in school-aged NT children. Finally, in **Section 4.3**, I will examine whether these effects are visible in the autistic population.

Chapter 5 shifts focus to *metalinguistic awareness*, with particular emphasis on the interplay between two metacognitive sets of skills: *metasemantic* and *metamorphosyntactic* awareness. Using a grammaticality judgment task designed to engage both of these metacognitive layers, I will investigate whether autistic children differ from their neurotypical peers in performance (**Section 5.1**). Additionally, in a preliminary

exploration, I will examine the effects of bilingualism on these skills in both autistic and neurotypical children (**Section 5.2**).

Finally, **Chapter 6** will investigate the effects of multilingual exposure on narrative macrostructure, shedding light on how bilingualism influences storytelling abilities in neurotypical and autistic children.

Ultimately, this thesis aims to enhance our understanding of the intersection between *bilingualism*, *autism*, and understudied aspects of *communication*. By bridging these domains, it seeks to provide empirical evidence to inform evidenced-based recommendations.

Experimental contributions

4 Co-speech gesture comprehension

4.1 Gesture comprehension in autism

Understanding gestures in context is crucial for effective communication, as it enhances the accurate interpretation of speakers' messages and minimizes misunderstandings (see **Section 1.2**). While gesture production has received increasing attention in autism research in recent years – particularly for its potential as an early marker of ASD and language impairment risk (see **Section 2.2.2**) – gesture *comprehension* in autistic individuals remains underexplored. Existing studies are limited and yield mixed findings: Some report no deficits in gesture comprehension (N. Dimitrova et al., 2017), others indicate persistent difficulties compared to neurotypical peers (Cossu et al., 2012; Perrault et al., 2019), while some suggest challenges restricted to speech and gesture integration (Silverman et al., 2010). It remains to be determined whether autistic children experience difficulties in gesture comprehension, relative to neurotypical peers, when gestures follow verbal information and require sequential processing to derive combined meaning. The following study examines this question in more depth.

Below, I present the manuscript: Wolfer, P., Baumeister, F., Cohen, D., Dimitrova, N., Solaimani, E., & Durrleman, S. (2025). *Co-speech gesture comprehension in autistic children*, as published in the *Journal of Child Language*.

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ARTICLE

Co-speech gesture comprehension in autistic children

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Abstract

Co-speech gestures accompany or replace speech in communication. Studies investigating how autistic children understand them are scarce and inconsistent and often focus on decontextualized, iconic gestures. This study compared 73 three- to twelve-year-old autistic children with 73 neurotypical peers matched on age, non-verbal IQ, and morphosyntax. Specifically, we examined (1) their ability to understand deictic (i.e., *pointing*), iconic (e.g., *gesturing ball*), and conventional (e.g., *gesturing hello*) speechless video-taped gestures following verbal information in a narrative and (2) the impact of linguistic (e.g., vocabulary, morphosyntax) and cognitive factors (i.e., working memory) on their performance, to infer on the underlying mechanisms involved. Autistic children displayed overall good performance in gesture comprehension, although a small but significant difference advantage was observed in neurotypical children. Findings suggest that combining speech and gesture sequentially may be relatively spared in autism and might represent a way to alleviate the demand for simultaneous cross-modal processing.

Keywords: autism spectrum disorder; co-speech gestures; gesture comprehension; gesture recognition; non-verbal communication

Résumé

Les gestes co-verbaux accompagnent ou remplacent la parole dans la communication. Les études évaluant la compréhension de ces gestes par les enfants autistes sont rares, présentent des résultats inconsistants et se concentrent généralement sur des gestes iconiques proposés sans contexte linguistique. Cette étude a comparé 73 enfants autistes âgés de trois à douze ans à 73 enfants neurotypiques appariés en âge, en QI non verbal et en compétences morphosyntaxiques. Nous avons examiné (1) leur capacité à comprendre des gestes

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déictiques (e.g., pointage), iconiques (e.g., geste représentant un ballon) et conventionnels (e.g., saluer de la main) complétant une phrase dans un récit, ainsi que (2) l'impact des facteurs linguistiques (e.g., vocabulaire, morphosyntaxe) et cognitifs (e.g., mémoire de travail) sur leur performance, afin de mieux comprendre les mécanismes sous-jacents impliqués. Globalement, les enfants autistes ont bien compris les gestes, bien qu'une différence faible mais significative ait été observée en faveur des enfants neurotypiques. Ces résultats suggèrent que la combinaison séquentielle de la parole et du geste pourrait être relativement préservée dans l'autisme. Cette présentation séquentielle pourrait ainsi constituer une stratégie permettant d'alléger la difficulté du traitement simultané de ces modalités.

1. Introduction

Communicative gestures (i.e., "co-speech gestures" or "gestures") are spontaneous body movements such as hand movements, which naturally accompany both the spoken and signed discourse (Kita et al., 1998; Kita & Emmorey, 2023; McNeill, 1992). Gestures constitute crucial non-verbal elements with linguistic meaning, enabling successful communication. Efforts have been recently made to better describe the gestural profiles of children with Autism Spectrum Disorder (ASD),[1] notably for their potential to constitute early markers for ASD diagnosis (Stewart et al., 2022; Zwaigenbaum et al., 2015) and language impairment (Choi & Rowe, 2024; Goldin-Meadow, 2015). While most work has focused on production, studies investigating their gestural comprehension abilities remain scarce. This study proposes to address this gap by investigating the gestural comprehension abilities of autistic children aged 3–12 embedded in a narrative, in comparison to neurotypical peers of comparable age, non-verbal reasoning, and morphosyntactic skills.

Gestures are essential for effective and efficient communication, benefitting both the speaker and the listener. On the one hand, they support message conceptualization and linguistic planning, enabling the transformation of abstract thoughts into structured information that can be verbalized (e.g., Kita, 2000; Kita & Özyürek, 2003). On the other hand, they promote understanding and disambiguating speech (Dargue et al., 2019) while facilitating information retention in short- and long-term memory (Cook et al., 2008). At times, gestures reinforce the spoken message, providing emphasis and enhancing comprehension; in other instances, gestures convey meaning that is absent from speech, providing additional information that enriches the communication by visually reflecting the speaker's underlying thoughts (Goldin-Meadow, 1999, 2003). These visual cues arguably also have a positive impact on thinking, learning, and problem solving (Goldin-Meadow & Alibali, 2013), by reducing the cognitive load in speakers and listeners (Goldin-Meadow, 2004, 2011, 2014; Goldin-Meadow & Alibali, 2013). While gestures often occur with concomitant speech, situations where they replace verbal information are also frequent, for instance in noisy settings (Meissner & Philpott, 1975), in case of word retrieval difficulties (Krauss et al., 2001), or taboos (Brookes, 2014; Kendon, 1988).

Not only are gestures pivotal in language production and conceptualization, but their role in spoken language acquisition is also well established: Gesture production and comprehension noticeably *precede* and *predict* speech outcomes in vocabulary and syntax, both in the neurotypical population and in children with ASD (see Choi & Rowe, 2024;

[1]Both person-first and identity-first language will be used when referring to individuals diagnosed with autism, aiming to acknowledge the diverse preferences within the autistic community (Kenny et al., 2016).

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Kilili-Lesta et al., 2022 for reviews). Indeed, the frequency and diversity of gestures used by infants reliably predict their subsequent vocabulary size, with early gestures corresponding to words that will subsequently appear in speech (Colonnesi et al., 2010; Rowe et al., 2008; Rowe & Goldin-Meadow, 2009). Gesture–speech combinations also precede and predict the onset of two-word phrases, underscoring their foundational role in the development of syntax (Goldin-Meadow & Butcher, 2003; Iverson & Goldin-Meadow, 2005; Özçalışkan & Goldin-Meadow, 2005). As such, gestures constitute not only an indicator of overall communicative ability, but also a "harbinger" of subsequent linguistic milestones (Goldin-Meadow, 2015, p. 3).

Importantly, not all gestures are the same, and different gesture *types* convey different meanings. A pioneer classification is McNeill's taxonomy of gestures (McNeill, 1992), distinguishing different gesture types based on their semantic function. In this study, we will focus on: (1) *deictic* gestures, pointing or referring to specific objects or locations in space, (2) *iconic* gestures, directly representing an object or action, by depicting a characteristic of the referent (e.g., mimicking DRIVING[2]), and (3) emblems or *conventional* gestures, which are culturally shared gestures with arbitrary meaning (e.g., THUMBS UP to convey "good"; Ekman & Friesen, 1969).

Co-speech gesture production is delayed, atypical, and/or impaired in children with ASD (see Ramos-Cabo et al., 2019 for an overview). Its pervasive impairment even represents a core characteristic of the non-verbal communicative behaviours identified to establish the autism diagnosis (American Psychiatric Association, 2013). Autistic children indeed have been described to produce fewer gestures in comparison to their typically developing (TD) peers (Mishra et al., 2021; Perrault et al., 2019). This difference is notably observable in toddlers, who produce fewer deictic gestures such as pointing (Manwaring et al., 2018; Mastrogiuseppe et al., 2015). However, differences in gesture use and comprehension between autistic and neurotypical children are not merely quantitative, but also qualitative. Precisely, pointing gestures can be distinguished based on their pragmatic function, aim, and social load (Baron-Cohen, 1989; E. Bates, 1976): *proto-imperative* pointing, on the one hand, is used to request or obtain objects. On the other hand, *protodeclarative* pointing serves to share attention and interest by directing addressees to objects or events. Research shows that while children with ASD may demonstrate relatively intact *protoimperative* pointing, they exhibit marked deficits in the comprehension and production of *protodeclarative* pointing (Baron-Cohen, 1989; E. Bates, 1976; Wetherby & Prutting, 1984). This lack of protodeclarative pointing has been associated with reduced interest in social interactions, as well as broader challenges in joint attention, Theory of Mind (i.e., ToM; the ability to attribute mental states to others and predict their behaviours accordingly; Premack & Woodruff, 1978), and social communication (Baron-Cohen, 1989; Brinck, 2004; Camaioni et al., 2004). They are considered hallmark characteristics of ASD. Lower rates of conventional gesture use have also been reported in four- to-twelve-year-old autistic children, in comparison to age-matched TD peers of comparable general language skills (Huang et al., 2020) and full-scale IQ (So et al., 2015).

Many efforts have been engaged to characterize the productive gestural profiles of children with ASD to better inform our understanding of their (non-verbal) communicative behaviours. However, studies exploring the extent to which autistic children *understand* gestures remain limited to date (see Choi & Rowe, 2024 calling for more studies on this

[2]Words in capital letters refer to gestures.

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topic). Yet, a better understanding of the gestural profiles of autistic children is highly valuable, for both diagnostic and intervention purposes. A recent review noticeably emphasized that gestures constitute an early diagnostic marker for ASD (Stewart et al., 2022), helping to detect and identify children at higher risk of autism at earlier stages. Early detection consequently promotes chances to receive early tailored interventions (Zwaigenbaum et al., 2015), which further lead to better social and communicative outcomes (Dawson, 2008; Estes et al., 2015). In addition, better descriptions of gestural profiles in autism may also support the development and implementation of gesture-based therapies, which benefit autistic children across the spectrum (So et al., 2018). Finally, in the light of the well-established relationship between gesture and language development, gestures can also serve as a screening tool for children at higher risk of language delays and impairments (Choi & Rowe, 2024; Goldin-Meadow, 2015; Kilili-Lesta et al., 2022), a common feature in autistic children (Rapin & Dunn, 2003; Schaeffer et al., 2023; Silleresi, 2023).

Moreover, work on the comprehension of gestures has so far yielded inconsistent findings, which may be explained by the variety of tasks and methodology used. In a study investigating the recognition of video-taped decontextualized speechless gestures, Perrault et al. (2019) showed that four- to-eight-year-old children with ASD recognized fewer gestures of iconic and conventional types, in comparison to both TD children and children with language impairment of the same age, suggesting difficulties in this realm beyond language impairment (Perrault et al., 2019). Yet, no mention of the non-verbal reasoning abilities of the sample was provided, nor of their linguistic abilities. Similarly, Stieglitz Ham et al. (2011) showed that 19 autistic children aged 7 to 15 recognized fewer video-taped pantomimes and actions depicting object use compared with their neurotypical peers matched on chronological age, gender, and full-scale IQ (Stieglitz Ham et al., 2011). Evidence of impaired understanding of iconic gestures in combination with speech has also been previously reported in autistic adolescents (Silverman et al., 2010; Hubbard et al., 2012), supporting the possibility of a cross-modal, audiovisual integration deficit.

These findings, however, do not align with previous work conducted by Dimitrova et al. (2017), exploring the gesture comprehension abilities of autistic children aged 2–12 in comparison to vocabulary-matched TD peers. They found no difference in the recognition performance of deictic, iconic, and conventional gestures when participants had to select the picture, out of two choices, corresponding to the gesture performed by the experimenter, either proposed alone or in combination with single words (Dimitrova et al., 2017). Furthermore, in a pantomime comprehension task in which participants were required to select the picture corresponding to a video-taped actor performing a pantomimic action (e.g., *a girl kissing a boy*), 7- to-11-year-old autistic children also performed on par with their TD peers of comparable age and IQ level (Adornetti et al., 2019). Even better recognition performance was exhibited by children with autism compared with neurotypical peers matched on vocabulary (Hamilton et al., 2007), though in a task that did not involve live or video-taped gesturing. Precisely, participants were required to select the correct hand position, among three black-and-white pictures of a hand, that matched a drawing representing a protagonist performing a gesture with a missing hand (e.g., when shown a drawing of a soldier with a missing hand, participants had to choose the corresponding hand from three available options). The group of autistic children provided more correct responses than their neurotypical peers who were younger in chronological age but had comparable vocabulary knowledge (autistic children: 8;1 ± 1; neurotypical children: 4;1 ± 0). The offline nature of the task, which did not involve processing the motion of the gesture, may have favoured the autistic participants' strength in analytic processing and attention to the details (Brosnan et al., 2016; U. Frith, 2003).

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Different explanations as to why autistic individuals may experience challenges in co-speech gestures comprehension can be put forth. First, under the integrated-system hypothesis where gestures and speech constitute a unified communicative and cognitive system (e.g., Goldin-Meadow, 2003; Kendon, 2000; McNeill, 1992), difficulties in gesture comprehension may be linked to challenges with language processing (e.g., Goldin-Meadow & Alibali, 2013; Kelly et al., 2010). Second, difficulties with co-speech gestures might stem from reduced attention and appetence towards socio-communicative cues, widely documented in autism (e.g., Chevallier et al., 2012; Klin et al., 2009). Third, challenges may relate to a deficit in multimodal integration of speech and gesture, as suggested by neuroimaging studies (e.g., Hubbard et al., 2012), as well as by the observation that challenges in understanding gesture emerge when these are presented simultaneously with speech in autistic adolescents (Silverman et al., 2010). Noticeably, this difficulty was not attributable to lower comprehension of either speech or gesture alone. As the authors point out, however, it remains to be determined whether the difficulty in integrating speech and gesture stems from the "cross-sensory nature of the task itself" (Silverman et al., 2010, p. 389) or rather from the higher-order process of combining the verbal and gestural information together.

Previous studies on gesture comprehension have helped us to better describe the gestural profiles of autistic individuals. They nevertheless present an incomplete picture of the gestural communicative processes at play in comprehension: Indeed, co-speech gestures, either replacing, interacting, or co-occurring with speech, serve a cognitive or communicative purpose during communicative acts (Clough & Duff, 2020). Such gestures are thus to be understood in their linguistic context, an approach rarely adopted in previous research (e.g., Adornetti et al., 2019; Perrault et al., 2019; Silverman et al., 2010; Stieglitz Ham et al., 2011). Instead, decontextualized stimuli were often used, in the sense that the gestures to be recognized were not integrated into a discourse, contrary to naturalistic situations in which they most likely appear, such as conversations and narrations. Moreover, despite a few exceptions (Dimitrova et al., 2017; Perrault et al., 2019), previous studies have generally investigated a specific gesture type at a time (often iconic gestures), although autistic children tend to primarily face challenges with deictic and conventional gestures (Ramos-Cabo et al., 2019).

To address these gaps, the present study explored the gestural comprehension abilities of children with autism aged 3–12, in comparison to their neurotypical peers carefully matched on age, non-verbal IQ, and receptive morphosyntactic skills. This age range was selected because gesture comprehension is an evolving process developing throughout childhood (Kelly & Church, 1998). During this period, several cognitive skills that may be linked to gesture comprehension in narratives co-develop and undergo significant maturation: attention and executive functions (Anderson, 2002), social cognition such as ToM (Hughes & Devine, 2015), perspective-taking (Beatini et al., 2024), as well as narrative comprehension (Stein & Glenn, 1979). In the present study, we assessed the recognition of three types of gestures (i.e., deictic, iconic, and conventional) that replaced verbal information embedded in an overall story.

Specifically, this study aimed to answer two research questions: (1) Do autistic and neurotypical participants differ in their ability to understand *deictic*, *iconic*, and *conventional* gestures when they are integrated into a narrative and replace verbal information? (2) What is the impact of linguistic (i.e., receptive morphosyntactic and vocabulary skills) and cognitive (i.e., working memory, WM) variables on the performance, so as to shed light on the underlying mechanisms at play in gesture comprehension?

We predicted that children with ASD would show one of two types of performance: On the one hand, they could display lower performance than their TD peers, even after

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controlling for their non-verbal reasoning and linguistic abilities, as difficulties with both speechless iconic and conventional gesture recognition have been reported in autistic children (Perrault et al., 2019). Investigating the respective impact of the linguistic and cognitive variables on the performance will help to elucidate why autistic children might display lower gesture comprehension performance: Indeed, autistic children may experience challenges (a) in parsing the verbal part of the stimulus (namely the spoken sentence preceding the gesture) or (b) in processing the subsequent gestural part of the stimulus; alternatively, challenges may stem from difficulties (c) in integrating these two sources of information (i.e., language and gesture). In the latter case, examining the impact of WM will indicate whether the difficulties in multimodal integration stem from challenges in sequentially maintaining and manipulating these sources of information or whether difficulties lie rather in a higher-order combination of these sources to correctly interpret the message. On the other hand, children with ASD could show similar performance to their TD peers, since our task differed from those of previous studies by only requiring a non-verbal response. This design may have facilitated task performance in children with ASD, by steering clear of their more pronounced challenges in the realm of language production (Rapin & Dunn, 2003).

2. Method

2.1. Participants

2.1.1. Groups

A total of $N = 146$ children, predominantly White, participated in the study. The group of autistic children was composed of $N = 73$ participants aged 3;10 to 11;7 years ($M_{age} = 101 \pm 25.6$ months), to which corresponded $N = 73$ neurotypical children aged between 3;11 and 11;10 years ($M_{age} = 100 \pm 27.4$), carefully matched on age, non-verbal IQ, and receptive morphosyntactic skills with a propensity score (see Supplementary Material, Appendix 1 for further information on the matching procedure). There were more female participants in the neurotypical group than in the autistic group (χ^2 (1) = 38.50, $p < .001$). TD children had no suspicion or diagnosis of ASD, nor of any other developmental disorder or known linguistic or cognitive impairment. Children had no reported visual or auditory impairment. All participants in the autistic group had an official diagnosis of ASD following the criteria of the DSM-5 (American Psychiatric Association, 2013), established by a certified clinician prior to the study with gold-standard tools (e.g., *Autism Diagnostic Observation Schedule*: ADOS-2; Lord et al., 2012, *Autism Diagnostic Interview Revised*: ADI-R; Lord et al., 1994).

2.1.2. Sample recruitment and characteristics

Participants were recruited via flyers, contact with clinicians and hospitals, and websites of associations relevant to the autistic community. Interested families contacted the team via the project's website, emails, or phone calls. As part of an international project, 30.1% of the participants were tested in Switzerland, 32.9% in Germany, 26.7% in France, 3.4% in the UK, 5.5% in the USA, and 1.4% in Canada. Because multilingualism is a widespread phenomenon (Grosjean, 2010), we did not restrict inclusion in the study to monolingual participants, but instead carefully monitored the participants' language backgrounds with the caregiver questionnaire *Quantifying Bilingual EXperience* (Q-BEx; De Cat et al., 2022). The groups of children with ASD and TD children were balanced in their proportion of monolinguals and multilinguals (see Table 1, 47.9% of multilinguals in the group of children

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with ASD and 45.2% in the group of TD children; χ^2 (1) = 1.40, $p > .05$), with participants considered multilinguals if they had been exposed to two (or more) languages more than 20% of their lifetime, following previous studies (Hantman et al., 2023).

Parental educational level indexed socioeconomic status, given its important correlation with family income (Hauser & Warren, 1997), association with children's academic performance and cognitive development (Rindermann & Ceci, 2018). The highest level of education achieved between the two caregivers was selected and converted into a five-point Likert scale, from (1) elementary school to (5) university. The two groups had relatively high scores of socioeconomic statuses (Table 1). Yet, it was not possible to match participants on this criterion in addition to age, non-verbal IQ, and morphosyntactic skills, and the group of TD children had higher socioeconomic status scores on average (W = 2179.5, $p = .04$). Socioeconomic status was added as a covariate in the statistical analyses to control for its impact.

2.2. Measures

Each participant was individually tested in a quiet room, always accompanied by an experimenter. The *Gesture Comprehension Task* required participants to (1) sequentially process both the verbal and gestural part of the stimulus and (2) to successfully integrate them together to select the correct answer. To account for the cognitive and linguistic resources involved in the task, we monitored and controlled for the resources mobilized

Table 1. Sample description

	Children with ASD (N = 73)	TD children (N = 73)
Age (months)		
Mean ± SD	101 (25.6)	100 (27.4)
Median [min, max]	103 [46, 139]	102 [47, 142]
Sex assigned at birth		
F	18 (24.7%)	35 (47.9%)
M	55 (75.3%)	38 (52.1%)
Parental educational level (min 1, max 5)		
Mean ± SD	3.90 (1.28)	4.37 (0.89)
Median [min, max]	4 [1, 5]	5 [2, 5]
Language of testing		
English	7 (9.6%)	7 (9.6%)
French	41 (56.2%)	14 (19.2%)
German	23 (31.5%)	37 (50.7%)
Italian	2 (2.7%)	15 (20.5%)
Linguistic background		
Monolinguals	38 (52.1%)	40 (54.8%)
Multilinguals	35 (47.9%)	33 (45.2%)

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during the task, namely linguistic skills, visual perception of communicative cues, and WM. As such, the assessment started with first a *pre-assessment task* ensuring that the participant had sufficient attentional resources towards gestural cues. This was followed by the *Gesture Comprehension Task*. Then, the *Peabody Picture Vocabulary Test* (Dunn & Dunn, 2007) and the *Test for Receptive Grammar* (Bishop, 2003) monitored the participants' linguistic abilities. *Raven's Progressive Matrices* (Raven et al., 2018) were used to assess non-verbal IQ, and the *Frog Matrices Task* (Morales et al., 2013) measured WM.

2.2.1. Gesture Comprehension Task

To test the participants' gestural comprehension abilities in a narrative context, a new gamified task inspired by Botting et al. (2010) and Wermelinger et al. (2020) was developed. The task was digitalized and included 12 items preceded by two warm-up trials with explanatory feedback. All items formed a coherent story. The task was introduced by Gabi, a 3D character with a natural human-like voice, who was asking for help to understand the story played on TV. All instructions were given orally by this character, ensuring similar quantity and quality of instructions across participants. Participants were asked to watch and listen carefully to a short video and to select, by touching the screen, the corresponding picture out of four response choices.

Language versions. The task was made equivalent in four languages: English, French, German, and Italian. All items and instructions were translated from French to the other languages and were recorded by native speakers of the respective languages. The complete list of items in all languages is available in Supplementary Material, Appendix 2.

Stimuli description. Each stimulus consisted of a video of an actor enunciating a sentence and replacing the last part with a speechless gesture, either of deictic (i.e., pointing gesture, four items), iconic (four items), or conventional (four items) type (see Figure 1 for an example of each gesture type). Natural congruent facial emotions were kept ensuring a naturalistic context. The stimuli always appeared in the same order for all participants (i.e., stimulus with a deictic gesture, followed by an iconic, and a conventional gesture). The videos were recorded by a professional cameraman, which was subsequently post-edited for sound normalization and noise reduction. The stimuli's narrations were short sentences of maximum 12 words, with reduced morphosyntactic and vocabulary difficulties, to avoid penalizing participants with lower language skills (i.e., simple clause syntactic structures, verbs in present tense, words emerging in the first years of life present in the *Mac-Arthur Bates Checklist Inventory* in English (Fenson et al., 2007), German (Szagun et al., 2009), French (Kern et al., 2010), and Italian (Rinaldi et al., 2019)). Gestures were selected to minimize cultural variations in the Western countries the study took place in.

Response choices. Four response options (Figure 2) that did not require verbal naming were presented. This number was chosen following the original task (Botting et al., 2010) and enabled lowering the likelihood of hitting a correct response by chance to 25%. The verbal and non-verbal components of each item were intentionally designed to be ambiguous when processed separately. Accordingly, participants had to integrate both verbal and gestural parts to accurately select the correct item from the four presented options, except for the stimuli of deictic types where paying attention to the pointing gesture was sufficient to succeed. The response options were: (a) the *correct answer*, depicting the correct object or the protagonist performing the correct action, (b) a *gestural* distractor, referring to a gesture close to the target gesture that could be selected if the

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	Language	Sentence produced by the actor...	...speechless gesture ending the sentence
DEICTIC	ENGLISH	"Lewis goes into the forest to collect..."	 ...POINTING towards flowers
	FRENCH	"Louis va dans la forêt pour ramasser... "	
	GERMAN	"Luis geht in den Wald und sammelt..."	
	ITALIAN	"Luigi va nella foresta a raccogliere..."	
ICONIC	ENGLISH	"In a tree, there is an animal. It is a..."	 ...MONKEY gesture
	FRENCH	"Dans un arbre, il y a un animal. C'est un..."	
	GERMAN	"In einem Baum sitz ein Tier. Es ist ein..."	
	ITALIAN	"In un albero c'è un animale. È un..."	
CONVENTIONAL	ENGLISH	"Lewis stops. In front of him, there are two roads. Lewis..."	 ...DON'T KNOW gesture
	FRENCH	"Louis s'arrête. Devant lui, il y a deux routes. Louis..."	
	GERMAN	"Luis hält an. Vor ihm sind zwei Wege. Luis..."	
	ITALIAN	"Luigi si ferma. Davanti a lui ci sono due strade. Luigi... "	

Figure 1. Example of stimuli of *deictic*, *iconic*, and *conventional* gesture types in the four languages.

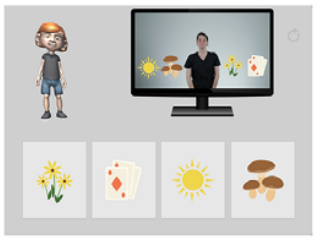
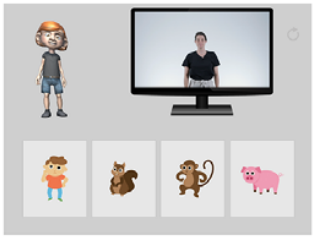
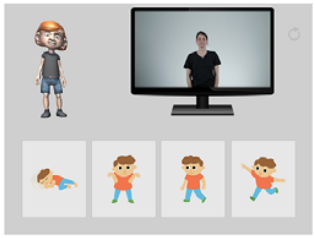
	Deictic gesture	Iconic gesture	Conventional gesture
Screen			
Response options	*From left to right...* (1) Correct response (2) Oddball (3) Visual distractor (4) Semantic distractor	*From left to right...* (1) Gestural distractor (2) Semantic distractor (3) Correct responses (4) Oddball	*From left to right...* (1) Oddball (2) Correct response (3) Semantic distractor (4) Gestural distractor

Figure 2. Example of response choices for stimuli of *deictic*, *iconic*, and *conventional* type.

participant paid only attention to the gesture, but not to the verbal part of the stimulus, (c) a *semantic* distractor, that matched the verbal content of the stimulus but not the gesture seen, and (d) an *oddball*, matching neither the stimulus' verbal information nor the gesture. The oddball pictures were of the same attractiveness and nature as the other response choices to ensure consistency (e.g., animate/inanimate object). For deictic gestures, the gestural distractor (c) was replaced by a *visual* distractor, namely a picture visually close to the target item in terms of colour and/or shape, as it was not possible to conceive a gestural distractor for this type of gesture. The response choices appeared simultaneously at the end of the stimulus in a random order.

Performance calculation. For each item, 1 point was awarded for a correct picture selection, while 0 point was given for an incorrect response, irrespective of the distractor

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selected. The total Gesture Comprehension Task score varied between a minimum of 0 and a maximum of 12 points.

2.2.2. Pre-assessment task

A short six-item pre-assessment task ensured that the participant had sufficient attention towards video-taped gestures. Each item consisted of a video-taped speechless gesture performed by an actor. Participants had to select the video of the same gesture performed by another actor amongst three choices. Participants performing below chance level (i.e., 33%) were excluded. All participants (N = 146) included in this study performed above chance level at this task.

2.2.3. Morphosyntactic assessment

As the Gesture Comprehension Task involved the comprehension of gestures embedded in a sentence, receptive morphosyntactic skills were assessed using the *Test For Receptive Grammar 2* (Bishop, 2003) and its respective adaptations in the different languages of testing, namely French (Lecocq 1996), German (Fox-Boyer et al., 2006) and Italian (Suraniti et al., 2009). This standardized task assesses the comprehension of different grammatical structures with increasing complexity (e.g., passive sentences, "neither nor" constructions, etc.), by requiring participants to select, among four choices, the image corresponding to the sentence heard. Z-scores were used in the analyses.

2.2.4. Receptive vocabulary assessment

Given the predictive role of vocabulary knowledge on the gestural development in both autistic and neurotypical children (Choi & Rowe, 2024; Kilili-Lesta et al., 2022), the PPVT was administered to assess the breadth of receptive vocabulary (i.e., English: Dunn & Dunn, 2007, French: Dunn et al., 1993, German: Lenhard et al., 2015, Italian: Stella et al., 2000). Participants selected, among four options, the picture corresponding to a word heard. Raw scores were converted into z-scores to allow comparison across languages.

2.2.5. Working memory (WM) assessment

As the Gesture Comprehension Task involved WM, the Frog Matrices Tasks (FMT) following Morales et al. (2013) was administered. In this variant of the *Corsi Blocks Task* (Berch et al., 1998), children had to recall the backward location of two to six frogs appearing sequentially. The memory span was determined as the longest sequence of frogs that the participant could recall accurately in at least one of the two trials proposed. Groups did not differ in their WM spans (W = 1884.5, p = .08).

2.2.6 Non-verbal reasoning assessment

The short version of the digitalized *Raven's Progressive Matrices (Raven's 2;* Raven et al., 2018) was used to assess and control for non-verbal reasoning. The participant selected the option, among five choices, that best fitted the visual geometric design displayed on the screen. The resulting standardized non-verbal IQ score was used in subsequent analyses.

Descriptive statistics of the linguistic and non-verbal measures are presented in Table 2.

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Table 2. Descriptive statistics of the linguistic and non-verbal measures

	Children with ASD (N = 73)	TD children (N = 73)
Receptive morphosyntax (TROG–2, z-score)		
Mean ± SD	−0.65 ± 1.32	−0.49 ± 1.19
Median [min, max]	−0.45 [−3.23, 1.42]	−0.40 [−3.00, 1.90]
Non-verbal IQ (Raven's 2 IQ score)		
Mean ± SD	95.50 ± 13.60	96.80 ± 13.20
Median [min, max]	93.00 [70.00, 128.00]	97.00 [71.00, 133.00]
Receptive vocabulary (PPVT, z-score)		
Mean ± SD	−0.47 ± 1.78	0.34 ± 1.17
Median [min, max]	−0.29 [−4.00, 3.00]	0.20 [−2.33, 2.30]
Missing values	5 (6.8%)	13 (17.8%)
Working Memory (WM span)		
Mean ± SD	3.49 (2.15)	4.15 (1.77)
Median [min, max]	4.00 [0.00, 6.00]	5.00 [0.00, 6.00]
Missing values	10 (13.7%)	1 (1.4%)

3. Data analyses

A binomial generalized mixed-effects model with a logit function on accuracy was constructed to investigate whether the two groups (children with ASD and TD children) had different gesture comprehension performances, and whether their scores were differently influenced by the type of gesture. Analyses were run in R using R Studio (Version 2023.12.0 + 369) with the *lme4* package (D. Bates et al., 2015).

The fixed effects of the model included group (autistic children, neurotypical children), gesture type (deictic, iconic, conventional), and their interaction. In addition, the following covariates were added to investigate their impact on performance: Receptive morphosyntax, vocabulary knowledge, and WM. Age, the interaction between age and group, socioeconomic status, sex assigned at birth, non-verbal reasoning, and language of testing were also entered as fixed effects to account for their effect and potential differences between groups. Participants and items were entered as random effects. We began by including a maximal random effects structure and only simplified the complexity of random effects in case of convergence issues (Barr et al., 2013). Information on contrast coding and model specifications is available in Supplementary Material, Appendix 3 and under: https://osf.io/vp764/

4. Results

Descriptively, both groups performed well on the task, above chance level with scores approaching ceiling performance for all gesture types (Figure 3). Overall, children with ASD produced an average of 12.10% incorrect responses, whereas TD children made only 3.54% errors, indicating a higher accuracy rate in the neurotypical group.

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The model showed a significant effect of group (β = − 1.64, SE = 0.68, p = .02) with autistic participants recognizing significantly fewer gestures than their TD peers (Supplementary Material, Appendix 4). However, the size of the difference was small, estimated at about 2.0% when accounting for all other variables. There was no significant effect of gesture types (all *ps* > *.05*), and the non-significant interaction between groups and gesture types (all *ps* > *.05*) suggests that both groups were not differentially impacted by the different types of gestures (deictic, iconic, and conventional).

Age was a significant positive predictor of the performance (β = 1.23, SE = 0.26, p < .001), suggesting better gesture comprehension in older children. However, the non-significant interaction between age and group (p > .05) suggests that age did not impact the group's performance differently. Illustrations of the predicted performance as a function of age are presented in Supplementary Material, Appendix 6. They suggest that participants reach a performance plateau around age 8. More advanced analyses, such as generalized additive models (GAMs) would be required to confirm these observations.

A significant effect of vocabulary knowledge was found (β = 0.39, SE = 0.16, p = .02), showing that participants with higher vocabulary skills also exhibited better gesture recognition performance. However, there were no significant effects of either receptive morphosyntactic skills or WM on accuracy. Additionally, sex assigned at birth, socio-economic status, non-verbal reasoning, and language of testing did not predict the performance either (all *ps* > .05).

To further examine the role of receptive vocabulary on the performance difference between autistic and neurotypical children, causal mediation analyses were conducted (see Supplementary Material, Appendix 5). Results showed that vocabulary knowledge significantly mediated the group difference in performance: On average, about 18.39% of the total effect of the difference between the two groups was explained by PPVT scores (proportion mediated estimate = 0.18, CI = [0.19, 0.35], p < .001; 25.96% in TD children, and 10.81% in children with ASD).

Explanatory post-hoc analyses were further conducted to investigate whether the *monolingual* versus *multilingual* status of the participants differently impacted the performance. *Multilingual status* (monolingual, multilingual) was sum-coded and included in the final model either as a fixed effect (model A) or in interaction with the

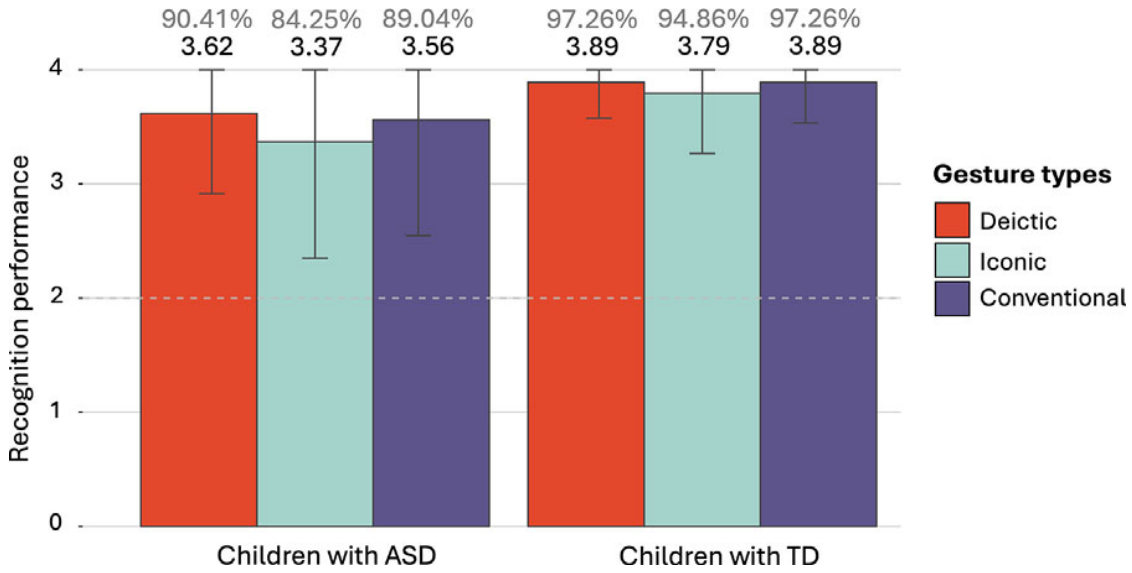


Figure 3. Mean recognition performance per group and gesture types.

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group variable (model B). Results revealed no significant effect of multilingual status in either model (see Supplementary Material, Appendix 7).

To further investigate whether autistic and neurotypical children differed in their error patterns (e.g., selecting the semantic distractor, visual distractor, or oddball), a series of chi-square tests of independence were conducted. These tests allowed us to evaluate whether the observed error frequencies differed significantly between the two groups for each combination of *gesture type* and *error type*, compared with the expected frequencies under the null hypothesis of no association. Given that multiple chi-square tests were conducted, a Bonferroni correction was applied to control for the increased risk of type I error (risk of false positives). Results indicated that when they did not select the correct answer, autistic children were significantly more likely to select the *semantic distractor* than neurotypical children (χ^2 (1) = 11.78, $p < .001$), but only in items with iconic gestures. No significant difference in the proportion of errors was evidenced for other *gesture* types, nor other *error* types. Moreover, both groups produced all three types of errors, without salient preference for a specific type over another. Supplementary Material, Appendix 8 shows a visualization of the distribution of errors for each group and gesture type.

5. Discussion

The first goal of this study was to examine whether and how autistic children understand three types of communicative gesture (i.e., *deictic*, *iconic*, and *conventional*) when these gestures replaced verbal information in a narrative. Their performance was compared to TD peers who were carefully matched on age, non-verbal IQ, and receptive morphosyntactic abilities. After accounting for their age, sex assigned at birth, non-verbal IQ, receptive morphosyntactic abilities, vocabulary knowledge, socioeconomic status, WM, and testing language, children with ASD recognized significantly fewer gestures than their TD peers, irrespective of the gesture type. Despite the small difference between groups, these findings suggest that autistic individuals may not fully grasp all the information conveyed by hand movements that naturally accompany speech in conversation and narration. Consequently, they may miss crucial elements of the intended message, potentially leading to challenges in understanding communicative partners who use gestures alongside speech. The findings go beyond previous work reporting challenges in gesture comprehension of *iconic* and *conventional* gestures in autistic children (Perrault et al., 2019; Stieglitz Ham et al., 2011): In the present study, we observed subtle challenges that seem to arise with gestures being embedded in a richer linguistic context. The (relatively) greater difficulty in integrating multiple sources of information (i.e., here speech and gesture) relative to neurotypical peers aligns with previous research using multimodal audiovisual tasks (Mongillo et al., 2008; Silverman et al., 2010). It is important to acknowledge, however, that all participants, including those with ASD, demonstrated good performance, performing above chance levels already at a younger age. While the group difference was statistically significant, it remained relatively small and may only indicate subtle repercussions in daily living. Moving beyond a deficit-based view of autism (Mottron, 2017), these results can be interpreted as evidence that autistic and neurotypical children, when carefully matched on key variables, perform similarly well in integrating gesture following speech.

As expected, age was identified as a positive predictor of performance in both groups, with older participants recognizing more gestures than younger ones and performing at ceiling. This pattern suggests a gradual maturation of the ability to process gestures over

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time (Capone & McGregor, 2004; Perrault et al., 2019). The size of the age-related improvement in gesture recognition appeared similar between autistic and neurotypical children, although a higher variability in the autistic group was visible. Future studies may examine in more depth developmental aspects in the comprehension of different gesture types in both children with ASD and TD children, for instance with the help of GAMs.

The second goal of this study was to identify the factors that may explain the difference between the groups in the current task. Interestingly, better performance could not solely be attributed to a better comprehension of the verbal story in which gestures were embedded. Indeed, the sole reliance on the verbal information (i.e., the sentential part of the stimulus) was insufficient to select the correct picture, as parsing the visual gestural information was necessary to disambiguate between the correct response and the so-called semantic distractor. Similarly, parsing only the gestural part of the stimulus would have led to confusion between the correct answer and the gestural distractor, potentially leading to a greater proportion of gestural distractors. Further examination of the error patterns revealed no striking differences between autistic and neurotypical children, except for items with *iconic gestures*: When they produced an error in iconic items, children with ASD selected the *semantic* distractor significantly more often than TD children. This behaviour suggests that autistic children accurately parsed the verbal information provided in the stimulus and likely relied on this information more heavily (than on the gesture) when confronted with these items. In other terms, these findings could also suggest a lower reliance on the *gestural* part of the stimulus: This would align with previous work examining the *production* of gesture–speech combinations in school-aged children, which reported lower reliance on gestures by autistic children than their neurotypical peers to add information to their speech (Baumann et al., 2019). Instead, the children with autism in that study relied more strongly on speech than on gestures. More effortful processing of gestures with high communicative load such as pointing, as compared to cues with lower communicative value (like grasping), has also been reported (Aldaqre et al., 2016). In addition, previous research also suggests impaired perception of biological motion in autistic children (Blake et al., 2003), with a preference towards non-social cues over social stimuli (Chevallier et al., 2012). According to the *social motivation theory*, the challenges autistic individuals experience in social cognition, including the detection, interpretation, and use of non-verbal cues such as gestures in the social context (C. D. Frith, 2008), may stem from reduced social motivation (Chevallier et al., 2012; Parish-Morris et al., 2021). This reduced social motivation reflects a diminished tendency to orient towards social cues, seek social interactions, and experience reward from social engagement and bonding maintenance. This possibility was ruled out in our task, as we ensured sufficient attention towards gestural stimuli by proposing a pre-assessment task: Only the participants who performed above chance level to this task were included in the study. Therefore, it is unlikely that group differences were driven by salient reduced attention to the gestures.

Pertaining to potential linguistic factors, morphosyntactic skills did not significantly impact the performance. This is arguably due to the intentionally limited morphosyntactic difficulty of the stimuli's verbal component, restricted to simple clauses with verbs in the present tense only. This reduced linguistic complexity was proposed to avoid penalizing children with language impairment, often represented in ASD (Rapin & Dunn, 2003).

Vocabulary knowledge, in contrast, significantly predicted gesture comprehension, in both children with ASD and TD children. This finding emphasizes the close link between speech and gesture, an intertwinement that has intrigued researchers for decades (e.g.,

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Goldin-Meadow & Alibali, 2013; Kita, 2000; Kita & Emmorey, 2023). It furthermore supports the claim of a probable bidirectional, mutual influence of gesture and language developments: Not only gesture (use) predicts later vocabulary size (e.g., Rowe & Goldin-Meadow, 2009), but vocabulary may in turn predict gesture production, as evidenced notably for word comprehension and gestures in children with high and low risk of ASD (Roemer et al., 2019). The present study aligns with this view and provides, for the first time, empirical evidence of a predictive role of vocabulary on gesture comprehension.

Mediation analysis enabled us to decipher the extent to which vocabulary knowledge mediated the group difference in performance and determine whether the effect of the group difference on gesture comprehension was a direct effect. Analyses showed that vocabulary knowledge significantly mediated the performance difference between autistic and neurotypical children, with about 18% of the total effect being mediated by vocabulary. While this contribution was pivotal, most of the effect (approximately 82% on average across groups) was therefore not explained by vocabulary alone. This indicates that other factors, or their combination, may have contributed to the difference in gesture comprehension between autistic and neurotypical children in this task.

Finally, the (small) gap in performance between groups might not stem from difficulties in recalling and holding both types of input (i.e., language and gesture) to further combine them to answer correctly. Indeed, neither group differed on average in their WM span, nor did this factor have a predictive impact on performance. Yet, challenges in integrating information from multiple sensory modalities, such as verbal descriptions and gestures, have been reported in autistic children and adolescents (Hubbard et al., 2012; Silverman et al., 2010). These studies presented speech and gestures simultaneously, which may have contributed to the difficulties observed. In our task, while the combination of both modalities was necessary to succeed, speech and gestures were processed sequentially. This sequential presentation may have alleviated the challenges associated with simultaneous multisensory integration: Such difficulties are frequently reported in autistic individuals and have been shown to contribute to sensory overload and processing challenges (Iarocci & McDonald, 2006). Thus, the difference in the mode of presentation may explain the relatively spared performance of the autistic participants in our task. While further research should allow confirmation of this possibility, this finding highlights the potential of sequentially presenting information, such as verbal input followed by gestures, as a means to reduce sensory overload. This approach aligns with outcomes from *sensory integration* therapy (Ayres, 2005), where structured and gradual exposure to sensory stimuli has been recognized as enhancing sensory processing and adaptive responses in autistic children (Camino-Alarcón et al., 2024; Schoen et al., 2019). Such interventions in occupational therapy are effective in improving sensory integration, communication, and functional outcomes in autistic children (see Camino-Alarcón et al., 2024 for a review).

These results may also inform augmentative and alternative communication interventions, such as *key-word signing* (KWS), which combines speech with simultaneous manual signs to emphasize key elements of the discourse. KWS has been shown to improve both language comprehension and production in autistic individuals (Tan et al., 2014). However, as underscored by Tan et al. (2014), KWS relies on sustained visual attention to the interlocutor's signs, and reduced attentional focus may impact its effectiveness. Individuals also show variability in their preferences for the modalities in which information is conveyed, depending on a range of factors such as the communicative situation and partners (Iacono et al., 2013; Wendt, 2009). Therefore, some

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flexibility in the presentation of speech with gestures is required to tailor interventions to each child's needs, thereby improving functional outcomes.

Two limitations pertaining to the representativeness of the sample might hinder the generalizability of the findings: First, our sample constitutes a WEIRD sample (i.e., Western, Educated, Industrialized, Rich, and Democratic; Henrich et al., 2010), with the majority of the participants stemming from higher socioeconomic backgrounds. Second, only participants who completed the whole battery of tests were included in the study, potentially excluding children with greater attentional or behavioural difficulties or with higher severity of autism symptoms, a variable that was not monitored in this study. Still, as previous work has reported a negative correlation between autism severity and gesture production (Mastrogiuseppe et al., 2015), a greater difference in gesture comprehension between our groups could be hypothesized if children with high severity scores were included.

Future work might investigate whether the understanding of co-speech gestures is differently impacted by the linguistic environment of autistic children. Indeed, existing work has shown that multilingual neurotypical children present an *increased sensitivity* to communication situations and can better interpret non-verbal elements such as pointing gestures (Yow & Markman, 2011) in comparison to monolingual peers. In the present work, a post-hoc examination revealed no significant impact of multilingual status (i.e., being monolingual or multilingual) on performance. However, multilingualism is a complex and multifactorial phenomenon which groups comparisons based on arbitrary criteria are unlikely to fully capture (de Bruin, 2019; De Houwer, 2023). Therefore, additional investigations are warranted to examine which aspect of the multilingual experience may impact gesture comprehension. Determining whether the multilingual effects observed in neurotypical children hold in the autistic population would help to inform cognitive and communicative processes and, crucially, help to build evidence-based recommendations that are currently lacking (Beauchamp & MacLeod, 2017).

6. Conclusion

The present study provides novel insights into the comprehension abilities of autistic and neurotypical children, particularly in their capacity to understand communicative gestures embedded in a narrative. Precisely, it revealed subtle group differences favouring neurotypical children in their ability to combine speech and gesture into a unified representation which was necessary for task success. Interestingly, this difference could not be attributable to lower linguistic or WM skills. While statistically significant, the difference between groups was small, and children with ASD displayed overall good performance. This relatively spared performance in gesture comprehension may be attributed to the sequential presentation of speech followed by gestures, which likely alleviated sensory processing demands compared with simultaneous multimodal input. These findings have valuable implications for therapeutic and intervention programmes, highlighting the potential of structured, sequential presentation of multimodal cues to enhance comprehension and reduce sensory challenges in autistic children, thereby supporting effective communication strategies.

Supplementary material. The supplementary material for this article can be found at http://doi.org/10.1017/S0305000925000157.

Data availability statement. Data, code to reproduce the analyses, and stimuli video examples are available under: https://osf.io/vp764/

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Authors contribution. PW: conceptualization, methodology, formal analysis, investigation, resources, data curation, supervision, visualization, and writing of the original draft. FB: methodology, investigation, resources, supervision, writing, review, and editing. DC: supervision, writing, review, and editing. ND: conceptualization, writing, review, and editing. ES: formal analysis, writing, review, and editing. SD: conceptualization, methodology, resources, supervision, writing, review, editing, project administration, and funding acquisition. All authors reviewed and approved the manuscript for publication.

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Appendix

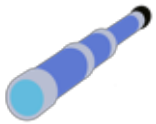
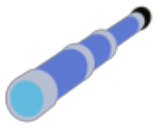
Appendix 1. Groups matching procedure

Propensity score matching (PSM) was used to create comparable groups of autistic (*N* = 73) and neurotypical children. From an initial pool of *N* = 145 neurotypical children, we matched *N* = 73 individuals to our autistic participants based on relevant covariates, namely biological age, non-verbal IQ (i.e., measured with the Raven's-2) and receptive morphosyntax (i.e., assessed with the TROG). This method allows for more robust comparisons by reducing potential confounding factors and selection bias.

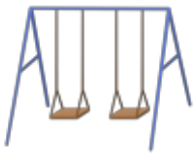
Matching was conducted automatically in R using R Studio (Version 2023.12.0 + 369) with the *MatchIt* package (Ho et al., 2011) using a one-to-one *nearest neighbor* method, in which for each participant of the ASD group, the algorithm searches for the participant with the most similar propensity score. The quality of the matching procedure was assessed using standardized mean differences (SMD) and statistical tests comparing group means. Good balance was achieved between autistic and neurotypical children in non-verbal IQ (SMD < .1, t (143.88) = - 0.58, p = .56), receptive morphosyntax (SMD <.15, W = 2539.5, p > 0.5) and age (SMD < .05, W = 2712.5, p > .05). We failed to match groups on their socioeconomic status in addition to age, non-verbal IQ and receptive morphosyntax (SMD = 0.42, W = 2179.5, p <.05). Therefore, socioeconomic status was added in the statistical model as a covariate.

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Appendix 2. List of items in all languages, with response options. Video examples for an iconic, deictic and conventional gesture in all languages are available following: https://osf.io/vp764/

	Sentence	Gesture	Correct response	Gestural/ Visual distractor	Semantic distractor	Oddball
Intro	C'est l'histoire de Louis. This is the story of Lewis. Das ist die Geschichte von Luis. Questa è la storia di Luigi.					
Practice 1	Louis sort de sa maison, et va donner à manger aux… Lewis likes to be outside and to watch animals with… Luis ist gerne draußen und beobachtet gerne die Tiere mit… Luigi ama stare fuori e guardare gli animali con…	*CHICKEN*				
Practice 1B	Regarde, ce sont des poules ! Look, these are chickens! Schau mal, das sind Hühner! Guarda, queste sono delle galline!	*CHICKEN*				
Practice 2	Louis aime être dehors et regarder les animaux avec… Lewis likes to be outside and to watch animals with… Luis ist gerne draußen und beobachtet gerne die Tiere mit… Luigi ama stare fuori e guardare gli animali con…	*BINOCULARS*				
Practice 2B	Regarde, ce sont des jumelles ! Look, they are binoculars! Guck, das ist ein Fernglas! Guarda, sono dei binocoli!	*BINOCULARS*				

DG 1	Louis va dans la forêt pour ramasser … [7words] Lewis goes into the forest to collect ... [7words] Luis geht in den Wald und sammelt ... [6 words] Luigi va nella foresta a raccogliere... [6 words]	*POINTING flowers*				
IG 1	Dans un arbre, il y a un animal. C'est un… [10words] In a tree, there is an animal. It is a… [10words] In einem Baum sitz ein Tier. Es ist ein ...[9words] In un albero c'è un animale. È un...[8words]	*MONKEY*				
CG 1	Louis s'arrête. Devant lui, il y a deux route[2]. Louis... [10words] Lewis stops. In front of him, there are two roads. Lewis...[11words] Luis hält an. Vor ihm sind zwei Wege. Luis ...[9words] Luigi si ferma. Davanti a lui ci sono due strade. Luigi... [11words]	*DON'T KNOW*				
Filler 1	Alors, il va à droite. Then he goes to the right. Dann geht er nach rechts. Quindi va a destra.					
DG 2	Dans le ciel il y a des…[7words] In the sky, there are...[5words] Im Himmel sind ...[3words] Nel cielo ci sono...[4words]	*POINTING cloud*				

IG 2	Maintenant Louis veut aller à la maison pour jouer… [9words] Now Lewis wants to go home to play...[7words] Jetzt will Luis nach Hause gehen und … spielen. [8words] Ora Luigi vuole andare a casa a sonare...[8words]	*GUITARE*			 *In the Italian version:* 	
CG 2	Mais sur le chemin, Louis voit sa copine Lisa. Il…[10words] But on the way, Lewis sees his friend Lea. He...[10words] Aber auf dem Weg sieht Luis seine Freundin Lea. Er …[10words] Ma sulla strada, Luigi vede la sua amica Lisa. Lui...[10words]	*HELLO*				
DG 3	Il y a un terrain de jeux. Louis et Lisa jouent sur… [12words] There is a playground. Lewis and Lea play on the... [10words] Es gibt einen Spielplatz. Luis und Lea spielen auf ...[9words] C'è un parco giochi. Luigi e Lisa stanno giocando su…[10words]	*POINTING* *seesaw*				
Filler 2	C’est chouette ! Ils s’amusent beaucoup. It's great! They have a lot of fun. Es ist toll! Sie haben viel Spaß. È fantastico! Si stanno divertendo molto.					

IG 3	Lisa s'assoit. Elle prend[1] sa bouteille et elle…[8words] Lea sits down. She takes her bottle and she...[9words] Lisa setzt sich hin. Sie nimmt ihre Flasche und sie ...[10words] Lisa si siede. Prende la sua bottiglia e...[8words]	*DRINKING*				
CG 3	Il fait bientôt nuit. Louis… [5words] It is almost dark. Lewis... [5words] Es wird bald dunkel. Luis ...[5words] È quasi buio. Luigi... [4words]	*COLD*				
DG 4	Il veut vite aller… [4words] He wants to go quickly...[5words] Er will schnell …. gehen.[4words] Vuole andarsene in fretta...[4words]	*POINTING home*				
IG 4	Alors Louis se dépêche, il....[5words] So Lewis hurries, he...[4words] Luis beeilt sich und…[4words] Così Luigi si sbriga, lui... [5words]	*RUN*				
CG 4	Louis retrouve sa maman et il dit tout ce qu'il a fait aujourd'hui. La maman de Louis écoute et elle… [7words] Lewis finds his mom and tells her everything he did today. Lewis ' mom listens and she…[6words] Luis sieht seine Mama und erzählt ihr alles, was er heute gemacht hat. Luis' Mutter hört zu und sie… [6words] Luigi ritrova sua madre e le racconta tutto quello che ha fatto oggi. La mamma di Luigi ascolta e... [6words]	*CLAP*				

Appendix 3. Information on the statistical approach: contrast coding, model checks and assessment.

The group variable was recoded using a scaled sum contrast method: a value of -0.5 was assigned to the typically developing (TD) children group, while a value of 0.5 was assigned to the group of children with autism spectrum disorder (ASD). Consequently, a negative coefficient associated with this variable implied lower performance exhibited by the group of children with ASD.

A scaled sum contrast was also implemented to recode the variable "language of administration" reflecting the language in which the participant completed the task. This approach facilitates the comparison of each language group against the mean overall performance in all languages.

A sliding contrast with weighted coefficients enabled to recode the 'gesture types' categorical variable so as to allow the assessment of relative performance differences: this method compared each gesture type directly, with assigned weights (-0.67, 0.33, and 0.67 for deictic, iconic, and conventional types, respectively).

Missing data on the receptive vocabulary measure (PPVT) and working memory span (FMT) were not imputed, given the robustness of generalized mixed-effects models against missing data (Vasishth et al., 2022). All continuous variables were centered around the mean. None of the variables including age, sex assigned at birth, non-verbal IQ, receptive morphosyntactic score, socioeconomic status, language, and gesture comprehension scores had any missing data: we included in this study only the participants who could complete the tasks mentioned.

Prior to model execution, no significant collinearity among variables was detected, as indicated by variance inflation factors below 5.

A first model with the most complex random structure was fitted, including random intercepts and random slopes for gesture type by *participant* and for *group* by item. As the model did not converge, correlations between random effects were not estimated. As it did not converge either, the random slope for group was removed. Eventually, the final model included random intercepts for both participant and items only. Fixed-effects included: group, gesture type and their interaction, group in interaction with age, as well as sex assigned at birth, socioeconomic status, receptive morphosyntactic skills score, non-verbal IQ, receptive vocabulary score, and language of test. The model demonstrated considerable overall explanatory power (conditional R2 = 0.60), with the fixed effects contributing substantially (marginal R2 = 0.42).

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Appendix 4. Fixed and random effects of the final model. *Gtype* holds for Gesture type. *DG*: deictic gesture, *IG*: iconic gesture, *CG*: conventional gesture.

	Performance					
	Odds Ratios	CI	β	Std. Err	Z value	*p*
(Intercept)	87.78	30.12 – 255.81	4.47	0.55	8.20	*< .001***
Group	0.2	0.05 – 0.76	-1.61	0.68	-2.37	***0.02 ****
Gtype_DG-IG	0.58	0.24 – 1.39	-0.54	0.44	-1.22	0.22
Gtype_IG-CG	1.99	0.81 – 4.93	0.69	0.46	1.49	0.43
Age	2.88	1.56 – 5.32	1.06	0.31	3.37	***< .001****
Sex [Reference F]	1.01	0.37 – 2.78	0.01	0.51	0.02	0.98
SES	0.89	0.59 – 1.34	-0.12	0.21	-0.56	0.58
Non-verbal_IQ	0.77	0.47 – 1.25	-0.26	0.25	-1.06	0.29
TROG_score	1.2	0.83 – 1.74	0.19	0.19	0.99	0.32
PPVT_score	1.47	1.07 – 2.01	0.38	0.16	2.39	***0.02 ****
Lang_English	0.37	0.01 – 15.08	-0.98	1.89	-0.52	0.60
Lang_French	1	0.06 – 16.40	0.00	1.43	0.00	0.99
Lang_German	0.95	0.04 – 22.72	-0.05	1.62	-0.03	0.98
WM_span	1.4	0.84 – 2.34	0.34	0.26	1.29	0.20
Group*Gtype_DG-IG	0.98	0.26 – 3.74	-0.02	0.68	-0.03	0.97
Group*Gtype_IG-CG	0.61	0.14 – 2.61	-0.49	0.74	-0.67	0.50
Group*Age	0.95	0.32 – 2.79	-0.05	0.55	-0.09	0.93

Random Effects

σ^2	3.29
$\tau_{00\ participant}$	1.38
$\tau_{00\ item}$	0.15
ICC	0.32
$N_{\ participant}$	119
$N_{\ item}$	12
Observations	1428
Marginal R^2 / Conditional R^2	0.42 / 0.60

Appendix 5. Complementary mediation analyses

We conducted a causal mediation analysis using R *mediation* package (Tingley et al., 2014) to examine the extent to which vocabulary knowledge (as measured with the PPVT) impacted (i.e., mediated) the ASD and TD group difference in performance.
Two models were fitted on a dataset exempt of missing data: (1) a *mediator* model, examining the impact of group on PPVT scores, controlling for sex assigned at birth, socioeconomic status and the language version of the task, and (2) an *outcome* model, corresponding to the model used in this study (see the Results section of the manuscript, and Appendix 3 and 4 for its specification and output).
Different estimations were then computed: (a) the Average Direct Effect (ADE), capturing the direct effect of group on the performance and excluding the mediation effect; (b) the Average Causal Mediation Effect (ACME), which measures the indirect effect of group on the performance through the mediator (i.e., vocabulary knowledge) and (c) the Total Effect, reflecting the overall relationship between group and performance, entailing both the direct effect and the indirect effect mediated through vocabulary knowledge. Finally, a quasi-Bayesian approximation method with 1000 simulations enabled to estimate confidence intervals and p-values for the 3 different effects (i.e., ACME, ADE, Total Effects).

Results (see Table Appendix 5) indicated that there were both significant direct and mediated effects: On the one hand, vocabulary knowledge significantly mediated the relationship between group and performance: the Average Causal Mediation Effect (ACME) was statistically significant for both children with TD (ACME = 0.0334) and ASD (ACME = 0.0142). On the other hand, the Average Direct Effects (ADE) was significant (ADE = 0.1176 for TD children; ADE = 0.0983 for children with ASD). The Total Effect was significant (Estimate = 0.1318), with approximately 25.96% and 10.81% of the effect that could be attributed to the mediation in the groups of TD children and children with ASD, respectively. On average, approximately 18.39% of the total effect was mediated by vocabulary skills (Estimate = 0.1839).

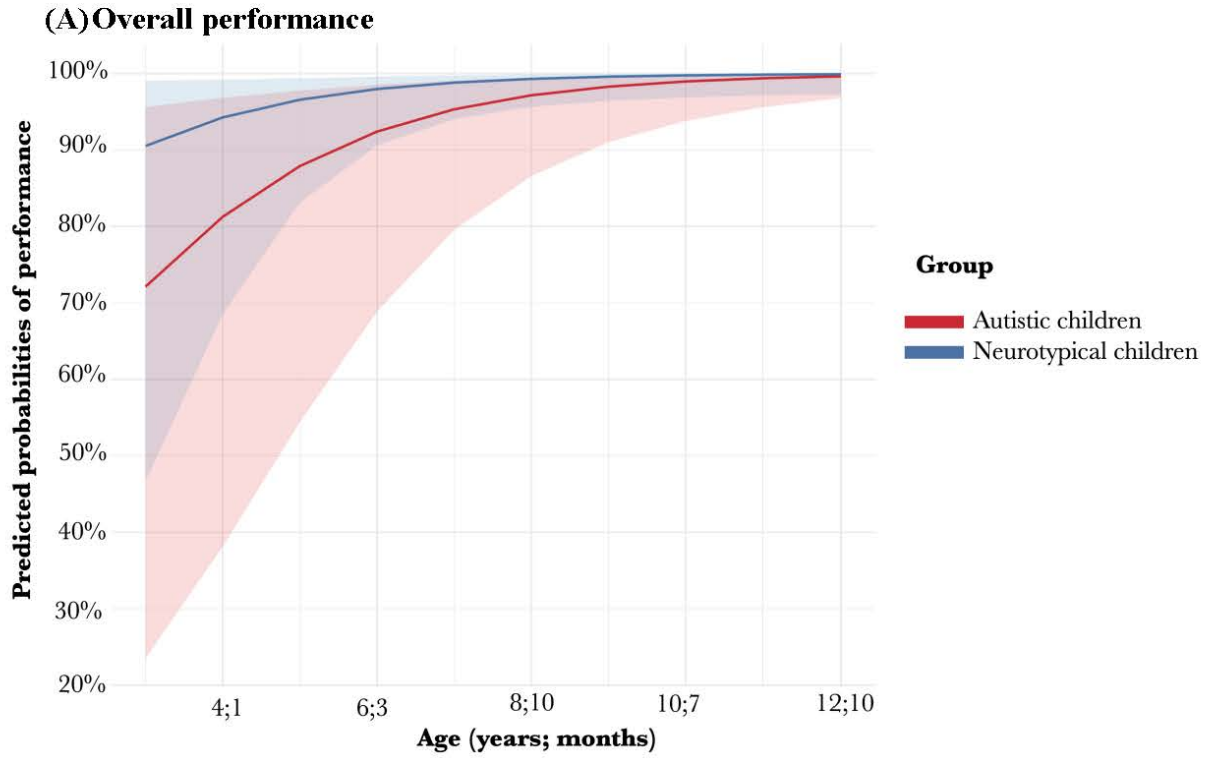
Table Appendix 5. Causal mediation for vocabulary knowledge (PPVT)

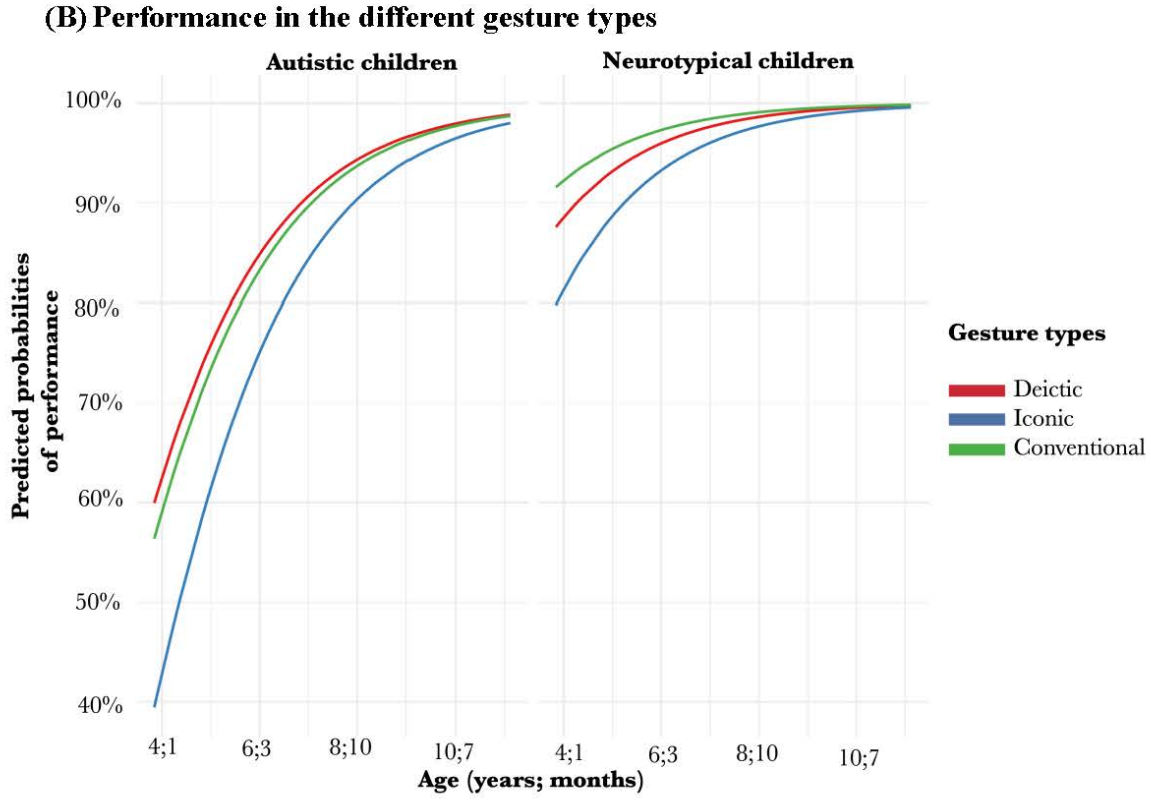
	Group	Estimate	95% CI Lower	95% CI Upper	*p* value
ACME	(TD)	0.0334	0.0162	0.0600	< .001***
ACME	(ASD)	0.0142	0.0068	0.0200	< .001***
ADE	(TD)	0.1176	0.0445	0.2200	< .001***
ADE	(ASD)	0.0983	0.0366	0.1800	< .001***
Total Effect		0.1318	0.0608	0.2300	< .001***
Prop. Mediated	(TD)	0.2596	0.1465	0.4200	< .001***
Prop. Mediated	(ASD)	0.1081	0.0441	0.2800	< .001***
ACME	(average)	0.0238	0.0126	0.0400	< .001***
ADE	(average)	0.1080	0.0412	0.2000	< .001***
Proportion Mediated	(average)	0.1839	0.0973	0.3500	< .001***

Note. ACME : Average Causal Mediation Effect; ADE: Average Direct Effect; TD: typically developping group, ASD: Autism Spectrum Disorder; CI : Confidence Interval.

Tingley, D., Yamamoto, T., Hirose, K., Keele, L., & Imai, K. (2014). Mediation: R package for causal mediation analysis. *Journal of Statistical Software*, *59*(5). https://doi.org/10.18637/jss.v059.i05

Appendix 6. Visualization of the predicted probabilities of performance as a function of age. These visualizations are only indicative and should be observed with caution, as age effects should be investigated more closely with appropriate tools to draw robust conclusions (e.g., with Generalized Additive Models; GAMs).





Appendix 7. Exploration of the impact of the multilingual status on performance: GLMM outputs

- Model A (multilingual status as a fixed effect)

Formula: performance ~ 1 + group * gesture type + group * age + Multilingual status + sex + SES + non-verbal IQ + TROG + PPVT + testing language + Working Memory + (1 | participant) + (1 | item)

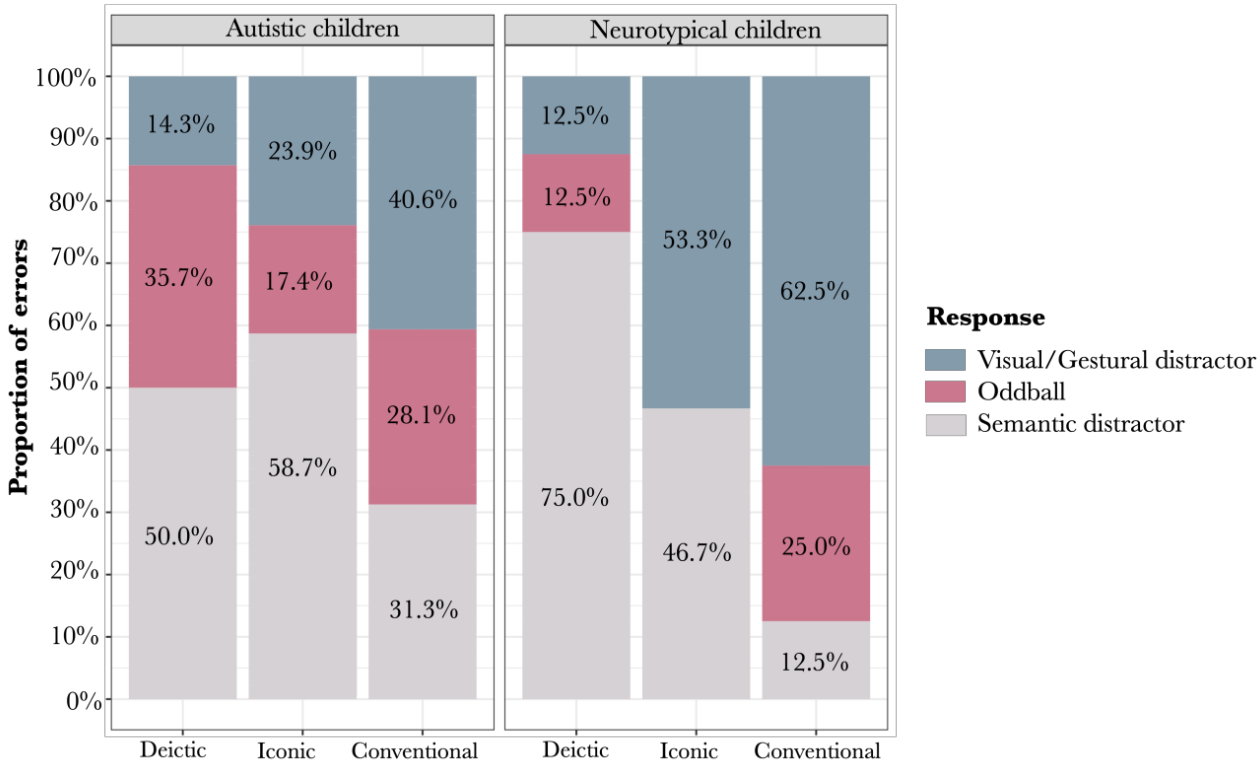
	β	Std. Err	Z value	*p value*
(Intercept)	4.49	0.55	8.19	*< .001****
Group	-1.60	0.68	-2.36	0.02*
Gtype_DG-IG	-0.54	0.44	-1.22	0.22
Gtype_IG-CG	0.69	0.46	1.49	0.14
Age	1.05	0.31	3.36	*< .001****
Multilingual_status	-0.10	0.45	-0.21	0.83
Sex [Reference F]	-0.01	0.52	-0.02	0.99
SES	-0.12	0.21	-0.59	0.56
Non-verbal_IQ	-0.26	0.25	-1.06	0.29
TROG_score	0.18	0.19	0.95	0.34
PPVT_score	0.39	0.16	2.40	0.02*
Lang_English	-1.00	1.88	-0.53	0.60
Lang_French	-0.02	1.43	-0.01	0.99
Lang_German	-0.12	1.65	-0.07	0.94
Working_memory	0.34	0.26	1.30	0.19
Group: Gtype_DG-IG	-0.02	0.68	-0.04	0.97
Group : Gtype_IG-CG	-0.49	0.74	-0.67	0.51
Group : Age	-0.07	0.55	-0.12	0.90

- Model B (multilingual status in interaction with *group*)

Formula: performance ~ 1 + *group* * gesture type + group * age + multilingual status * group + sex + SES + non-verbal IQ + TROG + PPVT + testing language + Working Memory + (1 | participant) + (1 | item)

	β	Std. Err	Z value	*p value*
(Intercept)	4.40	0.54	8.19	*< .001****
Group	-1.69	0.70	-2.43	0.02*
Gtype_DG-IG	-0.54	0.44	-1.22	0.22
Gtype_IG-CG	0.69	0.46	1.50	0.13
Age	1.03	0.31	3.31	*< .001****
Multilingual_status	0.11	0.49	0.23	0.82
Sex [Reference F]	-0.03	0.51	-0.05	0.96
SES	-0.11	0.21	-0.53	0.60
Non-verbal_IQ	-0.20	0.25	-0.79	0.43
TROG_score	0.12	0.19	0.60	0.55
PPVT_score	0.39	0.16	2.45	*0.01***
Lang_English	-0.87	1.86	-0.47	0.64
Lang_French	0.22	1.43	0.15	0.88
Lang_German	0.27	1.68	0.16	0.87
Working_memory	0.30	0.26	1.15	0.25
Group: Gtype_DG-IG	-0.02	0.69	-0.03	0.98
Group: Gtype_IG-CG	-0.50	0.74	-0.68	0.50
Group : Age	-0.14	0.55	-0.26	0.79
Group : Multilingual_status	-1.17	0.99	-1.19	0.24

Appendix 8. Visualisation of the proportions of errors produced by the two groups.
The group of neurotypical children produced a total of 31 errors, while the group of autistic children a total of 106 errors.



4.2 BILINGUALISM EFFECTS ON GESTURE COMPREHENSION IN NEUROTYPICAL CHILDREN

In the previous study, we found that children with ASD understood significantly fewer gestures than their neurotypical peers. Both groups were matched on key variables: age, non-verbal IQ and receptive morphosyntactic skills, to ensure that the difference observed was not driven by one of these factors. Noticeably, the difference between groups was small, and autistic children demonstrated fairly good performance. This preserved performance may stem from the sequential presentation of speech followed by gestures, which could have alleviated the difficulties associated with processing speech and gesture simultaneously.

Our sample included participants with diverse linguistic backgrounds: Some were exposed to only one language and could be classified as 'monolinguals', while others had varying degrees of exposure to additional languages. Post-hoc analyses suggested that monolingual/bilingual status did not play a significant role in gesture comprehension. However, the participants' *bilingual status* was defined by an arbitrary criterion (i.e., relative exposure to two languages more than 20% of the lifetime), a grouping variable potentially masking inter-individual variability.

Nevertheless, bilingualism - typically defined using an arbitrary criterion - has been shown to influence both gesture production (Gullberg, 2012; Nicoladis, 2007) and gesture comprehension (Yow & Markman, 2011) – although research on comprehension is still limited to date. Research suggests that neurotypical bilingual children are better than their monolingual peers at interpreting pointing gestures (Yow & Markman, 2011). One possible explanation is that exposure to multiple languages enhances children's sensitivity to social and communicative contexts, improving their perception and use of socio-pragmatic cues available in interactions. If this advantage extends beyond deictic gestures to include iconic and conventional gestures, bilingual exposure could play a facilitative role in gesture comprehension for both neurotypical and, importantly, autistic children, potentially enhancing their communicative skills.

Before investigating whether this effect is present in autistic children (**Section 4.3**), the following study, accepted for publication in *Applied Psycholinguistics*, first examines whether bilingual exposure influences the comprehension of deictic, iconic, and conventional gestures in school-aged neurotypical children.

The impact of balance of multilingual exposure on gesture comprehension in children above preschool age

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Conflict of interest. The authors declare that they have no conflict of interest or relevant financial or non-financial interests to disclose.

Compliance with Ethical Standards and informed consent. This study was approved by the Swiss Association of Research Ethics Committees *Swissethics* (Project ID-2022-00878), the Institutional Review Board of the University of Connecticut (US), the Research Ethics Board Office at McGill University in Montreal (Canada), the Psychology Research Ethics Committee of the University of Edinburgh (UK), and the Institutional Review Board of Emerson College Boston (US). All parents provided informed written consent for their child's participation prior to their inclusion in the study. All work has been carried out in accordance with The World Medical Association's Declaration of Helsinki for experiments involving humans.

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Data and code availability. Data and code are available at the following URL: https://osf.io/cusfk/. The analyses presented were not preregistered.

Abstract

Previous work had shown that multilingual preschool children are better at interpreting deictic gestures than their monolingual peers. The present study examines whether this multilingual effect persists beyond preschool age and whether it extends to iconic (i.e., representing the referent) and conventional (i.e., holding an arbitrary meaning) gestures. A total of N = 105 children (aged 3 to 8), varying in their balance of exposure to more than one language since birth, completed a gamified gesture comprehension task. The three gesture types were presented in four communicative conditions, namely (1) alone, with (2) reinforcing or (3) supplementing speech, compared to (4) speech produced alone. Analyses revealed that children with greater balance in their multilingual exposure understood significantly more speechless iconic gestures than children with less balanced multilingual exposure. Findings align with previous work and theoretical frameworks indicating that multilingual exposure enhances children's sensitivity to non-verbal communicative cues.

Keywords: bilingualism, gesture comprehension, multimodal integration, non-verbal communication

Multilingualism and communicative advantage

Multilingual children, defined as individuals exposed to two or more languages (Grosjean, 1982), have been reported to present "communicative advantages" compared to their monolingual peers (Wermelinger et al., 2017, p. 2). Indeed, it has been hypothesized that, due to their exposure to more diverse and complex linguistic and communicative environments, multilinguals display a *heightened sensitivity* towards the interactional situation and their interlocutors (e.g., Ben-Zeev, 1977; Fan et al., 2015). Such sensitivity would notably enable multilinguals to interpret the speaker's intent better (Yow & Markman, 2015), to repair misunderstandings more often (Wermelinger et al., 2017), and to more efficiently manage communicative breakdowns (Genesee et al., 1996).

Researchers have primarily highlighted the role of exposure to multilingual environments on communication effectiveness (Fan et al., 2015; Yow & Markman, 2015, 2016). In their view, the socio-linguistic and socio-pragmatic experience of growing up multilingual, with exposure to more diverse communicative environments and partners, improves the enhanced communicative competence of multilinguals. The more frequent and greater needs to monitor the interactional context (e.g. monitor the speaker's language to respond adequately and repair communicative failure more) would also train multilingual individuals to a larger extent, thus resulting in an increased *sensitivity* to the communicative environment (van Wonderen et al., 2023; Wermelinger et al., 2024).

The COMmunicative-Experience perspective (COME perspective; Wermelinger et al., 2024) provides a theoretical framework to shed light on why multilingual children may benefit in terms of their communicative development. Multilingual children may face more challenging communicative situations (e.g., limited vocabulary, language choice) and consequently develop a broader repertoire of communicative strategies, which they use with greater flexibility than their monolingual peers (Wermelinger et al., 2024).

Communicative gestures and their development

One important aspect of communication that may be affected in a multilingual environment is the use and understanding of non-verbal linguistic cues, such as gestures. Gestures (i.e., also called "co-speech gestures"), are hand movements accompanying, emphasizing or replacing speech (McNeill, 1992). These gestures provide communicative and cognitive benefits for both the speaker and the listener (see Clough & Duff, 2020 for a review). Because gestures often provide additional information and clarification that complements the spoken discourse, they appear crucial in multilingual settings, where linguistic expressions can be ambiguous or unfamiliar. They may help disambiguate intent, put emphasis, clarify speech, and are therefore important to be monitored efficiently.

Different types of gestures can be described based on their semantic function. Deictic gestures serve to locate, indicate, or refer to an entity in the physical or discourse space (Kita, 2003).

The most common form of gesture is pointing, typically produced with the index finger, which may refer to a concrete object of location (e.g., pointing to a cup), or to an abstract element in the discourse (e.g., pointing to an absent person or prior topic). Other forms, such as hand waves, may also serve a deictic function (Arikan et al., 2025; Moreno-Núñez et al., 2020). Iconic gestures represent aspects of objects or actions through a visual resemblance in form or movement (e.g., miming drinking, or shaping the hands to outline a ball). In contrast to pantomimes, which typically involve enacting a complete action sequence as if manipulating an object, iconic gestures usually provide a schematic, conventionalized depiction of key features of the referent (Behne et al., 2014; Kita et al., 2017; Ortega & Özyürek, 2020). Conventional gestures convey an arbitrary, culturally specific meaning within a given community (e.g., waving the hand to signify GOODBYE; McNeill, 1992). It is important to note that these gesture types lie on a continuum rather than forming strictly discrete categories, as they may share features and are not mutually exclusive (Kendon, 2004; McNeill, 1992).

Gesture production and comprehension are both dynamic and interrelated, following a similar developmental trajectory (Dimitrova & Özçalışkan, 2022). In particular, children start to produce and understand deictic gestures towards the end of the first year of life (Behne et al., 2012). Then, iconic gesture production and comprehension emerge around the age of 2 to 3 (Namy, 2008), followed by the development of conventional, arbitrary gesture slightly after (Namy et al., 2004).

Other studies, however, have observed that conventional gesture production, often occurring as a standalone gesture without language, sometimes emerges before the age of two (E. Bates et al., 1989; Nicoladis, 2002). Besides, conventional gestures are deemed more difficult to understand because of their arbitrary meaning, and lower transparency between the sign and the referent (Hodges et al., 2018).

Multilingualism and gesture comprehension

Gesture production, in particular, has received increased attention in multilingual research over the past decades, notably for its potential to inform language processing and development (e.g, Gullberg, 2012). While bilingual children gesture more than monolinguals in narrative tasks (Nicoladis et al., 2009; Zvaigzne et al., 2019), their gesture comprehension remains largely unexplored.

In a pioneering series of studies, Yow and Markman (2011) showed that 2-, 3-, and 4-year-old bilinguals (i.e., in this case, children exposed to an additional language more than 30% of the week) better interpreted pointing gestures enabling them the discovery of a hidden toy, in comparison to monolinguals peers.

This finding, however, has not been shown for iconic gestures. Indeed, in a study investigating iconic gesture comprehension in a narrative, no group difference was found between 3.5-year-old monolinguals and bilinguals in their gesture recognition accuracy (Wermelinger et al., 2020). In this study, bilinguals were defined as children exposed to two languages since birth, with a 20% minimum

of input of both languages. The authors presumed that the task was not challenging enough for multilinguals, who have been reported to show an advantage in more demanding communicative environments, such as situations with conflicting information (Bialystok & Martin, 2004; Yow & Markman, 2011) or where the integration of multiple cues is required.

In line with this perspective, Yow and Markman (2015) showed that 3-year-old multilinguals could better integrate verbal, non-verbal, and pragmatic cues than monolinguals when interpreting a speaker's intent. To date, no study has investigated multilingualism effects on the *comprehension* of conventional gestures.

Multilingualism as a continuum

Given these findings, one could expect a difference between children of various levels of exposure to multiple languages to emerge: (1) in a task requiring the integration of both verbal and non-verbal cues (i.e., multimodal integration), and (2) in participants benefiting from varied communicative environments, such as children attending primary school, which offers more diverse and complex communicative contexts compared to the home environment (e.g., diversity of interlocutors, additional socio-pragmatic parameters required for successful communication, such as social convention, speech registers, etc.).

However, work to date has not investigated these predictions. Indeed, the inconsistent findings of the few studies investigating multilingual effects on co-speech gesture comprehension (Wermelinger et al., 2020; Yow & Markman, 2011), do not allow us to draw firm conclusions as to whether multilingual children across childhood might better understand gestures than their monolingual peers. The findings are moreover restricted to preschoolers and the assessment of only one gesture type at a time.

Furthermore, it has been suggested that the very design of studies comparing monolinguals and multilinguals based on a single criterion of multilingualism needs to be reconsidered because it does not fully capture the multidimensional nature of multilingualism or the diversity of individuals' linguistic profiles (e.g., de Bruin, 2019; Luk & Bialystok, 2013).

While it is challenging to operationalize a score comprehensively reflecting the full richness of every multilingual experience such as a "bilingualism quotient" would (Marian & Hayakawa, 2021), we propose here to place all individuals on the same scale, based on an (1) explicit and (2) hypothesis-driven criterion (as recommended by e.g., de Bruin, 2019; Surrain & Luk, 2019). This allows to capture the variability between participants that a binary comparison inevitably masks (De Houwer, 2023; Marian & Hayakawa, 2021).

The present study

Building on previous findings showing that children with more exposure to a second language develop enhanced abilities in interpreting non-verbal communicative cues such as pointing gestures (Fan et al., 2015; Yow & Markman, 2015, 2016), the present study examined whether this effect extends to different types of co-speech gestures beyond the early (preschool) ages. While some studies suggest bilingualism may enhance gesture comprehension, findings remain mixed, and existing work has focused primarily on preschoolers using limited gesture types and categorical operationalization of multilingualism. To address these gaps, this study included children beyond preschool age and used a continuous measure of multilingual exposure: the ***balance of multilingual exposure (BME)*** *score*, estimating how evenly participants were exposed to the testing language and another language since birth (the more balanced a child's exposure to multiple languages since birth, the higher the BME *score*; see Methods and Appendix 4 for details). Children with more balanced exposure to multiple languages may encounter a wider range of communicative situations and partners, requiring them to monitor the paralinguistic context, and non-verbal cues more accurately than children with lower *balance of multilingual exposure*, including monolinguals (van Wonderen et al., 2023; Wermelinger et al., 2024).

This study investigated whether *balance of multilingual exposure* impacted the understanding of three different types of gestures in children above 3 years: deictic (i.e., POINTING to a cat to indicate "cat"), iconic (e.g., gesturing DRIVE, by miming holding and turning a steering wheel), and conventional gestures (e.g., gesturing LISTEN, by cupping a hand behind the ear). While gestures emerge early in development, the mastery of their comprehension is a long-term process that lasts beyond pre-school age, as demonstrated by the pivotal effect of age on gesture comprehension (Perrault et al., 2019) and the absence of a ceiling effect in previous studies with children both below 4 years (Dimitrova et al., 2017; Wermelinger et al., 2017) and, crucially, above (Perrault et al., 2019).

Different communicative conditions were tested: gestures were presented (1) alone (e.g., gesturing SLEEP by placing hands together and tilting them under the cheek), (2) with a label that reinforced the gestures (e.g., gesturing SLEEP and saying "sleeping"), and (3) with speech transmitting additional semantic information not conveyed by the gesture (i.e., gesturing SLEEP and saying "baby"). Children naturally develop and produce these three conditions gradually in their development, and the two latter conditions have been shown to significantly predict children's lexical and morphosyntactic development, respectively (see Capone & McGregor, 2004 for a review). Finally, a fourth condition corresponded to (4) speech produced alone, as a baseline.

This approach offers a more nuanced understanding of gesture comprehension in children and reflects different conditions in which these cues occur in real-life narrative and conversational

situations. Furthermore, it allowed us to test whether a multilingual exposure difference would be visible in a more challenging task with a condition requiring multimodal integration, as previously hypothesized (Wermelinger et al., 2020; Yow & Markman, 2015).

Research question and hypotheses

The current study asked: *"Does balance of multilingual exposure impact the comprehension of deictic, iconic and conventional gestures, presented alone, with reinforcing or supplementing speech in children above preschool age?"*

We predicted that children with greater balance in multilingual exposure would perform better in gesture comprehension than children with less balanced multilingual exposure. Within an exploratory approach, different predictions about performance in the different gesture types could be made: First, this effect could extend more strongly to conventional gestures, which hold an arbitrary and cultural component. Understanding which gesture is most appropriately used in a given community (e.g., to greet someone adequately) is just as important as using the adequate language or speech register. Arbitrary and cultural components are crucial socio-pragmatic parameters to consider and monitor for effective communication. Conventional gestures require understanding social norms for their interpretation, because they are embedded within specific cultural contexts. Children with more balanced multilingual exposure often navigate multiple cultural frameworks, and through this experience, they may become more adept at monitoring, recognizing and adapting to these socio-pragmatic nuances. In doing so, they would hone their ability to decode culturally specific gestures effectively.

Alternately, the heightened sensitivity to the communicative context shown in bilinguals could translate in a better comprehension of iconic gestures, because they directly represent the action they refer to, requiring close attention to the interactional situation. According to previous research and current theoretical considerations (Wermelinger et al., 2024; Yow & Markman, 2016), this skill has been more extensively trained in children with more balanced multilingual exposure than children with lower balance in multilingual exposure, due to their greater experience with diverse communicative contexts.

With respect to the communicative conditions, previous work in preschoolers has shown that bilingual participants better integrate multiple verbal and contextual cues to infer a speaker's intent (Yow & Markman, 2015). Based on this finding, we predicted the difference in gesture comprehension performance between children with greater balance of multilingual exposure, as compared to children with lower balance of multilingual exposure, to be particularly noticeable in the condition requiring multimodal integration (i.e., *supplementary speech-gesture combination*, see Methods section). This condition has indeed been shown to be the most difficult in previous work in

preschoolers (Dimitrova et al., 2017) as it requires to combine and integrate both verbal and gestural streams of information.

Methods

Participants

A total of *N* = 200 children aged 2;10 to 11;10 years with no reported or suspected cognitive, linguistic, neurological impairment or neurodevelopmental condition participated in this study. Participants were recruited via flyers, newsletters, and the project's website on the different sites in which this international project took place in (Switzerland: 36.0 %, Germany: 30.0%, France: 14.0%, UK: 11.5%, Canada: 2.0%, USA: 6.5%). The sample constitutes a WEIRD sample (Western, Educated, Industrialized, Rich and Democratic; Henrich et al., 2010) with predominantly White children.

Because this study aimed to inform about multilingual effects beyond early childhood, the initial sample comprised participants spanning a wide age range, from preschool to the end of primary school (i.e., *N* = 200 children between 3 and 11 years). However, data inspection showed that performance in older participants (96 months and above) started plateauing at high accuracy, suggesting that participants tended to perform at ceiling and that the task showed little sensitivity above this age (see Appendix 1). Therefore, subsequent analyses were only conducted on the younger participants (i.e., *N* = 105 children aged below 96 months), and data for the older participants (*N* = 95) were not further examined.

Before assessment, caregivers filled in the "Quantifying the Bilingual Experience" questionnaire (Q-BEx; De Cat et al., 2022), an extensive parental questionnaire precisely capturing key variables of the linguistic environment of the child since birth in the different language(s), such as their current and cumulative exposure and use of the language(s), the richness of their experience and estimated proficiency, among others (see Appendix 2 for the description of the participants' linguistic background and Appendix 3 for the visualization of the languages they were exposed to, in addition to the testing language). Participants were tested in their most proficient language, as estimated by their caregivers, when this language corresponded to a language of the task, namely English, French, German, or Italian (*N* = 92). When a task version was not available in the child's most proficient language, they were tested in the societal language of the country or region where testing occurred (*N* = 13).

Consistent with the hypothesis that children with more exposure to multilingual environments develop increased sensitivity to the communicative context and better interpret gestures, a *balance of multilingual exposure score (BME)* was operationalized as follows: The absolute difference between the percentage of cumulative exposure to the language of testing and the second language was calculated, then subtracted from 100 *(Formula: 100 - | Exposure to L1 - Exposure to L2|)*. This yielded a score between 0 and 100 translating the participants' balance in their multilingual

exposure (with a higher score reflecting a greater balance of exposure to multiple languages since birth). Specifically, a score of 100 reflected a balanced exposure between two languages, in the sense that participants had been equally exposed in average to two languages since birth (e.g., lifetime exposure to the testing language 50% of the time, 50% to an additional language, *score = 100 - (50 - 50) = 100*). In contrast, a participant who had been mainly exposed to a single language would present a low *BME score* with a score approaching 0 (e.g., a strict monolingual with exposure to a language at 100% and 0% to an additional language would have a BME *score = 100 - (100 - 0) = 0*). In the case of participants being exposed to three languages, the maximum rate of exposure between the second and the third language was selected. For instance, a participant with an exposure of 50% to the L1, 30% to the L2 and 20% to the L3 would obtain a *BME score = 100 - (|50 – 30|) = 80* (see Appendix 4 for additional examples).

To index the participant's socioeconomic status, the highest value of the caregivers' educational levels was used (i.e., 5-point Likert scale from (1) "elementary school" to (5) "university degree"), since this factor is strongly linked to children's academic achievement (Sirin, 2005) and cognitive development (Rindermann & Ceci, 2018).

Table 1. *Descriptive statistics of participant characteristics, including verbal and non-verbal measures. Analyses were conducted on the group of younger participants.*

	Participants (N=105)
Age (months)	
Mean (SD)	70.4 (15.8)
[Min, Max]	[34, 95]
Sex assigned at birth	
F	55 (51.4%)
M	50 (47.6%)
Parental Educational Level (min 1 – max 5) [a]	
Mean (SD)	4.72 (0.62)
Median [Min, Max]	[2, 5]
Receptive vocabulary (PPVT, z-score) [b]	
Mean (SD)	0.27 (1.10)
Median [Min, Max]	[-2.87, 2.30]
Non-verbal IQ (Ravens-2) [c]	
Mean (SD)	99 (12.8)
Median [Min, Max]	[70, 126]
Testing Language	
ENGLISH	21 (20.0%)
FRENCH	27 (25.7%)
GERMAN	36 (34.3%)
ITALIAN	21 (10.0%)
Balance of Multilingual Exposure (BME)	
Mean (SD)	34.8 (37.4)
[Min, Max]	20.0 [0, 100]

Note. PPVT = Peabody Picture Vocabulary Test.

[a]Parental educational level was measured on a scale from 1 to 5. The highest value of the two caregivers was selected. [b]Data were missing for 14 participants (14.7%). [c]Data were missing for 12 participants (12.4%).

Measures

Participants were tested individually by a trained experimenter in a quiet room. Measures included the gesture comprehension task, the *Raven's Progressive Matrices* (Raven's 2, Raven et al., 2018) and the *Peabody Picture Vocabulary Test* (PPVT-4, Dunn & Dunn, 2007).

Gesture Comprehension Task

This task was inspired by Dimitrova and colleagues (2017) and was embedded in a so-called *serious game* (i.e., a game-like activity) on a tablet (iPad), explicitly developed for the purpose of the study. The task was introduced and entirely explained by a 3D human-like character, Gabi, with a natural voice, who was watching TV and asking for help to understand the videos better. All pre-recorded instructions and stimuli were translated, adapted and recorded by native speakers in four languages (i.e., English, German, French, Italian), ensuring consistent quantity and quality of instructions between participants and across language versions.

NATURE OF THE STIMULI. The task consisted of 48 pre-recorded short video sequences of a gesture preceded by two warm-up trials (i.e., 4 items*3 gesture types*4 communicative conditions, resulting in 48 stimuli). Participants watched one gesture at a time and were asked to select, out of three options, the picture corresponding to the gesture displayed. Gestures could be of three types: 1/3 of the stimuli were deictic, 1/3 iconic and 1/3 conventional. Each gesture item appeared in four different communicative conditions: (1) *gesture-only* condition (GO), where a speechless actor performed the target gesture; (2) *reinforcing speech-gesture combination* (REINF), where the actor performed the target gesture accompanied by naming the corresponding label; (3) *supplementary speech-gesture combination* (SUPP), where the actor performed the target gesture and enunciated supplemental verbal information necessary to select the correct picture; and (4) *speech-only* condition (SO) as a control, where the actor named the label of the gesture without gesturing.

As in the original task (Dimitrova et al., 2017), stimuli were pseudo-randomized: for each item, the *gesture-only* and *supplementary speech-gesture combination* conditions always appeared before the *speech-only* and *reinforcing speech-gesture combination* conditions for this item, to avoid directly providing the participant with the label.

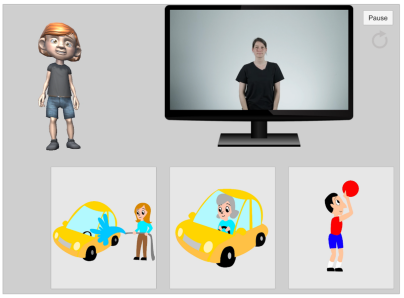
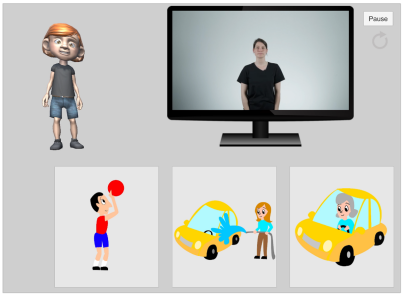
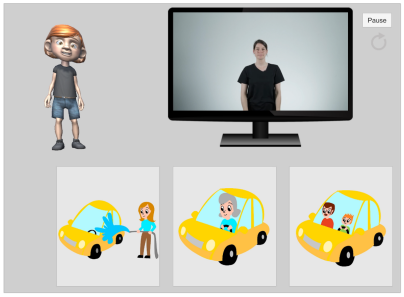
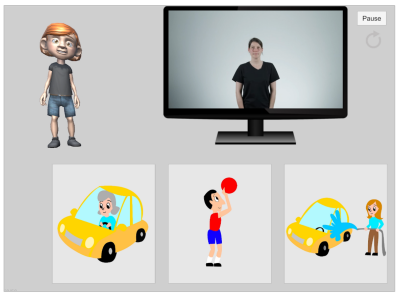
All labels were selected from the Mac-Arthur Bates Communicative Development Inventory of the respective languages (i.e., English: Fenson et al., 2006; French: Kern et al., 2010; German: Szagun et al., 2009; Italian: Rinaldi et al., 2019), ensuring limited lexical complexity as these words

are considered acquired at 36 months. The conventional gestures were selected for their universality and minimal variations across the four testing languages and Western countries where testing took place. The nature of the congruent speech proposed with the gesture (i.e., in the reinforcing speech and gesture condition) was chosen to reflect how they are most naturally encountered (McNeill, 1992): Because deictic gestures rarely represent verbs, and conventional gestures rarely nouns, a noun accompanied deictic gestures in the *reinforcing speech and gesture condition* (e.g., POINTING + "hat"), and a verb accompanied conventional ones (e.g., LISTEN + "listening"). For iconic gestures, verbs were selected, but iconic gestures representing nouns are also common (see the Limitation section for a discussion of this choice). The stroke (i.e., most expressive and meaningful phase of a gesture (McNeill, 1992), like the thumb and index pinching the nose to convey DISGUSTING) was not depicted in the picture options for conventional gestures, in order to have the participant access the meaning of the gesture, rather than operating a mere gesture-to-picture matching. Figure 1 describes a stimulus for an item of the iconic type and video examples are accessible in Appendix 5. The complete item list is available in Appendix 6.

NATURE OF THE RESPONSE CHOICES. For each stimulus, three pictures were proposed in random order: (1) the correct response, (2) a visual distractor (i.e., for deictic gesture: a picture close to the target; for the other gesture types: a picture corresponding to another gesture made in the same area), (3) a third response choice corresponding to both an oddball in the *gesture-only, speech-only* and *reinforcing speech and gesture* conditions, and to a verbal distractor in the case of the *supplementary speech and gesture* condition, as it matched the stimulus' verbal part. Thus, responding accurately to the *supplementary speech-gesture combination* required processing both the verbal and the gestural part of the item. The task was designed such that the correct picture of one item was an incorrect response for another item to avoid repeating the same picture as the correct option across trials (see 5 for further details on response options).

SCORING. Each correct picture selection was awarded 1 point, while each incorrect response received 0 points, yielding a maximum score of 48.

Figure 1. ***Example for the item DRIVE in the four conditions.*** *The "stimulus" column depicts the video presented to the participant, that was followed by the screen displaying the 3 response options (right column). Numbers refer to pictures from left to right.*

Condition	Stimulus	Response choices
Gesture only ***(GO)***	 Gesturing DRIVE (no label)	 (1) Oddball (2) Correct response (3) Visual distractor
Reinforcing speech + gesture combination ***(REINF)***	 Gesturing DRIVE + saying "driving"	 (1) Visual distractor (2) Oddball (3) Correct response
Suplementary speech + gesture combination ***(SUPP)***	 Gesturing DRIVE + saying "lady"	 (1) Verbal distractor (2) Correct response (3) Visual distractor
Speech only ***(GO)***	 Saying "driving" (no gesture)	 (1) Correct response (2) Visual distractor (3) Oddball

Raven's Progressive Matrices 2nd Edition (Raven's-2)

The short version of the digitalized Raven's-2 (Raven et al., 2018) was proposed to estimate of non-verbal reasoning abilities. Among five choices, participants selected the missing piece of various puzzles of increasing complexity. Standardized IQ scores were selected for the analyses.

Peabody Picture Vocabulary Test (PPVT-4)

The participants' receptive vocabulary breadth was measured using the PPVT-4 (Dunn & Dunn, 2007) and respective adaptations in the languages of the test (French: Dunn et al., 1993, Italian: Dunn et al., 2016; German: Lenhard et al., 2015). Participants listened to pre-recorded words of increasing difficulty and selected the corresponding picture among four choices. Z-scores were used to enable comparison across language versions.

Statistical Analysis

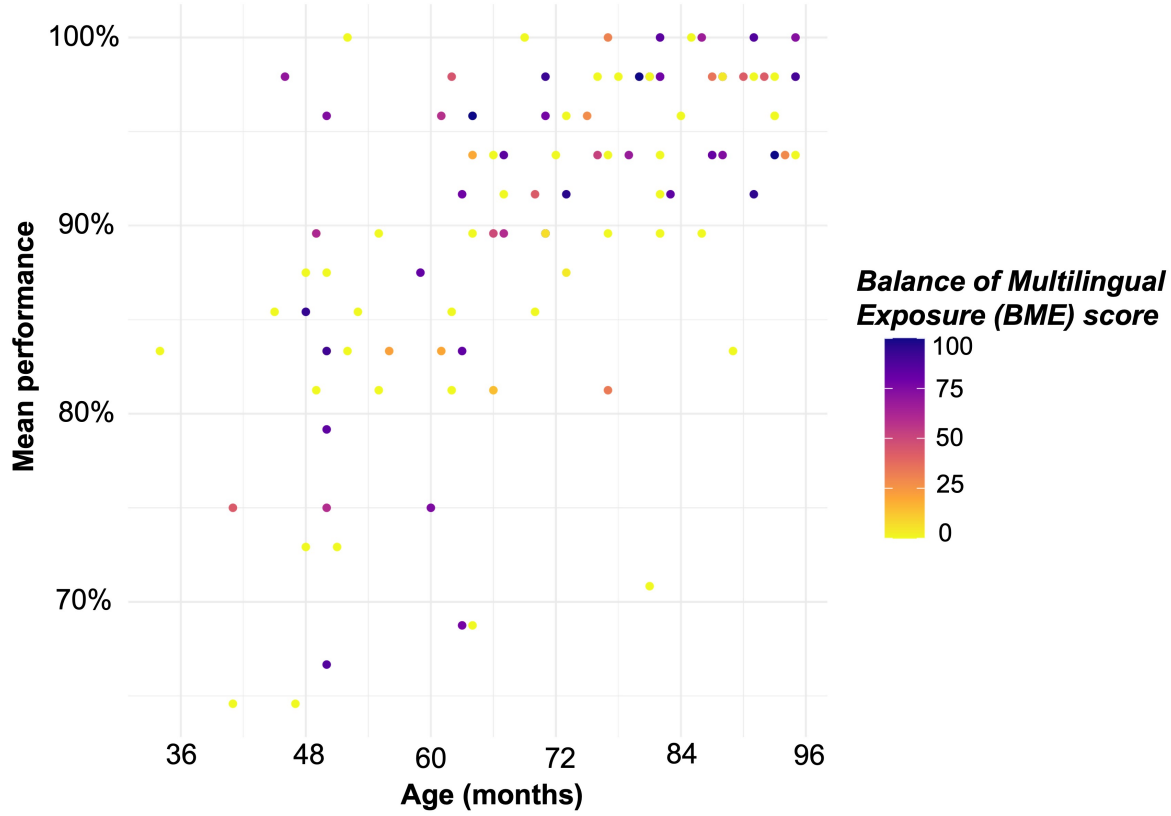
To determine whether greater balance of multilingual exposure differently impacted the participants' gesture comprehension while accounting for differences in their demographic information (age, sex assigned at birth, socioeconomic status) and verbal and non-verbal abilities, binomial generalized linear mixed effects models were fitted in R and R Studio Version 2023.12.0+369 (R Core Team, 2020) using *lme4* package (D. Bates et al., 2015).

The testing language variable (English, French, German, Italian) was sum-coded, while sliding contrasts were used for gesture type (deictic, iconic, conventional). For the communicative conditions (SO, GO, REINF, SUPP), customized contrasts were created: (a) the first contrast compared SO to all other conditions, to compare performance when a gesture is present, to when it is absent; (b) the second compared the GO to the SUPP communicative condition to examine multimodal integration, i.e., compare the performance when a supplementary verbal information is provided to when the gesture is presented alone; and (c) the third contrast compared REINF to SUPP, to index the change in the label nature (i.e., reinforcing versus supplementing speech). All models included random effects for participants and items; the (scaled) *balance of multilingual exposure score*, *gesture types*, *conditions* and their interaction were added as fixed effects. To account for developmental changes in the comprehension of specific gesture types, the model included the main effect of *age* and *gesture types,* as well as their interaction. In addition, *sex assigned at birth*, *vocabulary breadth*, *non-verbal IQ*, *parental educational level* and *testing language* were entered as covariates. Given GLMER's robustness against missingness, missing data were not imputed (Vasishth et al., 2022). All covariates were scaled, and no multicollinearity issues were detected (i.e., Variance Inflation Factor for each variable was below 5). Full details on statistical analysis and data are available at https://osf.io/cusfk/.

Results

Participants performed relatively well on the task (**Figure 2**).

Figure 2. Observed gesture comprehension accuracy as a function of age and balance of multilingual exposure score. *A higher balance of multilingual exposure score (i.e., darker dot) reflects a greater balance in exposure to several languages since birth, while a lower score (i.e., lighter dot) reflects a greater imbalance (e.g., greater exposure to one language as compared to another).*



The results of the statistical model showed a significant effect of gesture type: irrespective of the condition, conventional gestures exhibited lower performance than iconic gestures (β = -0.92, SE = 0.23, z = -4.02, $p < .001$) for all participants (**Table 2**). However, this effect cannot be interpreted as such because it further interacted with both *multilingual exposure score* and *condition*: Precisely, the 2-way interaction between *conventional* gesture relative to *iconic* gesture and the *gesture-only condition* relative to *supplementary speech-and-gesture condition* was significant (β = 0.84, SE = 0.35, z = 2.43, $p = .02$). It furthermore interacted significantly with the *balance of multilingual exposure score*, resulting in a significant 3-way interaction between balance of multilingual exposure, gesture type (conventional – iconic), and condition (*gesture-only – supplementary speech-and-gesture condition*) (β = 0.57, SE = 0.27, z = 2.11, $p = .03$). Additionally, the 3-way interaction between balance of multilingual exposure, gesture type (deictic – iconic) and condition (*gesture-only – supplementary speech-and-gesture condition*) also yielded significance (β = -0.78, SE = 0.29, z = -2.71, $p = .006$).

To locate the source of this interaction, nested contrasts were created to examine simple effects (see Appendix 7). The results showed that the *balance of multilingual exposure score* differently impacted the gesture comprehension of iconic gestures in the *gesture-only condition* (β = 1.04, SE = 0.49, z = 2.12, *p* = .03), but not in the *supplementary speech-and-gesture condition* (β = 0.35, SE = 0.25, z = -0.94, *p* = .35*)*: Children with higher *balance of multilingual exposure score* recognized more iconic gestures than children with lower *multilingual exposure score* in the *gesture only* condition.

In addition, the *speech-only condition* exhibited better performance than the other conditions (β = -0.63, SE = 0.17, z = -3.61, *p* < .001), just as the *reinforcing speech-and-gesture* condition yielded better scores than the *supplementary speech-and-gesture* conditions (β = 0.73, SE = 0.15, z = 4.82, *p* < .001). As expected, performance significantly increased with age (β = 0.61, SE = 0.11, z = 5.69, *p*< .001). However, it did not interact significantly with the type of gesture (*p* > .05). None of the other covariates such as non-verbal IQ, vocabulary breadth, parental education level or sex assigned at birth predicted gesture comprehension (all *p* values > .05).

Table 2. *Fixed effects of the final model*.

	β	SE	Z	*p*
Intercept	2.79	0.15	18.24	*< .001****
Balance of Multilingual Exposure (BME)	0.15	0.12	1.29	0.20
GestureDeicticIconic	0.38	0.24	1.58	0.11
GestureIconicConv	-0.92	0.23	-4.02	<.001***
CondSpeechToAll	-0.63	0.17	-3.61	<.001***
CondReinfToSupp	0.73	0.15	4.82	<.001***
CondGestOnlyToSupp	0.29	0.14	2.10	0.04*
Age	0.61	0.11	5.69	<.001***
Sex_at_birth	-0.10	0.20	-0.48	0.63
ParentalEducLevel	0.02	0.10	0.25	0.80
NonVerbal_IQ	0.15	0.11	1.41	0.16
Vocabulary	0.09	0.10	0.90	0.37
Lang_English	-0.95	0.65	-1.46	0.14
Lang_French	0.01	0.71	0.02	0.99
Lang_German	0.86	0.64	1.33	0.18
BME:GestureDeicticIconic	0.04	0.19	0.19	0.85
BME: GestureIconicConv	0.00	0.18	0.00	1.00
BME: CondSpeechToAll	-0.26	0.15	-1.77	0.08
BME: CondReinfToSupp	0.04	0.12	0.35	0.73
BME: CondGestToSupp	-0.11	0.11	-1.09	0.28
GestureDeicticIconic: CondSpeechToAll	0.05	0.44	0.11	0.92
GestureIconicConv: CondSpeechToAll	-0.28	0.43	-0.65	0.51
GestureDeicticIconic: CondReinfToSupp	-0.36	0.39	-0.92	0.36
GestureIconicConv: CondReinfToSupp	0.34	0.36	0.96	0.34

	β	SE	Z	*p*
GestureDeicticIconic: CondGestToSupp	-0.48	0.36	-1.34	0.18
GestureIconicConv: CondGestToSupp	0.84	0.35	2.43	0.02*
GestureDeicticIconic:Age	-0.20	0.17	-1.18	0.24
GestureIconicConv: Age	0.02	0.16	0.11	0.91
BME: GestureDeicticIconic: SpeechToAll	0.04	0.38	0.11	0.92
BME: GestureIconicConv: SpeechToAll	-0.17	0.36	-0.47	0.64
BME: GestureDeicticIconic: CondReinfToSupp	-0.51	0.32	-1.59	0.11
BME: GestureIconicConv: CondReinfToSupp	0.08	0.28	0.27	0.78
BME: GestureDeicticIconic: CondGestToSupp	-0.78	0.29	-2.71	.006**
BME: GestureIconicConv: CondGestToSupp	0.57	0.27	2.11	0.03*

Note. *BME* stands for Balance of Multilingual Exposure Score; *CondSpeechToAll* refers to the contrast of the condition speech-only compared to reinforcing, gesture-only and supplementary conditions combined; *CondReinfToSupp* reflects the contrasts between conditions reinforcing and supplementary speech-gesture combinations; *CondGestToSupp* reflects the contrast between the conditions gesture-only and supplementary; *GestureDeicticIconic* refers to the contrast Deictic versus Iconic; *GestureIconicConv* refers to the comparison Iconic versus Conventional gestures; *ParentalEducLevel* means Parental Educational Level. *Lang* means Testing Language. * shows significant *p* values at .05 level, ** at .01 and *** at .001. *β* stands for estimates, *SE* for Standard Error and *z* for Z-value.

Discussion

This study explored whether balance of cumulative multilingual exposure impacts how children above preschool age understand deictic, iconic and conventional gestures, while accounting for key variables (i.e., age, sex assigned at birth, parental educational level, vocabulary breadth, non-verbal IQ). The novel gamified task performed in four languages allowed a nuanced picture of the impact of multilingualism on the comprehension of these gestures by exploring the comprehension of gestures in different conditions, closer to how they are naturally encountered in daily communicative situations. Findings revealed a positive effect of *balance of multilingual exposure* on the comprehension of iconic gestures presented without speech.

Impact of multilingual exposure on gesture comprehension

Balance of cumulative multilingual exposure differently affected the comprehension of iconic gestures, when these were presented without speech. More precisely, children with greater balance in their multilingual exposure since birth recognized significantly more iconic gestures, than their peers who were less balanced in their multilingual exposure, when iconic gestures were not accompanied by speech. This finding is consistent with previous work (e.g., Yow & Li, 2024; Yow & Markman, 2011) and aligns with theoretical frameworks (Fan et al., 2015; Wermelinger et al., 2024)

suggesting that multilingual individuals develop a *heightened sensitivity* to the communicative contexts and the non-verbal cues they entail. Children with higher multilingual exposure may develop increased attentiveness to visual and contextual cues such as iconic gestures that directly link to the environment, through regular interactions in situations where non-verbal signals often support communication. According to the COME perspective (Wermelinger et al., 2024), multilingual individuals experience greater variability in both effective and non-effective communicative situations, leading to a larger repertoire of communicative means, and the flexibility to apply them appropriately. Multilingual children may frequently encounter situations requiring them to infer meaning from gestures in the absence of accompanying speech, thereby strengthening their comprehension of iconic gestures presented without verbal support. For instance, they may interact with adults who speak their language less fluently or with peers and educators using a language in which they are less proficient. In such contexts, communication may rely more heavily on gestures and contextual cues. These scenarios align with the ***Compensation Hypothesis*** (van Wonderen et al., 2023), which proposes that multilingual children may attend more to non-verbal cues to compensate for occasional gaps in linguistic knowledge. *The* ***Monitoring Hypothesis*** (van Wonderen et al., 2023) further suggests that multilingual children develop heightened sensitivity to communicative cues, including gestures, because they routinely track which language to use with whom, in order to avoid misunderstandings. As this process likely draws on attentional resources (e.g., monitoring and selectively attending to the visual cue, retrieving its meaning, and linking it to the context), future work may investigate whether this effect is mediated by attention skills in children with different balance of multilingual exposure.

It is also possible that multilingual and monolingual children may differ in their processing strategies, for instance, in the extent to which they rely on gesture as a scaffold (see Botting et al., 2009 for a similar suggestion in children with Developmental Language Disorder). However, since all target words in the present study were highly familiar, and vocabulary was controlled in the analyses, we interpret the effect of balance of multilingual exposure as reflecting broader differences in sensitivity to non-verbal cues (van Wonderen et al., 2023; Wermelinger et al., 2024).

Interestingly, no effect of balance of multilingual exposure was detected for conventional gestures, despite their greater arbitrary and culturally shared component that could favor children with greater balanced in multilingual exposure. Scrutiny at the item level revealed great variability and overall lower performance across the four conventional gestures tested (Appendix 8), specifically in the *gesture-only* condition (see Appendix 9 for the detail of the errors produced). This suggests that conventional gestures in the current task may have been more ambiguous and therefore more difficult to recognize overall, eventually not discriminating between children with greater and lower multilingual exposure.

Previous research had shown that bilingual children integrated multimodal cues such as eye gaze presented with speech in order to locate an object more efficiently than monolinguals peers (Yow & Markman, 2015). In contrast, no effect of balance of multilingual exposure was detected in our task in the condition requiring multimodal integration (i.e., *supplementary speech-and-gesture combination*). However, the absence of this effect is actually consistent with previous work conducted with monolingual and bilingual preschoolers (Wermelinger et al., 2020): In a gesture perception task where a speechless iconic gesture completed a sentence, no difference between groups was found in the participants' ability to integrate both verbal and gestural streams of information.

Altogether, these findings raise the possibility that an effect of multilingualism on multimodal integration may not be ubiquitous but rather tied to situations and tasks requiring more salient communicative intent. Indeed, multilingual children generally present enhanced Theory of Mind skills (i.e., defined as the ability to attribute mental states; Premack & Woodruff, 1978) compared with their monolingual peers (Schroeder, 2018; but see Baumeister et al., 2025; Dahlgren et al., 2017). Arguably, both the 2015 task by Yow and Markman, which required participants to infer the experimenter's intent by integrating a word and the experimenter's gaze (Yow & Markman, 2015), and the 2011 task, where participants attended to pointing or eye gaze to locate an object (Yow & Markman, 2011), mobilized higher pragmatic and mentalizing skills as compared to the study by Wermelinger et al. (2020) and the current work. This, consequently, may explain the lack of multilingual effect observed on multimodal integration on the one hand, and on deictic gestures that directly pointed to the referent, on the other.

In the future, studies using eye-tracking may help to shed light on the multimodal integration in children with diverse multilingual backgrounds. For instance, eye tracking can reveal whether children efficiently coordinate their gaze between gestures and speech, and whether multilingual children show greater flexibility or faster gaze shifts when integrating these modalities. Prior work suggests that looking at gestures plays a critical role in supporting comprehension, particularly when the linguistic input is more difficult to process (Zielinski & Wakefield, 2021). Moreover, multilingual children may attend more readily to gestures when the verbal input is ambiguous or cognitively demanding (Demir-Lira et al., 2018; Yow & Markman, 2011). Such gaze patterns could clarify whether multilingual experience enhances children's ability to dynamically integrate verbal and non-verbal communicative signals.

Additional effects

As expected and previously reported (Perrault et al., 2019), age was a significant positive predictor of gesture comprehension ability, with participants demonstrating improved performance with age.

This effect seemed consistent across the different gesture types, as there was no evidence of an interaction between age and gesture type in the current study.

Unsurprisingly, the *speech-only condition* yielded better performance for all participants than all other conditions, irrespective of their balance of cumulative multilingual exposure. Similarly, recognizing a gesture when it was accompanied by reinforcing speech (i.e., REINF condition) was easier than when the gesture was presented with supplementary speech, consistent with previous work in preschoolers (Dimitrova et al., 2017).

Limitations and considerations for future research

While this study offers valuable insights into how multilingualism modulates gesture comprehension, it is important to acknowledge some limitations.

First, for the sake of clarity, gestures were classified into three types, following McNeill (1992). However, some overlaps between these categories exist, and the types of gestures rather lie on a continuum (also known as *Kendon's continuum*; McNeill, 1992). Therefore, some flexibility in the gesture classification is warranted because, for instance, iconic gestures can become conventionalized with context and use (Müller, 2017). Conversely, conventional gestures can vary in their iconicity (Kendon, 2004). This suggests that the conventional gestures in this study, assumed to be present in all the Western countries where the study was conducted, might vary in their iconic and conventional dimensions. More broadly, as the present sample was limited to European languages and Western cultural contexts, caution is warranted in generalizing these findings to non-European languages and cultures, where gesture use and its interaction with multilingual experience may differ (Kita, 2009).

Second, the very nature of the verbal information provided with the gesture in the *reinforcing speech and gesture* condition was different between deictic gestures on the one hand, and iconic and conventional gestures on the other (i.e., a noun or a verb, respectively) to best reflect how gesture and speech are most commonly naturalistically paired. Previous research suggests that while deictic gestures predict and precede the acquisition of spoken nouns (Iverson & Goldin-Meadow, 2005), iconic gestures representing actions may emerge after the acquisition of corresponding verbs (Özçalişkan et al., 2014), possibly constituting a confound between *gesture type* and *word form* in the current task. Investigating predictive relationships between gestures and speech acquisition fall outside the scope of this study, which aimed at better understanding gesture comprehension and its interaction with speech in children after preschool age from various multilingual backgrounds. As all words were selected from a validated checklist of early-acquired words (i.e., MacArthur-Bates Communicative Development Inventories), it is unlikely that any observed differences in gesture comprehension are attributable to variations in word familiarity. Nonetheless, future studies should

include a greater number of gesture items within each type, along with more consistent verbal pairings across gesture types, in order to confirm and extend these findings.

Third, in order to address common limitations in previous studies using binary approaches to bilingualism (see e.g., de Bruin, 2019; Kremin & Byers-Heinlein, 2021; Leivada et al., 2023; Surrain & Luk, 2019 for discussions), the current work sought to operationalize more transparently a continuous bilingual variable according to the study hypotheses, namely the balance of exposure to several languages since birth. However, multilingualism is a multifaceted and heterogeneous phenomenon, with no two multilingual individuals identical in their language combinations, proficiency, amount and balance of use or exposure, age of onset, attitudes towards their languages, mean and context of acquisition, among other factors (De Cat et al., 2023; Luk, 2015; Marian & Hayakawa, 2021). The *balance of multilingual exposure score* used in the current study, while informative in indicating how balanced a child's exposure to two languages has been, does not capture other dimensions of multilingual experience, such as participants' mastery of their additional languages or actual use. Moreover, it focuses on the balance between the testing language and the most prominent additional language, and therefore does not fully reflect the complexity of multilingual profiles in children exposed to more than two languages. Future work may consider whether more comprehensive measures, such as entropy-based indices (Gullifer & Titone, 2020), better capture this variability. Adequately characterizing and measuring multilingualism *is* challenging. Transparently reporting sample characteristics, and specifying and justifying the bilingual measures considered may be first steps towards ensuring the interpretability and generalizability of the findings across diverse populations (De Houwer, 2023; Hantman et al., 2023; Kremin & Byers-Heinlein, 2021).

Research perspectives

Given the positive role of multilingualism found on the comprehension of iconic gestures, it would be valuable to investigate *whether* this effect is also present in children experiencing specific challenges in this realm. For instance, difficulties in gesture production (Ramos-Cabo et al., 2019) and comprehension (Perrault et al., 2019; Silverman et al., 2010) have been reported in children diagnosed with Autism Spectrum Disorder (ASD). However, findings remain mixed (Dimitrova et al., 2017; Wolfer et al., 2025), and may vary depending on gesture type, presentation context and methodological approach (McKern et al., 2023). Exploring the potential benefits of multilingual exposure in such populations could offer promising insights for both research and clinical practice. Autistic children, in particular, may benefit from evidence-based recommendations about dual-language exposure (Beauchamp & MacLeod, 2017).

Conclusion

This work is grounded in a framework hypothesizing that individuals with greater multilingual exposure may be more sensitive to the communicative situation and to their interactional partners, enabling them to detect and better use the socio-pragmatic cues at their disposal (e.g., Wermelinger et al., 2024). This study investigated how balance of multilingual exposure since birth impacted the comprehension of deictic, iconic, and conventional gestures in children aged 3 to 8, with a gamified task available in four language versions. Gestures were presented in different conditions commonly encountered in real-life situations, and all participants were considered on a multilingual scale to circumvent the caveats of groups comparisons with an arbitrary bilingual criterion. Findings indicated that greater balance of multilingual exposure positively influenced the comprehension of speechless iconic gestures.

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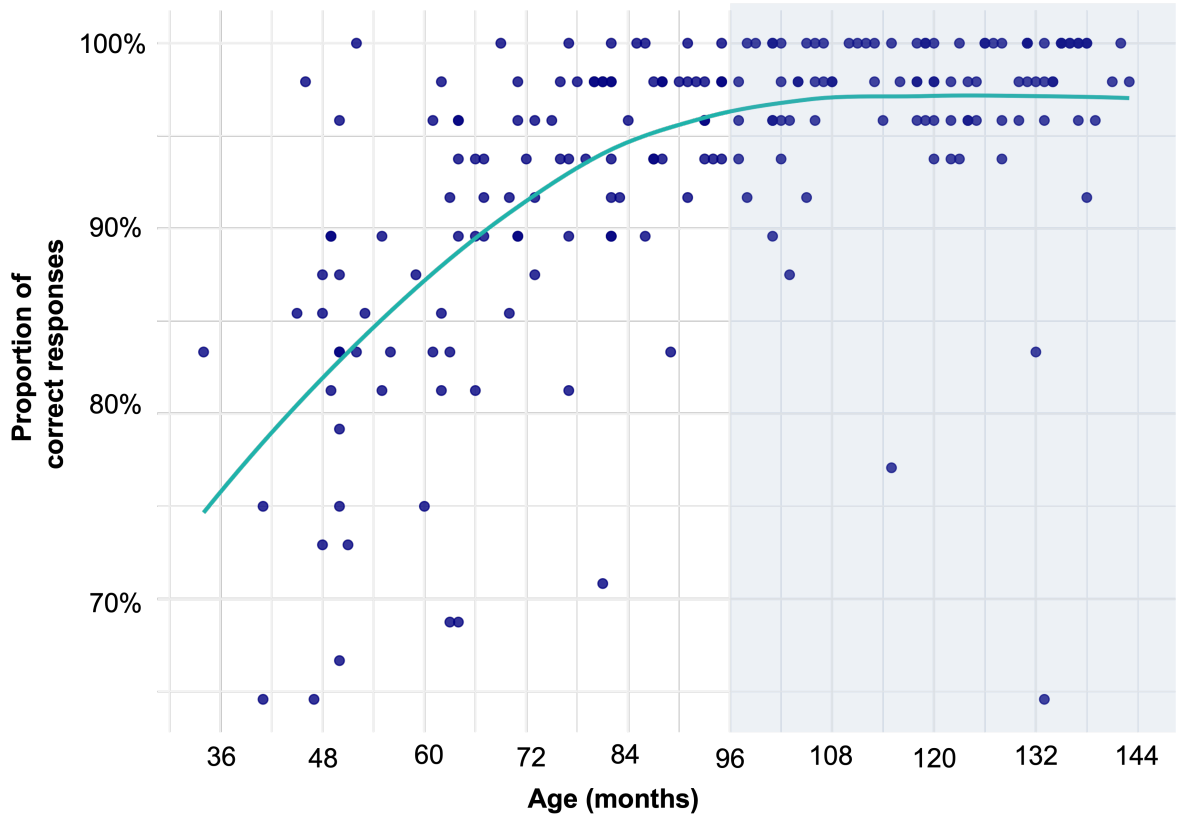
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Appendix 1. Observed accuracy per participant as a function of age.

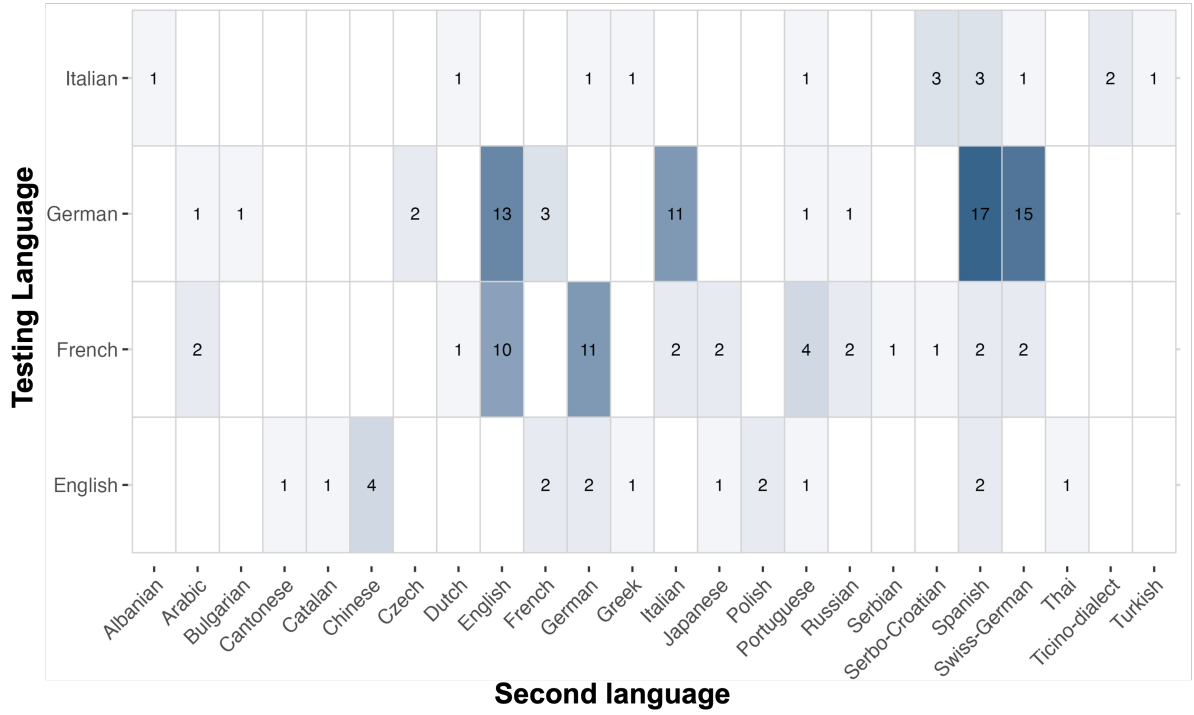


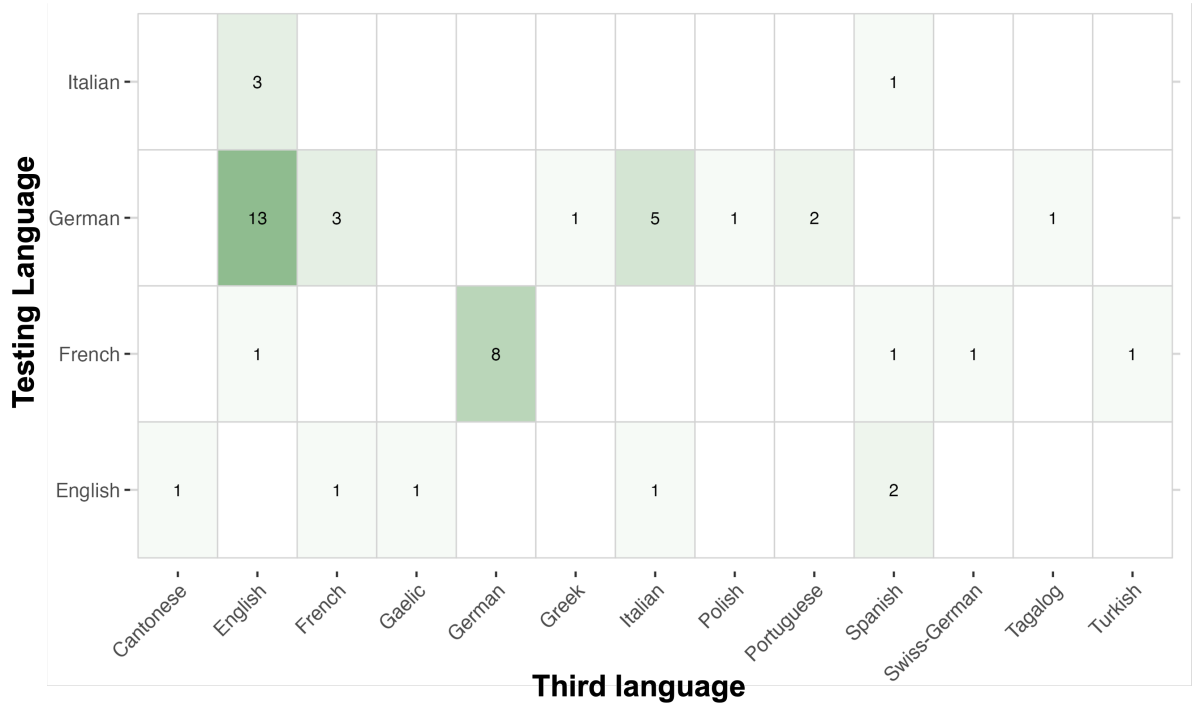
The highlighted zone represents older participants, on which subsequent analyses have not been carried out, given that performance is plateauing at high accuracy.

Appendix 2. Linguistic background of the younger participants (*N* = 105)

	Testing Language	**Second Language**	**Third Language**
	N=105 reported (100%)	**N=65 reported** (61.9%)	**N=20 reported** (19.0%)
Age of First Exposure (months)			
Mean (SD)	3.76 (11.7)	4.54 (13.2)	18.4 (23.9)
[Min, Max]	[0, 74]	[0, 72]	[0, 60]
Cumulative exposure (%)	74.0 (29.7)	37.1 (24.1)	16.0 (12.9)
Cumulative use (%)	78.0 (28.7)	32.2 (27.2)	10.7 (11.8)
Current exposure (%)	77.8 (27.3)	31.5 (24.3)	14.0 (10.7)
Current use (%)	80.8 (27.3)	27.0 (26.6)	12.9 (11.9)
Richness of the linguistic experience (%)	0.63 (0.14)	0.36 (0.16)	0.29 (0.16)
Place of First Exposure			
Home	85 (81.0%)	50 (47.6%)	9 (8.6%)
School	6 (5.7%)	7 (6.7%)	2 (1.9%)
Other	14 (13.3%)	8 (7.6%)	9 (8.6%)
Parent rated proficiency (%)	84.9 (16.9)	62.9 (29.6)	44.7 (32.5)

Appendix 3. Variety of the second and third languages participants were exposed to. Numbers indicate how many families reported that their child was exposed to these languages, in addition to the testing language.





Appendix 4. **Additional examples for the *balance of multilingual exposure (BME) score* calculation**.

Parents completed the Q-BEx questionnaire (De Cat et al., 2022), which provided a detailed assessment of the child's exposure to various languages over their lifetime (e.g., hours spent exposed to language 1, language 2, etc.).

To calculate the balance of multilingual exposure score, the absolute difference between the cumulative percentage of exposure to the child's testing language (typically their most proficient language) and a secondary language was determined, then subtracted from 100. This score ranged from 0: indicating a highly unbalanced multilingual exposure (closer to a *monolingual* experience), to 100: reflecting a highly balanced multilingual exposure. For children exposed to three languages, the calculation used the language with the highest exposure percentage among the second and third languages.

Cumulative exposure to… since birth			***Balance of Multilingual Exposure (BME) score***	**Interpretation**
Language 1	**Language 2**	**Language 3**		
100%	0%	0%	100 - (|100 – 0 |) = **0**	Highly unbalanced multilingual
85%	0%	15%	100 - (|85 – 15 |) = **30**	Relatively unbalanced multilingual
50%	50%	0%	100 - (| 50 – 50 |) = **100**	Balanced multilingual
33 %	33 %	33 %	100 - (| 33 – 33 |) = **100**	Balanced multilingual
50 %	40%	10%	100 - (| 50 – 40 |) = **90**	Balanced multilingual
30%	20%	50%	100 - (| 30 – 50 |) = **80**	Balanced multilingual
70%	10%	20%	100 - (| 70 – 20 |) = **50**	Balanced multilingual

The values underscored (L2 or L3) represent the value selected in the calculation to be subtracted from the percentage of L1.

Appendix 5. **Video example of the stimulus DRIVE** in French, English, Italian and German available at: https://osf.io/cusfk/files/osfstorage.

Appendix 6. Items description in the four language versions (English in red, German in yellow, French in blue and Italian in green). The visual distractor of an item corresponded to a correct item for another item, and vice-versa. The 3rd response choice corresponds to an oddball for the *gesture-only*, *speech-only* and *reinforcing speech-gesture combination*, while it becomes a verbal distractor for the *supplementary speech-gesture combination. Response* images appeared in random order from left to right.

DEICTIC Gestures		Stimulus (video)				Response options		
	Gesture description	**Gesture only (GO)**	**Speech only (SO)**	**Reinforcing Speech-gesture combination (REINF)**	**Supplementary Speech-gesture combination (SUPP)**	**Correct Response**	**Visual distractor** *(counterbalancing picture)*	**Oddball / Verbal distractor**
DG - BALLOON	POINTING  balloon-go.mp4 balloon-so.mp4 balloon-reinf-mp4 balloon-supp.mp4	POINTING	**"ballon" "balloon" "Luftballon" "palloncino"**	POINTING + **"ballon" "balloon" "Luftballon" "palloncino"**				
					POINTING + **"souffler" "blowing" "pusten" "soffiare"**			
DG - GRAPES	POINTING  grapes-go.mp4 grapes-so.mp4 grapes-reinf.mp4 graped-supp.mp4	POINTING	**"raisins" "grapes" "Trauben" "Uva"**	POINTING + **"raisins" "grapes" "Trauben" "Uva"**				
					POINTING+ **"goûter" "tasting" "probieren" "provare"**			

DG - HAT	POINTING  hat-go.mp4 hat-so.mp4 hat-reinf.mp4 hat-supp.mp4	POINTING	**"chapeau" "hat" "Hut" "cappello"**	POINTING + **"chapeau" "hat" "Hut" "cappello"**				
					POINTING + **"mettre" "put" "aufsetzen" "mettere"**			
DG - CAKE	POINTING  cake-go.mp4 cake-so.mp4 cake-reinf.mp4 cake-supp.mp4	POINTING	**"gateau" "cake" "Kuchen" "torta"**	POINTING + **"gateau" "cake" "Kuchen" "torta"**				
					POINTING + **"couper" "cut" "schneiden" "tagliare"**			

ICONIC Gestures	**Stimulus (video)**				**Response options**		
	Gesture description VIDEO	**Gesture only (GO)**	**Speech only (SO)**	**Reinforcing Speech-gesture combination (REINF)**	**Supplementary Speech-gesture combination (SUPP)**	**Correct Response**	**Visual distractor** *(counterbalancing picture)*	**Oddball / Verbal distractor**
IG - DRIVE	Gesture CAR DRIVING 	CAR DRIVING	**"conduire" "driving" "fahren" "guidare"**	CAR DRIVING + **"conduire" "driving" "fahren" "guidare"**				

	drive-go.mp4 drive-so.mp4 drive-reinf.mp4 drive-supp.mp4				CAR DRIVING + "dame" "lady" "Frau" "signora" "dame"			
IG -THROW	Gesture THROWING BALL  throw-go.mp4 throw-so.mp4 throw-reinf.mp4 throw-supp.mp4	THROWING BALL	"lancer" "throwing" "werfen" "lanciare"	THROWING + "lancer" "throwing" "werfen" "lanciare"				
					LANCER + "monsieur" "man" "Mann" "unomo"			
IG - SWIM	Gesture SWIM  swim-go.mp4 swim-so.mp4 swim-reinf.mp4 swim-supp.mp4	SWIM	"nager" "swimming" "schwimmen" "nuotare"	SWIM + "nager" "swimming" "schwimmen" "nuotare"				
					SWIM + "fille" "girl" "Mädchen" "ragazza"			
IG- CLIMB	Gesture CLIMB *Hands grasp one after the other above head*	CLIMB	"grimper" "climbing" "klettern" "salire"	CLIMB + "grimper" "climbing" "klettern" "salire"				

	 climb-go.mp4 climb-so.mp4 climb-reinf.mp4 climb-supp.mp4		CLIMB + **"pompier"** **"firefighter"** **"Feuerwehrmann"** **"pompiere"**			

CONVENTIONAL Gestures		**Stimulus (video)**				**Response options**		
	Gesture description VIDEO	**Gesture only (GO)**	**Speech only (SO)**	**Reinforcing Speech-gesture combination (REINF)**	**Supplementary Speech-gesture combination (SUPP)**	**Correct Response**	**Visual distractor** *(counterbalancing picture)*	**Oddball / Verbal distractor**
CG-SLEEP	Gesture SLEEPING  sleep-go.mp4 sleep-so.mp4 sleep-reinf.mp4 sleep-supp.mp4	SLEEPING	**"dormir"** **"sleeping"** **"schlafen"** **"dormire"**	SLEEP + **"dormir"** **"sleeping"** **"schlafen"** **"dormire"**				
					SLEEP + **"bébé"** **"baby"** **"Baby"** **"bebe"**			
CG- LISTEN	Gesture LISTEN  listen-go.mp4 listen-so.mp4 listen-reinf.mp4 listen-supp.mp4	LISTEN	**"écouter"** **"listening"** **"zuhören"** **"ascoltare"**	LISTEN + **"écouter"** **"listening"** **"zuhören"** **"ascoltare"**				
					LISTEN + **"enfants"** **"children"** **"Kinder"** **"bambini"**			

CG - DISGUSTING	Gesture DISGUSTING  disgusting-so.mp4 disgusting-go.mp4 disgusting-reinf.mp4 disgusting-supp.mp4	DISGUSTING	**"dégoutant" "disgusting" "ekelig" "disgustoso"**	DISGUSTING + **"dégoutant" "disgusting" "ekelig" "disgustoso"**				
					DISGUSTING + **"cochon" "pig" "Schwein" "maiale"**			
CG -LOOK	Gesture LOOK  look-go.mp4 look -so.mp4 look -reinf.mp4 look -supp.mp4	LOOK	**"regarder" "looking" "schauen" "guardare"**	LOOK + **"regarder" "looking" "schauen" "guardare"**				
					LOOK + **"garçon" "boy" "Junge" "ragazzo"**			

Appendix 7. **Outputs of the nested models, to identify the source of the significant effect of the 3-way interactions between multilingual exposure, gesture types and conditions.**

- Model on *iconic* gestures

Predictors	β	SE	Z	*P*
(Intercept)	3.37	0.28	11.92	< .001***
Balance of Multilingual Exposure (BME)	0.24	0.22	1.07	0.29
conditionso_to_all	-0.54	0.31	-1.74	0.08
conditionreinf_to_supp	0.51	0.25	2.03	0.04*
conditiongo_to_supp	-0.18	0.26	-0.69	0.49
Age	0.56	0.19	2.90	< .001***
Sex_at_birth	-0.16	0.37	-0.43	0.67
ParentEducLevel	0.01	0.16	0.08	0.94
Non-verbal_IQ	0.14	0.19	0.71	0.48
Vocabulary	0.27	0.19	1.43	0.15
Lang_English	-0.94	1.14	-0.82	0.41
Lang_French	0.03	1.30	0.03	0.98
Lang_German	1.03	1.17	0.88	0.38
BME: CondSpeechToAll	-0.21	0.30	-0.70	0.49
BME: CondReinfToSupp	-0.15	0.24	-0.61	0.54
BME: CondGestToSupp	**-0.60**	**0.25**	**-2.43**	**0.02 ***

- Model on *iconic* gestures in *gesture-only condition*

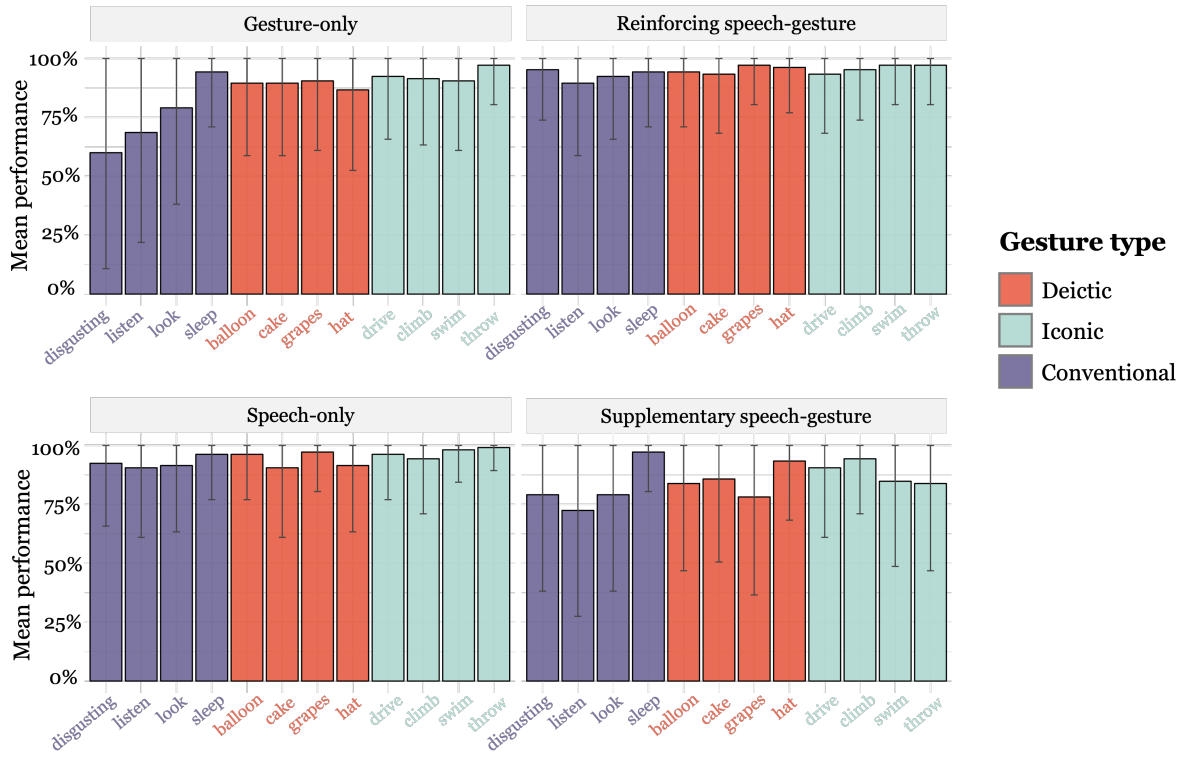
Predictors	β	SE	Z	*P*
(Intercept)	3.94	0.71	5.58	< .001
Balance of Multilingual Exposure (BME)	**1.04**	**0.49**	**2.12**	**0.03***
Age	0.45	0.34	1.30	0.19
Sex_at_birth	-0.70	0.71	-0.99	0.32
ParentEducLevel	-0.15	0.28	-0.51	0.61
Non-verbal_IQ	-0.02	0.35	-0.05	0.96
Vocabulary	0.45	0.40	1.09	0.28
Lang_English	-2.48	2.00	-1.24	0.22
Lang_French	1.27	2.63	0.48	0.63
Lang_German	0.78	2.10	0.37	0.71

- Model on iconic gestures in *supplementary speech and gesture condition*

Predictors	β	Std. Err	Z value	*P*
(Intercept)	2.44	0.48	5.06	<.001***
Balance of Multilingual Exposure (BME)	-0.24	0.25	-0.94	0.35
Age	0.51	0.25	2.02	0.04*
Sex_at_birth	-0.16	0.47	-0.33	0.74
ParentEducLevel	-0.27	0.25	-1.06	0.29
Non-verbal_IQ	0.26	0.25	1.06	0.29
Vocabulary	0.28	0.22	1.27	0.20
Lang_English	-0.47	1.49	-0.31	0.75
Lang_French	-0.78	1.53	-0.51	0.61
Lang_German	1.85	1.59	1.17	0.24

The 2-way interaction between *balance of multilingual exposure score* and condition *gesture-only versus supplementary speech-gesture combination* were not significant in the models conducted on *deictic* gestures and *conventional* gestures separately.

Appendix 8. Observed performance for each item in the different conditions.



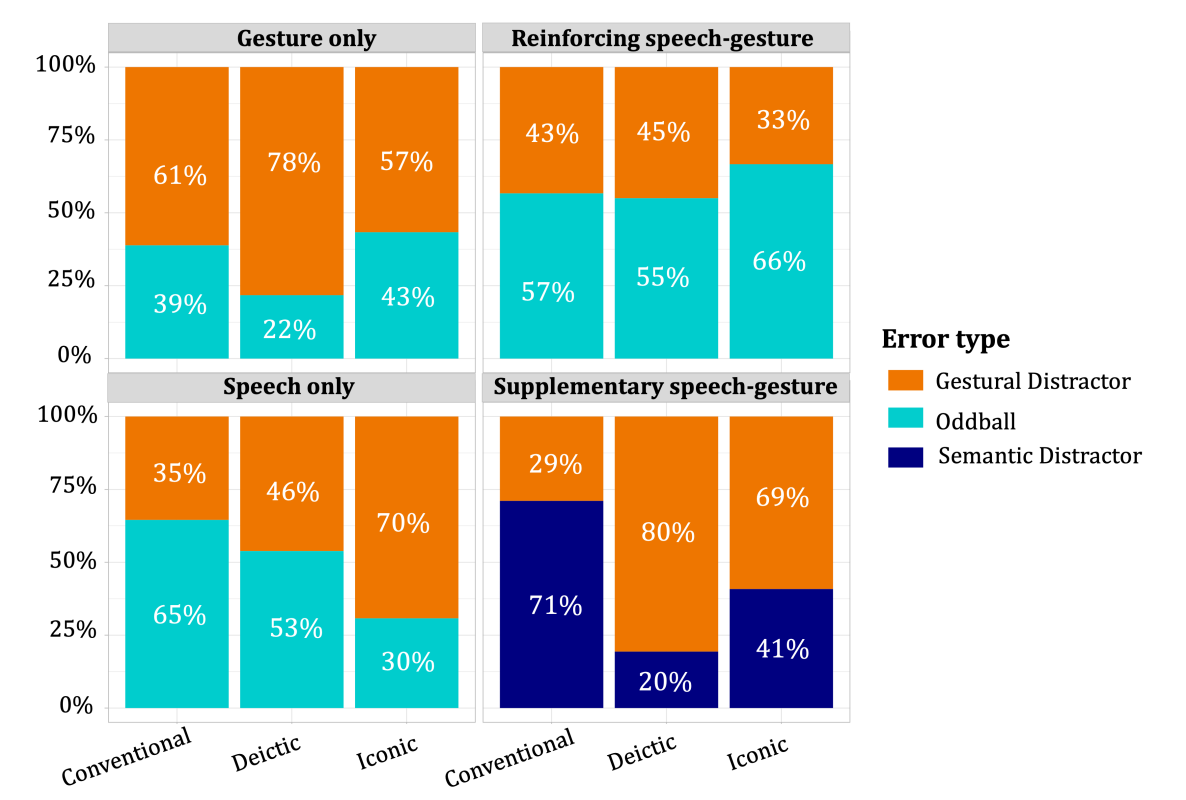
Appendix 9. Additional information on the errors produced

Table 9A. Percentage of errors produced by gesture type and condition

	Condition			
	Gesture only	**Reinforcing speech and gesture**	**Speech only**	**Supplementary speech and gesture**
Conventional	15%	7%	7%	18%
Deictic	11%	5%	6%	15%
Iconic	7%	4%	3%	12%

Figure 9B. Distribution of the errors produced by gesture type and condition

NB: there was no semantic distractor in the conditions gesture only, reinforcing speech and gesture, speech only; there was no oddball in the condition supplementary speech and gesture.



4.3 BILINGUALISM EFFECTS ON GESTURE COMPREHENSION IN AUTISTIC CHILDREN

The previous study investigated the impact of multilingual exposure on gesture comprehension in neurotypical school-aged children, examining gestures presented either with speech or alone. Results indicated that children with more balanced multilingual exposure, defined as relatively equal exposure to multiple languages throughout their lifetime, understood significantly more iconic gestures compared to those with less balanced multilingual exposure. This finding is consistent with both empirical findings (Yow & Markman, 2011) and theoretical frameworks (Fan et al., 2015; Wermelinger et al., 2024) supporting the perspective that children with bilingual exposure present a greater sensitivity to the communicative situation, leading them to monitor and understand non-verbal cues such as gestures more effectively.

Children with ASD often present difficulties in understanding gestures, including iconic gestures presented without speech (Adornetti et al., 2019; Perrault et al., 2019; but see N. Dimitrova et al., 2017; McKern et al., 2023). If the effect of multilingual exposure observed in **Section 4.2** also applies to autistic individuals, it may help mitigate some of their challenges in gesture comprehension.

Therefore, the next study, accepted for publication in the *Journal of Speech, Language, and Hearing Research*, examines how *balance of multilingual exposure* influences gesture comprehension in autistic children.

Does balance of multilingual exposure impact gesture comprehension in autistic children?

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Disclosure. The authors have declared that no competing interests existed at the time of publication.

Compliance with Ethical Standards and informed consent. This study was approved by the Swiss Association of Research Ethics Committees *Swissethics* (Project ID-2022-00878), the Institutional Review Board of the University of Connecticut (US), the Psychology Research Ethics Committee of the University of Edinburgh (UK), the Institutional Review Board of Emerson College Boston (US), and the Research Ethics Committee of Ethical Review of Unió Catalana Hospitals Foundation (Spain). All parents provided informed consent for their child's participation prior to their inclusion in the study. All work has been carried out in accordance with The World Medical Association's Declaration of Helsinki for experiments involving humans.

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Data Availability Statement

The data that support the findings of this study are openly available in OSF at https://osf.io/4tfzp/ [doi: 10.17605/OSF.IO/4TFZP].

Abstract

Purpose: This study explores whether and how balance of multilingual exposure impacts gesture comprehension in children with Autism Spectrum Disorder (ASD).

Method: Eighty-six autistic children (aged 4 – 12 years) varying in their balance of exposure to different languages completed a gamified task assessing the comprehension of deictic, iconic and conventional gestures presented in four communicative modalities: (1) gesture presented alone (e.g., gesturing DRIVE), (2) with reinforcing speech (e.g., gesturing DRIVE and saying "driving"), (3) with supplementing speech (e.g., gesturing DRIVE and saying "lady"), compared to (4) speech alone (e.g., saying "driving"). A balance of *multilingual exposure* score reflected the participants' balance of exposure to more than one language since birth, based on parental reports.

Results: Overall, children with ASD performed well on the task (i.e., above chance level). Accounting for age, biological sex, socioeconomic status, autism severity, non-verbal IQ and general language skills, mixed effects logistic regressions showed no differential effect of balance of multilingual exposure on the comprehension of *deictic*, *iconic* and *conventional* gestures. Age and language skills were significant independent positive predictors of the performance, highlighting the maturating process of gesture comprehension over time on the one hand, and reflecting the importance of language for gesture comprehension on the other.

Conclusion: This preliminary study paves the way for future research exploring the impact of multilingualism on the gesture comprehension abilities of individuals with ASD, and provides new evidence suggesting that multilingual exposure is not detrimental to their communicative development.

Keywords: Gestures; Bilingualism; Autism Spectrum Disorder (ASD)

Gesture comprehension seems to be challenging in children diagnosed with Autism Spectrum Disorder (ASD; Ramos-Cabo et al., 2019 for a review), who are in the present work also referred as *autistic children* to acknowledge the variety of preferences among the autistic community (Kenny et al., 2016). Moreover, in neurotypical (NT) children, exposure to multiple languages seems advantageous for communication, including better interpretation of gestures such as pointing (Yow & Markman, 2015). Exploring *whether* and *how* multilingual exposure impacts gesture comprehension in children with ASD may promote both better understanding of these children's communicative profiles, and contribute to deciphering the role of multilingualism for their non-verbal communicative skills.

Gesture comprehension in ASD

Gestures (or also co-speech *gestures*) are hand movements, naturally produced alongside speech, which enhance communication (see Clough & Duff, 2020 for a detailed review of the communicative and cognitive benefits; also Goldin-Meadow, 2003). Gestures are crucial elements of an individual's social-communicative functioning, and qualitative and quantitative differences in gestural profiles constitute recent criteria for an autism diagnosis (American Psychiatric Association, 2022). While gesture *production* in autistic individuals reveals impairments and atypicalities at various ages (de Marchena, 2021; Ramos-Cabo et al., 2019), the study of gesture *comprehension* remains scarce to date. Previous work notably reports lower comprehension of *iconic gestures* (i.e., gestures representing the referent, such as gesturing BALL; McNeill, 1992) in adolescents with ASD (e.g., Stieglitz Ham et al., 2011), as compared to NT peers matched on full scale-IQ and chronological age. Difficulties in integrating gestures with speech have also been reported in autistic adolescents aged 12 to 18 (e.g., Silverman et al., 2010), leading researchers to suggest a "slowed and inefficient (…) bimodal processing [of gesture]" in individuals with ASD (de Marchena, 2021, p. 2230). Although iconic gestures have been the most thoroughly investigated, gesture comprehension difficulties also arise for gestures referred to as *deictic* (e.g., pointing) and *conventional* (i.e., culturally shared hand movements holding an arbitrary meaning, such as the THUMBS UP gesture conveying "all good"; McNeill, 1992). More specifically, autistic children aged 3 to 6 have been reported to show reduced understanding of deictic pointing compared to age-matched children with developmental delays (Carpenter et al., 2002; Mundy et al., 1986, 1990). Children with ASD aged 4 to 8 also exhibit lower comprehension of conventional gestures, than peers with typical development (TD) and with Developmental Language Disorder of comparable developmental age (Perrault et al., 2019).

However, preserved accuracy in comparison to NT vocabulary-matched peers on tasks assessing the comprehension of *deictic*, *iconic* and *conventional* gestures with and without speech, has nevertheless been reported in children with ASD aged 2 to 12 (Dimitrova et al., 2017). Recent

work also showed that children with ASD ages 4 to 12 presented relatively spared performance in understanding speechless gestures completing a narrative (Wolfer et al., *in press*).

In this study, autistic children showed good performance in understanding video-taped deictic, iconic, and conventional gestures that followed speech in a narrative context. Moreover, studies assessing gesture comprehension using offline tasks, such as those involving cartoons, have generally shown that autistic children performed similarly to neurotypical peers (Hamilton et al., 2007; Smith & Bryson, 2007). Both the limited research and the presence of inconsistent findings highlight the need for further studies to fully describe and understand the gestural profile of children with ASD.

Multilingualism effects on gesture comprehension

Gestures are complex processes: Their production is linked to language acquisition (Goldin-Meadow, 2015) and development in both NT (Capone & McGregor, 2004) and autistic children (Choi & Rowe, 2024; Kilili-Lesta et al., 2022; but see also Blume et al., 2021). Multilingualism, namely the use of, or exposure to multiple languages rather than a single one (Grosjean, 1982), has been shown to influence gestures (Gullberg, 2012). Specifically, bilingual children have been found to gesture more than monolinguals (Nicoladis, 2007), and are better at interpreting pointing gestures (Yow & Markman, 2011). Researchers have thus argued in favor of a *multilingual exposure advantage* (Fan et al., 2015) comprising a *heightened sensitivity* to the communicative situation and to their interaction partners (Yow & Markman, 2011): Their exposure to two or more language systems, and greater experience with more diverse socio-communicative environments, would allow multilingual children to realize that individuals hold varied, nuanced linguistic and cognitive perspectives (Fan et al., 2015). This awareness is relevant to avoid communicative failures, and results in a higher propensity for multilinguals to monitor the pragmatic, social and non-verbal communicative cues as compared to monolinguals (van Wonderen et al., 2023; Yow & Markman, 2016).

A potential awareness and monitoring associated with multilingualism can therefore explain the better performance exhibited by multilinguals, relative to monolinguals in various tasks assessing communicative effectiveness, such as: repairing misunderstandings (Wermelinger et al., 2017), addressing communicative breakdowns (Genesee et al., 1996), and interpreting a speaker's intent (Yow & Markman, 2015). This view is also consistent with the COMmunicative-Experience Perspective (COME; Wermelinger et al., 2024), which posits that multilingual children develop a wider repertoire of communicative means as compared to monolingual peers, due to the greater variability in the communicative situations that they are exposed to. Recent research indeed suggests a predictive role of lifetime exposure to multilingual environments, showing that neurotypical children with greater balance in their exposure to multiple languages better

understood iconic gestures, in comparison to children with lower balance of multilingual exposure (Wolfer et al., under review). Whether this positive effect of balance in multilingualism on the comprehension of gesture is also observable in autistic children is the question of the current work.

The current study

To decipher the potential compensatory role of balance of multilingual exposure on the comprehension of gestures with and without speech in autistic children, this study explored the comprehension of *deictic*, *iconic* and *conventional* gestures by 4-to-12 year old children diagnosed with ASD, who varied in their *balance of multilingual exposure (BME)* since birth. We used BME as a continuous measure of multilingual exposure to avoid the caveats of monolingual-bilingual groupings (De Houwer, 2023; Luk, 2015). Greater balance in multilingual exposure may enhance children's ability to process non-verbal cues, as more balanced multilinguals engage in diverse communicative contexts where sensitivity to pragmatic cues is essential (van Wonderen et al., 2023; Wermelinger et al., 2024; Yow & Markman, 2011). This approach aligns with recent efforts to conceptualize bilingualism as a continuous experience rather than a binary trait (De Cat et al., 2023), encompassing monolinguals, who, by default, represent one end of the spectrum with an unbalanced multilingual exposure, and bilinguals, who encompass the rest of the spectrum, representing both less- and more-balanced multilingual exposure. This perspective follows established recommendations in the field, reflecting a hypothesis-driven selection of bilingual variables (Luk, 2015), investigating *which aspects* of bilingual experience may impact the outcome (Marian & Hayakawa, 2021; van Wonderen et al., 2023), and avoiding a *monolingual bias* (De Houwer, 2023; Leivada et al., 2023; Rothman et al., 2023).

This study aimed to address the following research question: Does the *balance of exposure to multiple (two or more) languages* impact the comprehension of gestures in autistic children? We hypothesized a positive predictive role of balance of multilingual exposure on gesture comprehension in children with ASD: Relative to autistic children with lower balance of multilingual exposure, autistic children with greater balance in multilingual exposure would be more experienced in integrating the non-verbal communicative cues relevant for communication, and would, therefore, show better gesture comprehension. Following previous work on autistic children (Dimitrova et al., 2017), we presented gestures and speech alone or in combination (see the *Procedure and stimuli* subsection for details).

Method

This study included a sample of children with ASD, and followed previous work conducted on NT children (Wolfer et al., under review), adopting similar methodology and design (i.e., multilingual exposure characterization, statistical approach).

Participants

Eighty-six children (17 girls, 69 boys) aged 4 to 12 were included in the study (mean age = 9;0 ± 2;1). To be included in the study, children had to be diagnosed with ASD following the criteria of the DSM-5 (American Psychiatric Association, 2022), established prior to the study by a certified clinician. Children had no visual or auditory impairment. The severity of the autism symptoms was estimated via the parental *Social Communication Questionnaire* (SCQ) (Rutter et al., 2003). All participants were tested in their most proficient language (i.e., either French, German, English, Italian or Spanish) as reported by their parents. As part of an international project, assessments took place in Europe (Switzerland, France, Germany, Spain, UK) and in the USA. The participants varied in their exposure to an additional language since birth: We computed a *balance of multilingual exposure* score *(BME)*, a continuous measure ranging from 0 ("monolingual exposure") to 100 ("balanced multilingual exposure"), which included bilinguals with uneven exposure. BME was derived from carevigers' estimates retrieved from the "Quantifying the Bilingual Experience" questionnaire (Q-BEx; De Cat et al., 2022). The BME score reflects the degree of balance in multilingual exposure, including participants with minimal or no exposure to additional languages (traditionally considered monolinguals). This approach aligns with recent perspectives that conceptualize multilingualism as a continuum rather than a categorical distinction (De Houwer, 2023; Luk, 2015). See Appendix A for the BME score calculation, and Appendix B for the second languages participants were exposed to. Background information (Table 1) included socioeconomic status, indexed by parental educational level (i.e., ranging on a 5-point Likert scale from (1) the parent completed primary school, (2) middle school, (3) high school, (4) post-secondary school to (5) university), and non-verbal IQ, measured with the *Raven's Progressive Matrices* (Raven's-2, Raven et al., 2018). Given the variety of linguistic profiles in autistic children, a composite score was calculated based on standardized measures of vocabulary and morphosyntax to index general language skills (see the *Measures* section).

Table 1. *Descriptive statistics of the sample (N = 86)*

Variable	M (SD) or n (%)	Median [Min, Max]
Age (months)	108.0 (24.7)	113.0 [52, 144]
Sex assigned at birth		
Female	17 (19.8%)	
Male	69 (80.2%)	
Parental educational level[a]	4.0 (1.2)	4.0 [1, 5]
Testing language		
English	10 (11.6%)	
French	40 (46.5%)	
German	17 (19.8%)	
Italian	2 (2.3%)	
Spanish	17 (19.8%)	
General Language skills[b]	-0.6 (1.3)	-0.6 [-4.0, 1.7]
Non-verbal IQ (Raven's-2)[c]	95.9 (14.3)	94 [55, 128]
Autism Severity (SCQ Score)[d]	19.9 (7.0)	19.5 [7, 34]
Balance of Multilingual Exposure (BME-score)	45.5 (38.2)	54.7 [0.0, 100.0]

Note. SCQ = Social Communication Questionnaire (range 0 – 40).

[a] Parental educational level on a scale from 1 to 5. The highest value between the caregivers was selected. [b] General language skills are reported as z-scores, standardized against reference norms. Z-scores fall within the normal range for age when between -1 and +1; a z-score of 0 corresponds to a standard score of 100, indicating average performance, while z = ±1 corresponds to standard scores of 85 and 115, representing one standard deviation below or above the mean. See Appendix C for additional details on raw, standard and z-scores. Value was missing for 1 participant. [c] Values were missing for 5 participants. [d] Values were missing for 6 participants.

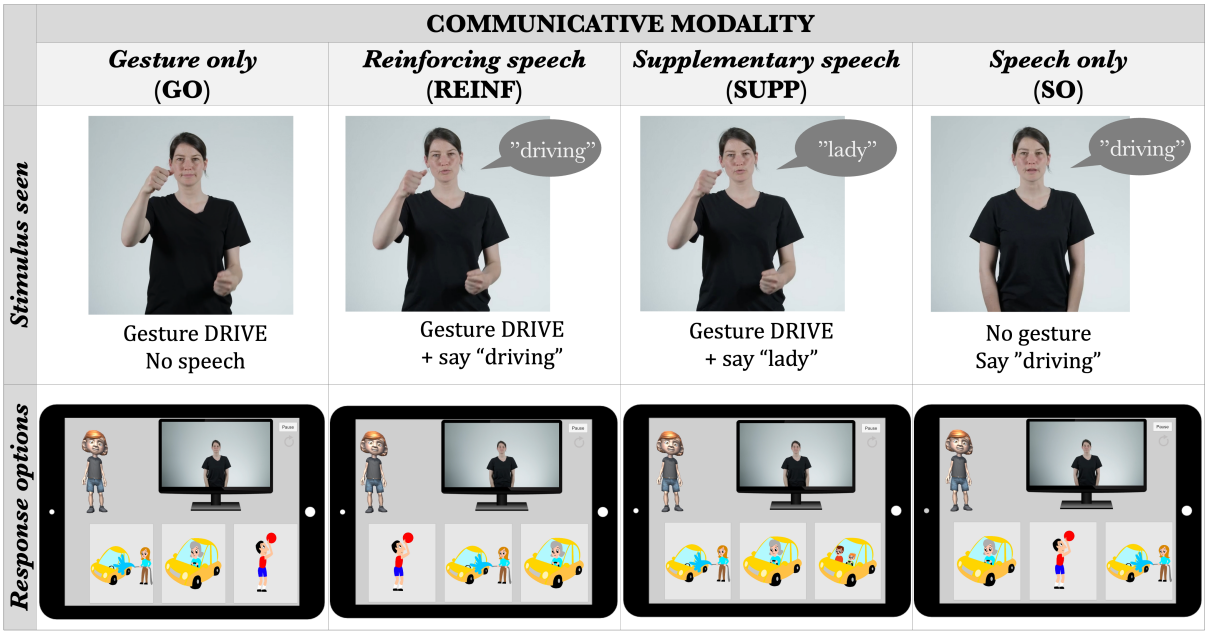
Procedure and stimuli

Participants were tested individually in a quiet room, accompanied by a trained experimenter who guided them through the tasks. The study was part of a larger protocol conducted over three to four sessions of 40-to-60 minutes, with one to six days between sessions. Children were allowed to take as many breaks as needed between individual tasks.

Following previous work on autistic children (Dimitrova et al., 2017), we presented gestures four different *communicative modalities*: (1) gestures only without speech (GO), (2) gestures with reinforcing speech (e.g., gesturing DRIVING and saying "driving"; REINF), (3) gestures with supplementing speech (e.g., gesturing DRIVING and saying "lady"; SUPP), and (4) speech produced alone, without the gesture (e.g., saying "driving"; SO; see Fig. 1 for an example). Gestures belonged to three *gesture types* (i.e., deictic, iconic and conventional). There were 4 items per gesture type (i.e., 4 deictic, 4 iconic and 4 conventional), each displayed in the 4 modalities. Gestures and speech were pre-recorded in a video, and presented within a gamified, tablet-based assessment

to ensure systematic presentation across participants. Each participant saw all stimuli presented in random order.

Figure 1. *Example of stimulus and response options for the iconic gesture DRIVE.*



The stimuli are designed to answer our main research question, that is, the influence of BME on the comprehension of deictic, iconic and conventional gestures. In addition, data from different modalities will be grouped in three different planned comparisons to allow for a more detailed exploratory analysis:

- Comparison [a]: Modality SO (4) vs. all modalities with gestures, i.e., GO, REINF and SUPP (1, 2 and 3). This comparison will reveal the general impact of adding gestures to speech.
- Comparison [b]: Modality REINF (2) vs. modality GO and SUPP (1 and 3). This comparison will reveal the effect of doubling the information in the gesture with linguistic input with the same meaning, in contrast to other modalities involving gestures.
- Comparison [c]: Modality SUPP (3) vs. modality GO (1). This comparison will reveal the effect of adding supplementing linguistic information to the gesture.

Measures

Gesture comprehension task. Participants completed a non-verbal gamified video-taped gesture comprehension task assessing the recognition of three *gesture types* in four different *communicative modalities* (see *Procedure and stimuli* subsection above). After each stimulus was presented, participants had to select, among 3 choices, the picture on screen that corresponded to the video seen. Each correct picture selection was awarded 1 point, each incorrect selection or response omission 0, resulting in a total maximum score (i.e., performance) of 48 points. All instructions were pre-recorded by a native speaker and enunciated by a 3D-character with natural human-like voice,

ensuring that the same information was provided to every participant across language versions and testing sessions. All participants completed the task entirely. Task video examples in all languages are available under: https://osf.io/muwyq/

General language skills. Participants completed a digitalized version of the *Test for Reception of Grammar, 2nd Edition (TROG-2)* to indicate their receptive morphosyntactic skills in the testing language (i.e., in English (Bishop, 2003), French (Lecocq, 1996), German (Fox-Boyer, 2006), Italian (Suraniti et al., 2009), and Spanish (Mendoza et al., 2005)), as well as a digitalized version of the *Peabody Picture Vocabulary test,* 4th Edition (PPVT-4) to assess receptive vocabulary (English: Dunn & Dunn (2007), French: Dunn et al., (1993), German: Lenhard et al., (2015), Italian: Stella et al., (2000), Spanish, PPVT 3rd Edition: Dunn et al., (2006)). Both tests demonstrate high test-retest reliability and internal consistency (Cronbach's alpha > .85 - .90) and strong construct validity through correlations with other language assessments (Bishop, 2003; Dunn & Dunn, 2007). Participants listened to pre-recorded words (for the PPVT) and sentences of increasing morphosyntactic complexity (for the TROG), and selected on the screen the corresponding picture among four choices. Z-scores were calculated for the TROG and PPVT separately, based on the normative data provided in the respective test manuals for each language version (see Appendix C for the details of the scores per language versions). The mean of the two values was used in the analyses, following the approach in Engberg-Pedersen (2018) and Yau et al. (2016), to create a composite score reflecting both lexical and morphosyntactic skills.

Non-verbal IQ. The online, short version of the *Raven's Progressive Matrices, 2nd Edition* (Raven et al., 2018) was administered to assess fluid reasoning (i.e., non-verbal IQ). This test demonstrates strong internal consistency (α > .90) and high construct validity, correlating well with general intelligence measures (Raven et al., 2018). Participants selected, among five choices, the missing piece of a sequence or visual puzzle. Standardized IQ scores were used in the analyses.

Statistical analysis

To examine the impact of *balance of multilingual exposure* on the participants' comprehension of gestures, generalized linear mixed effect models with logistic regression were fitted using R and R Studio Version 2024.04.2+764 (R Core Team, 2020) and *lme4* package (Bates et al., 2015). Specifically, the GLMM enabled us to investigate whether BME scores differently impacted (a) autistic children's overall performance in the task, and (b) their ability to understand each deictic, iconic and conventional gesture across the four *communicative modalities* (as assessed in the three planned comparisons spelled out above). The model accounted for key variables (i.e., age, parental educational level, autism severity, non-verbal IQ, language skills, testing language; see Appendix D for more details on the statistical approach).

Results

Descriptively, individual task performance averaged above 70% (fig. 2; see Appendix E for detailed performance by gesture type and modality).

Figure 2. *Individual task performance (all gesture types and modalities), as a function of age and balance of multilingual exposure.*



There was no significant impact of the *balance of multilingual exposure* (BME) on general performance, nor on a specific *gesture type* or modalities (all interactions *ps* > .05; Appendix F). The interaction between *BME score* and the modality *speech-only* relative to the modalities with a gesture (comparison [a]) was marginally significant (β = 0.27, SE = 0.15, z = 1.78, *p* = .08). This suggests a tendency for participants to exhibit different performance when a gesture was present as opposed to when it was not, depending on their balance of *multilingual exposure*: Descriptively, children with a lower BME score obtained better scores in the *speech-only* modality than in the modalities containing a gesture (e.g., *gesture-only, supplementary speech and gesture combination* combined). In contrast, children with a higher BME score showed no such difference between modalities with and without gestures, such that the difference in performance between the modalities with and without gestures was reduced for children with higher BME scores (Appendix G). However, both the variability in performance and the marginally significant trend warrant interpretation with appropriate reservations.

Additional effects. For all children, regardless of their BME, scores in the *speech-only* modality were significantly higher than in all other modalities (comparison [a]; β = -0.58, SE = 0.20, z = - 2.91, *p* = .004). Similarly, performance in the *reinforcing* modality was better than in the *gesture-only* and

supplementary modalities combined (β = - 0.88, SE = 0.18, z = -4.87, $p < .001$; comparison [b]). There was no significant difference in the comprehension of gestures presented alone (GO) compared to when they were presented with a supplementing label (SUPP; comparison [c]; $p > .05$)

In addition, general language skills significantly positively predicted performance, indicating that children with higher language scores performed significantly better than those with lower language scores (β = 0.25, SE = 0.12, z = 2.00, $p < .0045$). Age was a significant positive predictor (β = 0.57, SE = 0.12, z = 4.93, $p < .001$), indicating task performance improved with age. Non-verbal IQ, autism severity, socioeconomic status and testing language did not significantly impact performance (all *p*s > .05).

Post-hoc examinations. Given that a substantial proportion of participants scored above 95% accuracy (45.35%), we examined potential ceiling effects by reanalyzing the data excluding these high-performing participants. The main effect of BME remained non-significant (Appendix H). When high-scoring participants were excluded, language skills were no longer a significant predictor, while socioeconomic status became significant. This suggests that language skills may play a greater role in high-performing children, whereas socioeconomic status may be more influential among low-performing participants. Nevertheless, the overall conclusion regarding the non-significant effect of BME on gesture comprehension, the positive impact of *age,* and the modalities *speech-only* (comparison [a]) and *reinforcing speech-and-gesture* (comparison [b]) remained unchanged.

Discussion

Controlling for age, non-verbal IQ, language skills, autism severity and socioeconomic status, lifetime *balance of multilingual exposure (BME)* did not significantly impact the comprehension of *deictic*, *iconic* and *conventional* gestures. Consequently, there was not enough evidence to indicate that children with different BME understood these gestures differently. This indicates that there was no harmful influence of multilingual exposure on the understanding of these cues in children with ASD. Overall, participants, irrespective of their mono- or multilingual backgrounds, performed relatively well on the task, above chance level.

Participants were able to recognize gestures either presented alone, with *reinforcing,* or with *supplementing* labels. This finding is pivotal to the autistic community and policy makers, as it suggests that a higher balance of multilingual exposure does not negatively impact the comprehension of crucial non-verbal elements such as gestures. Highly balanced bi/multilingual children perform comparably to monolingual children and those with lower exposure to multiple languages. It extends the accumulating literature showing no detrimental impact of bilingualism on autistic individuals for a range of other communicative abilities, be they language skills (Hambly & Fombonne, 2012), such as vocabulary (Petersen et al., 2012) and narratives (Peristeri et al., 2020),

or cognitive skills, including executive functions (Gonzalez-Barrero & Nadig, 2019), and Theory of Mind (Peristeri et al., 2021). These findings should inform clinical practice, ensuring that recommendations align with the mounting evidence that bilingualism poses no barrier to development in autistic individuals (Beauchamp & MacLeod, 2017).

Nevertheless, the absence of an effect of *balance of multilingual exposure* on performance with gestures does not align with previous work conducted in younger NT children aged 3 to 4, reporting better interpretation of pointing gestures (Yow & Markman, 2011) and integration of verbal and non-verbal cues (Yow & Markman, 2015) by bilinguals in comparison to age-matched monolinguals. Consequently, the *exposure advantage* (Fan et al., 2015) and the *increased sensitivity* to socio-communicative parameters observed in the bilingual neurotypical population (e.g., Yow & Markman, 2011, 2016) are not evident within our autistic sample. Rather, instead of an impact of *balance of multilingual exposure*, age and language abilities played a crucial role in understanding communicative gestures in our task. More specifically, on the one hand, chronological age independently significantly predicted performance: Older participants understood more gestures than younger children, irrespective of the type of gestures and the communicative modalities in which they were presented. This finding emphasizes the maturation of gesture comprehension over time, and confirms the relevance of its assessment throughout childhood in autistic individuals. On the other hand, children presenting higher language skills obtained better gesture comprehension scores than children presenting lower linguistic skills. This result suggests that children with ASD relied on speech to help understand the gesture. Alternatively, it could reflect the tight link between gesture and spoken language, as evidenced in autistic children by recent reviews (Choi & Rowe, 2024; Ramos-Cabo et al., 2019). According to this literature, both verbal and gestural information are integrated into a single mental representation reflecting underlying thoughts, which is activated automatically during speech and gesture production *and* perception (see Clough and Duff (2020) for a detailed overview). More studies are warranted to substantiate these possibilities.

Finally, when gestures were presented in the *reinforcing* communicative modality (i.e., the label corresponded to the gesture visible), all children performed better than when the gesture was presented alone (i.e., *gesture-only* modality), or with supplementing speech (i.e., *supplementary speech-gesture combination*). This finding replicates previous work on autistic and NT children (Dimitrova et al., 2017), and highlights the benefits of multimodal channels to fully grasp an intended communicative message (Goldin-Meadow, 2003).

Limitations

While this study offers preliminary insights into multilingual effects on gesture comprehension in children with ASD, a few limitations have to be mentioned: First, the current statistical approach assumes a linear effect of age on performance. Using *Generalized Additive Models* (GAMS) could

provide a nuanced view of *how* age influences gesture comprehension differently across a wide age range. Second, participants were exposed to a variety of second languages, and specific culturally-related effects were not examined. Third, the nature of the task designed as a lab-based experiment may have reduced ecological validity: While the controlled stimuli allowed for the examination of specific variables, they did not fully represent the varied and naturalistic contexts in which children typically encounter gestures and speech. Consequently, the findings may not entirely reflect how gesture comprehension occurs in everyday communication, where additional environmental socio-pragmatic cues are present. Future research could shed light on these issues by investigating the comprehension of gestures in more naturalistic settings, and exploring whether the effects of multilingualism arise in children with different cultural backgrounds. Fourth, a substantial proportion of participants scored above 95%, raising concerns about ceiling effects. However, reanalysis excluding high-performing participants confirmed the robustness of the main findings (Appendix H). Future research could explore more challenging tasks to assess how multilingualism influences gesture comprehension at varying levels of difficulty. Finally, although the model captured key effects, the number of predictors may have limited power to detect smaller interaction effects. Future research with larger samples could help confirm these effects.

Conclusion

This study investigated, for the first time, the impact of balance of multilingual exposure on the *deictic*, *iconic* and *conventional* gesture comprehension skills of children with ASD between 4 and 12 years. The tablet-based, gamified task elicited a non-verbal response to be more inclusive, and assessed all three gesture types in four communicative modalities. Findings suggest no predictive impact of balance of multilingual exposure on the comprehension of gestures, irrespective of their type, and the communicative modality in which they were presented. Noticeably, age and language skills positively predicted the comprehension of gestures. These preliminary results call for more studies exploring the interplay between bilingualism and the comprehension of non-verbal cues to better understand the socio-communicative profiles of autistic individuals. By applying a continuous approach to explore multilingual effects on the gestural profiles of autistic children, this study provides new evidence that multilingual exposure is not detrimental to the communicative development of children with ASD.

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Appendix

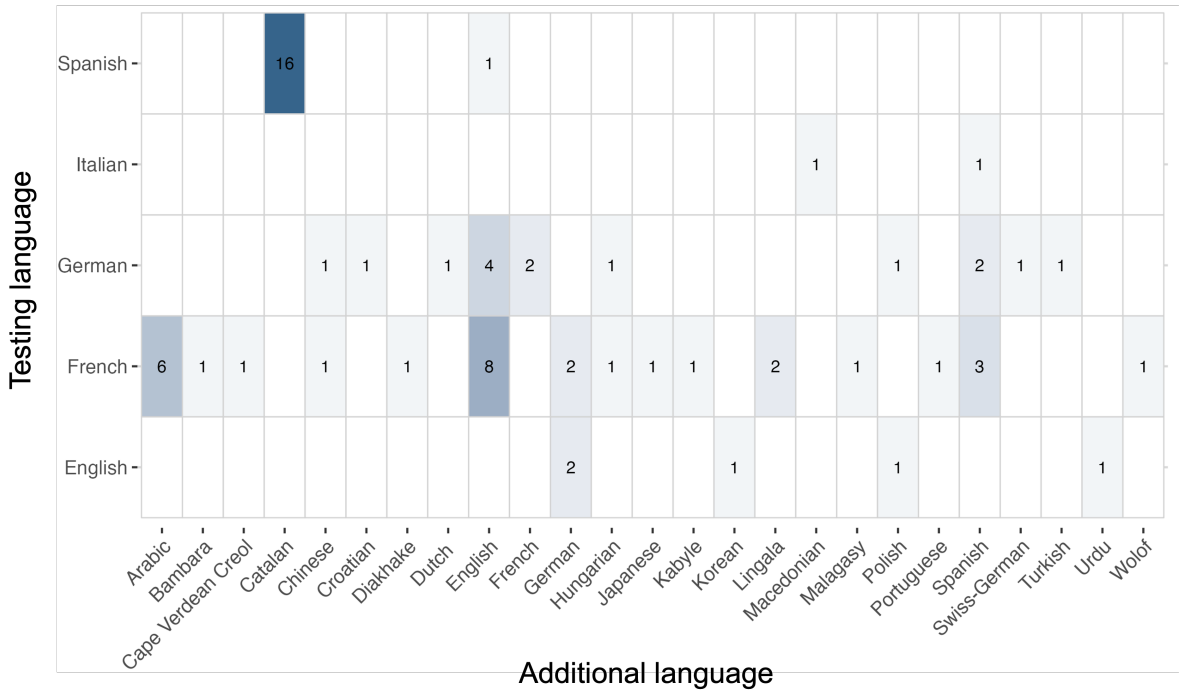
Appendix A. *The Balance of Multilingual Exposure (BME) score operationalization*

Parents completed the Q-BEx questionnaire (De Cat et al., 2022), comprising a precise estimation of the child's exposure to different languages throughout their lives (e.g., number of hours exposed to language 1, to language 2, etc.). The absolute difference between the percentage of cumulative exposure, since birth, to the language in which the child has been tested (i.e., their most proficient language) and a second language was calculated, then substracted to 100. The final Balance of *Multilingual Exposure score (BME score)* varied between 0: representing a highly unbalanced multilingual experience (i.e., comprising monolinguals) and 100: a highly balanced multilingual exposure. Thus, an increase in BME score represented an increase in balance of exposure between languages.

When parents reported exposure to 3 languages, the data of the language with the maximum exposure percentage between language 2 and 3 was selected in the computation.

Percentage of exposure to…			**Balance of Multilingual Exposure** (BME) score	**Interpretation**
Language 1	**Language 2**	**Language 3**		
100%	0%	0%	100-(|100-0|) = **0**	Children with no exposure to multiple languages (monolinguals)
90%	10%	0%	100-(|90-0|) = **10**	Unbalanced multilingual
50%	50%	0%	100-(|50-50|) = **100**	Balanced multilingual
60%	40%	0%	100-(|60-40|) = **80**	Relatively balanced multilingual
33 %	33 %	33 %	100-(|33-33|) = **100**	Balanced multilingual
50 %	40%	10%	100-(|50-40|) = **90**	Balanced multilingual
30%	20%	50%	100-(|30-50|) = **80**	Balanced multilingual

Appendix B. ***Language background of the participants.*** *Participants were tested in their most proficient language, and had various exposure to an additional language.*



Appendix C. ***Participants' raw scores, Standard scores and Z-scores for the PPVT-4 and the TROG-2.***

Testing language	**ENGLISH (N=10)**	**FRENCH (N=40)**	**GERMAN (N=17)**	**ITALIAN (N=2)**	**SPANISH (N=17)**
Peabody Picture Vocabulary Test (PPVT-4)					
	Raw score (240 items max)	**Raw score (170 items max)**	**Raw score (228 items max)**	**Raw score (175 items max)**	**Raw score (192 items max)**
Mean (SD)	154 (41.7)	78.4 (39.5)	151 (36.9)	56.5 (7.78)	97.9 (24.6)
Median [Min, Max]	155 [88, 211]	78.0 [2, 161]	151 [91, 197]	56.5 [51, 62]	105 [45, 128]
Missing values	0 (0%)	0 (0%)	4 (23.5%)	0 (0%)	2 (11.8%)
	Standard score	**Standard score**	**T-score**	**Standard score**	**Standard score**
Mean (SD)	99.6 (21.7)	90.0 (28.4)	47.8 (11.6)	67.5 (3.54)	89.9 (13.8)
Median [Min, Max]	99.5 [67, 140]	87.5 [40, 145]	52.0 [30, 63]	67.5 [65, 70]	92.0 [55, 113]
Missing	0 (0%)	0 (0%)	4 (23.5%)	0 (0%)	2 (11.8%)
	Z-score	**Z-score**	**Z-score**	**Z-score**	**Z-score**
Mean (SD)	-0.027 (1.45)	-0.67 (1.89)	-0.22 (1.16)	-2.17 (0.233)	-0.68 (0.92)
Median [Min, Max]	-0.04 [-2.20, 2.67]	-0.84 [-4.00, 3.00]	0.20 [-2.00, 1.30]	-2.17 [-2.33, -2.00]	-0.53 [-3.00, 0.87]
Missing values	0 (0%)	0 (0%)	4 (23.5%)	0 (0%)	2 (11.8%)
Test for Reception of Grammar (TROG-2)					
	Raw score (80 items max)	**Raw score (92 items max)**	**Raw score (84 items max)**	**Raw score (80 items max)**	**Raw score (80 items max)**
Mean (SD)	10.6 (6.70)	14.8 (8.02)	15.4 (4.97)	3.00 (1.41)	9.65 (5.30)
Median [Min, Max]	11.5 [1, 19]	14.0 [2, 28]	18.5 [6, 20]	3.0 [2, 4]	10.0 [0, 17]
Missing values	2 (20.0%)	2 (5.0%)	1 (5.9%)	0 (0%)	0 (0%)
	Standard score		**T-score**	**Standard score**	**Percentile**
Mean (SD)	87.0 (17.7)		51.5 (11.9)	71.0 (22.6)	32.4 (24.6)
Median [Min, Max]	87.5 [55, 111]		56.0 [28, 64]	71.0 [55, 87]	20.0 [10, 90]
Missing values	2 (20.0%)		1 (5.9%)	0 (0%)	0 (0%)
	Z-score	**Z-score**	**Z-score**	**Z-score**	**Z-score**
Mean (SD)	-0.87 (1.18)	-0.87 (1.30)	0.15 (1.19)	-1.94 (1.51)	-0.54 (0.765)
Median [Min, Max]	-0.83 [-3.00, 0.73]	-0.56 [-3.23, 1.42]	0.60 [-2.20, 1.40]	-1.94 [-3.00, -0.87]	-0.84 [-1.28, 1.28]
Missing values	2 (20.0%)	2 (5.0%)	1 (5.9%)	0 (0%)	0 (0%)

Note: The raw score in the French Version of the TROG corresponds to the number of errors produced, whereas the raw scores for the other language versions correspond to the number of 4-item blocks passed. Raw scores were converted into Standard or T-scores (when appropriate), according to the normative data provided in each language version's manual. The Standard/T- scores were then converted into Z-scores to enable cross-linguistic comparison, using the formula: Z-score = (Standard Score – 100) / 15 and Z-score = (T-score – 50) / 10. The Spanish version of the PPVT correponds to the PPVT-3rd Edition (Dunn et al., 2006).

Appendix D. ***Statistical approach specifications.***

Missing data curation. Missing data were not imputed, given GLMM's accuracy despite missing data (Vasishth et al., 2022).

Statistical procedure. Models with the most complete structure were created, then simplified in case of convergence issues. Continuous variables were scaled, and prior checks revealed no harmful multicollinearity between the covariates (i.e., Variance Inflation factor > 5). All models included random effects for *items* and *participants*. Specifically, the final model examining the impact of BME score contained a random intercept for *items* and *participant* and was estimated using LK and BOBYQA optimizer. Fixed-effects entailed: *balance of multilingual exposure score (BME)*, *gesture types*, *modality* (i.e., communicative modalities), and their interactions, as well as main effects of *age*, *sex assigned at birth*, *language skills*, *non-verbal IQ*, *Social Communication Questionnaire (SCQ) score* and *testing language* (i.e., formula: performance ~ 1 + BME * gesture type * modality + scq score + age + sex + SES + non-verbal IQ + language skills + testing language).

Contrasts coding and planned comparisons. A sliding contrast was applied to code *gesture type* (deictic, iconic and conventional). The *testing languages* were sum coded (English, French, German, Italian, Spanish). A customized contrast was applied to investigate modalities: (a) Comparison [a]: the *speech-only* modality was compared to the average of all other modalities; (b) Comparison [b]: the *reinforcing speech-gesture* modality was compared to the *gesture-only* and *supplementary speech-gesture combination* combined; (c) Comparison [c]: the *supplementary speech-gesture* modality was compared to the *gesture-only* modality.

Model checks. The final model for multilingual exposure had a total explanatory power of R = .36, with the part relative to the fixed effects alone of R = .23.

Appendix E. ***Observed performance by modality and gesture type***

Table E1 and E2. ***Observed performance by modality (left panel), and gesture type (right panel) - (total sample, N = 86)***

Modality	**Mean Accuracy (%) ± SD**
Gesture-only	87.88 ± 32.64
Reinforcing	96.12 ± 19.31
Speech-only	95.06 ± 21.68
Supplementary	86.43 ± 34.26

Gesture Type	**Mean Accuracy (%) ± SD**
Deictic	93.60 ± 24.48
Iconic	92.51 ± 26.32
Conventional	88.01 ± 32.50

Table E3. ***Observed performance by modality and gesture types - (total sample, N = 86)***

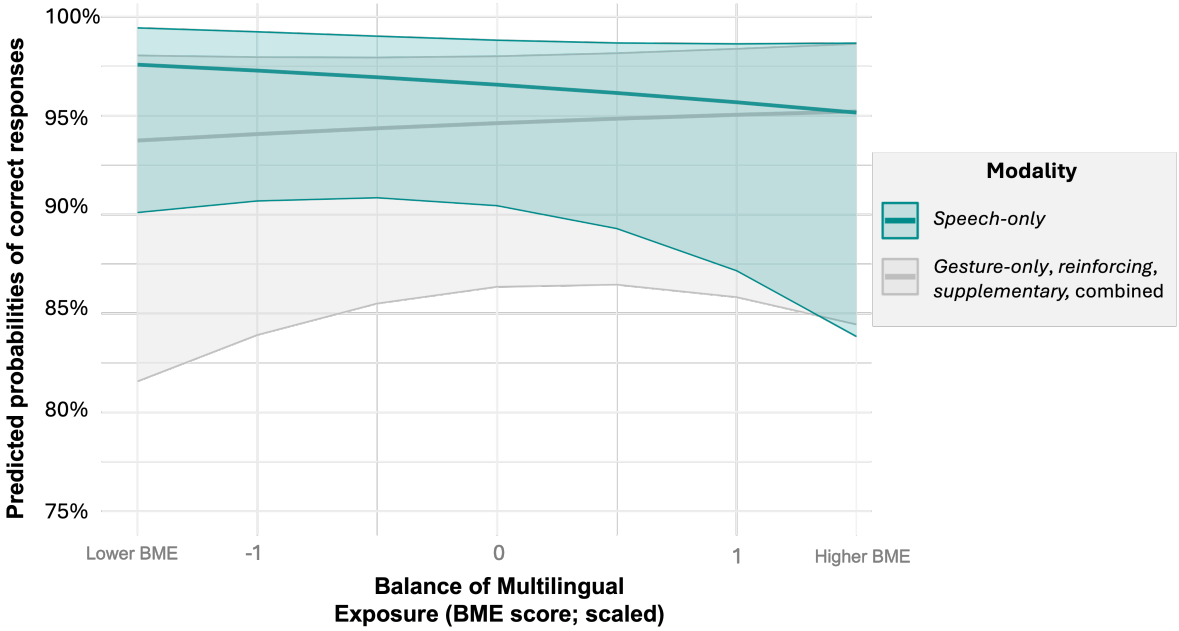
Modality	**Deictic** (Mean% (SD))	**Iconic** (Mean% (SD))	**Conventional** (Mean% (SD))
Gesture-only	90.988 (28.677)	93.314 (25.014)	79.360 (40.531)
Reinforcing	97.093 (16.825)	95.930 (19.788)	95.349 (21.090)
Speech-only	94.767 (22.301)	94.767 (22.301)	95.640 (20.451)
Supplementary	91.570 (27.825)	86.047 (34.701)	81.686 (38.734)

Appendix F. ***Output of the final statistical model for Balance of Multilingual Exposure.***

	β	Std. Err	Z value	*P*
(Intercept)	**3.332**	**0.333**	**9.997**	**< .001**
BME	-0.202	0.127	-1.583	0.113
gestureDeicticIconic	-0.042	0.262	-0.159	0.874
gestureIconicConv	-0.367	0.259	-1.417	0.156
modSpeechOnly [a]	**-0.577**	**0.198**	**-2.914**	**0.004**
modReinforcing [b]	**-0.875**	**0.180**	**-4.868**	**< .001**
modGestureOnlySupp [c]	-0.075	0.131	-0.573	0.567
SCQ_score	-0.005	0.117	-0.043	0.965
Age	**0.574**	**0.116**	**4.934**	**< .001**
Sex_birth	-0.199	0.266	-0.749	0.454
SES	0.173	0.113	1.531	0.126
Non-verbal_IQ	-0.042	0.136	-0.305	0.761
Language_skills	**0.249**	**0.124**	**2.004**	**0.045**
Lang_ENGLISH	-1.227	1.618	-0.759	0.448
Lang_FRENCH	0.744	1.227	0.606	0.544
Lang_ITALIAN	-0.518	1.435	-0.361	0.718
Lang_GERMAN	1.271	3.443	0.369	0.712
BME: gestureDeicticIconic	-0.301	0.191	-1.577	0.115
BME: gestureIconicConv	0.129	0.185	0.695	0.487
BME: modSpeechOnly [a]	0.268	0.151	1.776	0.076
BME: modReinforcing [b]	-0.066	0.134	-0.493	0.622
BME: modGestureOnlySupp [c]	-0.028	0.081	-0.345	0.730
GestureDeicticIconic: modSpeechOnly [a]	-0.197	0.473	-0.416	0.677
GestureIconicConv: modSpeechOnly [a]	-0.622	0.496	-1.253	0.210
GestureDeicticIconic:modReinforcing [b]	0.222	0.453	0.489	0.625
GestureIconicConv: modReinforcing [b]	-0.404	0.425	-0.950	0.342
GestureDeicticIconic: modGestureOnlySupp [c]	-0.480	0.331	-1.449	0.147
GestureIconicConv: modGestureOnlySupp [c]	0.563	0.319	1.763	0.078
BME: GestureDeicticIconic:modSpeechOnly [a]	0.044	0.355	0.125	0.901
BME: GestureIconicConv:modSpeechOnly [a]	0.129	0.381	0.339	0.735
BME: GestureDeicticIconic: modReinforcing [b]	-0.403	0.345	-1.168	0.243
BME: GestureIconicConv: modReinforcing [b]	-0.151	0.306	-0.492	0.623
BME: GestureDeicticIconic: modGestureOnlySupp [c]	-0.109	0.212	-0.515	0.606
BME:GestureIconicConv: modGestureOnlySupp [c]	-0.059	0.194	-0.305	0.760

Note. Lines in bold represent statistically significant predictors with *p* values below .05. [a] reflects the planned comparison [a] between SO vs. GO, REINF and SUPP; [b] represents the planned comparison [b] between REINF vs. GO and SUPP; [c] represents the planned comparison between SUPP vs. GO.

Appendix G. ***Predicted probabilities of performance for all children as a function of their balance of multilingual exposure, in the items with a gesture (i.e., modality gesture-only, reinforcing and supplementary speech-gesture combinations combined), and without (i.e. speech-only modality)***



Appendix H. ***Post-hoc investigation of ceiling effects***

Output of the statistical model for Balance of Multilingual Exposure on children who performed below 95% of accuracy (N = 39)

	β	Std. Err	Z value	*p*
(Intercept)	**2.329**	**0.261**	**8.928**	**< .001**
BME	-0.032	0.100	-0.315	0.753
gestureDeicticIconic	-0.029	0.258	-0.113	0.910
gestureIconicConv	-0.393	0.259	-1.516	0.129
modSpeechOnly [a]	**-0.575**	**0.200**	**-2.879**	**< .001**
modReinforcing [b]	**-0.862**	**0.178**	**-4.837**	**< .001**
modGestureOnlySupp [c]	-0.073	0.129	-0.567	0.571
SCQ_score	-0.092	0.092	-1.002	0.316
Age	**0.285**	**0.098**	**2.907**	**0.004**
Sex_birth	0.187	0.218	0.859	0.390
SES	**0.199**	**0.082**	**2.439**	**0.015**
Non-verbal_IQ	-0.188	0.103	-1.836	0.066
Language_skills	0.095	0.096	0.989	0.323
Lang_ENGLISH	-0.157	1.139	-0.138	0.890
Lang_FRENCH	-0.961	0.897	-1.071	0.284
Lang_ITALIAN	-0.066	0.999	-0.066	0.947
Lang_GERMAN	2.046	2.232	0.917	0.359
BME: gestureDeicticIconic	-0.173	0.199	-0.868	0.386
BME: gestureIconicConv	0.034	0.199	0.169	0.866
BME: modSpeechOnly [a]	0.283	0.160	1.767	0.077
BME: modReinforcing [b]	-0.174	0.140	-1.247	0.213
BME: modGestureOnlySupp [c]	-0.002	0.088	-0.026	0.979
GestureDeicticIconic: modSpeechOnly [a]	-0.114	0.462	-0.246	0.806
GestureIconicConv: modSpeechOnly [a]	-0.897	0.506	-1.773	0.076
GestureDeicticIconic:modReinforcing [b]	-0.032	0.451	-0.072	0.943
GestureIconicConv: modReinforcing [b]	-0.300	0.426	-0.704	0.481
GestureDeicticIconic: modGestureOnlySupp [c]	-0.255	0.326	-0.783	0.434
GestureIconicConv: modGestureOnlySupp [c]	0.455	0.311	1.463	0.143
BME: GestureDeicticIconic:modSpeechOnly [a]	0.008	0.361	0.022	0.982
BME: GestureIconicConv:modSpeechOnly [a]	0.257	0.409	0.628	0.530
BME: GestureDeicticIconic: modReinforcing [b]	-0.477	0.361	-1.322	0.186
BME: GestureIconicConv: modReinforcing [b]	-0.101	0.330	-0.307	0.759
BME: GestureDeicticIconic: modGestureOnlySupp [c]	-0.239	0.230	-1.038	0.299
BME:GestureIconicConv: modGestureOnlySupp [c]	0.102	0.210	0.488	0.626

Note. Lines in bold represent statistically significant predictors with *p* values below .05. [a] reflects the planned comparison [a] between SO vs. GO, REINF and SUPP; [b] represents the planned comparison [b] between REINF vs. GO and SUPP; [c] represents the planned comparison between SUPP vs. GO.

In this study, the effect of multilingual exposure on gesture comprehension found in neurotypical children (**Section 4.2**) was not demonstrated in the autistic sample (**Section 4.3**). Children with ASD showed relatively good performance on the task, irrespective of their multilingual exposure. These findings indicate that bilingual exposure did not seem to significantly enhance or hinder their ability to interpret co-speech gestures. Instead, age and general language skills emerged as the strongest predictors of gesture comprehension in autism, highlighting the close relationship between language development and non-verbal communicative abilities (Capone & McGregor, 2004; Choi & Rowe, 2024; Kilili-Lesta et al., 2022; Singleton & Shulman, 2014).

The absence of an effect in the autistic population could have stemmed from the greater variability in performance that these children exhibited. Indeed, differences in individual language profiles within ASD may have obscured potential benefits of multilingual exposure at the group level.

These three studies provide new insights about gesture comprehension in both neurotypical and autistic children with varying balance in their multilingual exposure. Firstly, while neurotypical children showed slight advantages in combining gesture with speech, autistic children also performed relatively well, suggesting minimal repercussions for daily functioning (**Section 4.1**). Secondly, multilingual exposure appeared to confer a specific advantage for iconic gesture comprehension in neurotypical children (**Section 4.2**), but did not have the same impact in autistic children (**Section 4.3**). Taken together, these findings suggest potential benefits in NT children and challenge concerns about a detrimental impact of dual-language exposure on communication in autism (e.g., Howard et al., 2021; Yu, 2013).

In the next chapter, I turn to another area potentially affected in ASD and argued to be boosted by bilingualism in neurotypical children: metalinguistic awareness.

5 METALINGUISTIC AWARENESS

5.1 METALINGUISTIC AWARENESS IN AUTISM

Autistic individuals exhibit diverse linguistic profiles and heterogeneous morphosyntactic abilities (see **Section 2.1.2**), ranging from no impairment to subtle difficulties and persistent challenges in syntactic and grammatical aspects of language. However, little is known about how autistic children *reflect* on morphosyntactic features. This thesis, therefore, aims to investigate metalinguistic awareness at the *morphosyntactic* level through a task that also engages *metasemantic* knowledge: a 'two-dimensional' Grammaticality Judgment Task (GJT). In this **Section 5.1**, I will explore whether school-aged autistic children, in comparison to their neurotypical peers, demonstrate differences in grammaticality judgment, particularly in cases where meaning may be misleading.

The dual nature of the GJT allows for a more in-depth investigation of both cognitive and linguistic aspects of metalinguistic performance. Consequently, it has been widely used in neurotypical children to examine how multilingual experience influences linguistic and cognitive processes (Bialystok, 1988, 2024; Bialystok & Ryan, 1985; Cromdal, 1999). In **Section 5.2**, I will investigate whether bilingualism effects on two-dimensional GJTs are confirmed in neurotypical children, and present in autistic children. In doing so, I continue exploring how language experience influences metalinguistic awareness in these populations.

This section first examines metalinguistic awareness in autistic children before turning to the effects of bilingualism in **Section 5.2**. This work has been published in the *Journal of Autism and Developmental Disorders* (2024).

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ORIGINAL ARTICLE

Exploring Metalinguistic Awareness in School-Aged Autistic Children: Insights from Grammatical Judgment

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Abstract
Metalinguistic awareness, the ability to manipulate and reflect upon language, remains largely unexplored in the autistic population. To address this gap, this observational cross-sectional study examines the metalinguistic abilities of school-aged autistic children in comparison to neurotypical peers in a novel tablet-based Grammatical Judgment Task (GJT) of reduced linguistic complexity engaging two kinds of metacognitive resources. Children had to judge non-verbally whether pre-recorded sentences were grammatically correct or not, following the traditional GJT paradigm assessing *metamorphosyntactic* skills. In addition, sentences with anomalous meaning that were either grammatically correct or grammatically incorrect were introduced to test *metasemantic* knowledge. Findings reveal no difference in performance between the groups, with participants performing on average above chance level both on the sentences assessing mere metamorphosyntactic skills and on the sentences placing an additional demand on metasemantics. This study shows that autistic individuals are able to mobilize metalinguistic resources when tested via a task of reduced linguistic complexity.

Keywords Autism · Metalinguistic awareness · Grammatical judgment task · Morphosyntactic awareness · Semantic awareness

Autistic individuals experience challenges in communication and social interactions (American Psychiatric Association, 2013), including difficulties using language in context (i.e., pragmatics) (Bartak et al., 1975). Much work striving to establish communicative profiles in individuals with Autism Spectrum Disorder (ASD)[1] has focused on these pragmatic impairments, but less is known about how they understand, evaluate, and manipulate language beyond social contexts (i.e., metalinguistic awareness), another important communicative skill which is the focus of the current study. To begin, we will describe metalinguistic awareness, highlight its importance for communication and language, and explain why it is relevant to further investigate this ability in school-aged autistic children. Then, we will undertake an experimental study of children with ASD, who reportedly struggle more with meaning than form (Naigles & Tek, 2017), and thus we expect to show relatively strong *metamorphosyntactic* abilities as compared to their *metasemantic* skills.

Metalinguistic awareness refers to the ability to reflect on language as an object of thought (Tunmer & Herriman, 1984). This awareness implies distancing oneself from language (Ramirez et al., 2014), so as to be able to evaluate and manipulate linguistic elements at different levels: for instance, *morphosyntactic awareness* is activated when detecting and correcting grammatical mistakes (Gombert, 1990); *semantic awareness* is involved when one is able

[1] Both person-first and identity-first language will be used indistinctively throughout the manuscript to refer to individuals with an Autism diagnosis, so as to reflect the variety of preferences amongst the autistic community (Bottema-Beutel et al., 2021).

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to detach word form from meaning, subsequently enabling the use and comprehension of figurative language. Whether consciously or automatically activated in daily-life interactions, in laboratory-based settings, or in educational environments, metalinguistic awareness involves a range of skills that enable the examination of language structure and use beyond the realms of language production and comprehension (Sinclair, 1986).

The impact of these higher-order skills is not limited to language in and of itself – be it written or oral – but extends to communication in a broader sense. In view of its importance for effective communication, the study of metalinguistic awareness in populations experiencing communication challenges, such as individuals on the Autism Spectrum, seems particularly relevant. Indeed, these abilities play a crucial role not only in understanding the linguistic message within a communicative context but also in grasping the nuances of the interactional context, as well as the hidden intention(s), to formulate an adequate response. Metalinguistic awareness is constantly mobilized to repair miscommunications, adapt to the conversation and to the communicative partners (Patterson, 2011). For the speaker, notably, being able to detect grammatical mistakes in a sentence is the first step for self-correction, which will foster message intelligibility and discourse coherence maintenance for the interlocutor. Being able to spot grammatical mistakes such as morphological omissions or word reversal, can also inform and advise a speaker about the language proficiency of their communicative partner (e.g., presence of a language impairment, use of another language variety, partner's register preference). Just like body language interpretation and facial emotion processing, this enables capturing all the cues of a communicative situation and allows for smooth adaptation essential for an effective communication. The ramifications of metalinguistic awareness extend beyond that of communication *per se*, being also an important predictor of academic achievement (Al-Ahdal & Almarshedi, 2022), vocabulary learning (Altman et al., 2018; Ramirez et al., 2014), spelling performance (McNeill & Everatt, 2013), and reading comprehension (Dong et al., 2020).

In an attempt to better characterize this construct (Bialystok, 2001; Sinclair, 1986), Bialystok & Ryan (1985) identified two crucial dimensions involved in metalinguistic activities within a cognitive framework: *(linguistic) knowledge analysis*, referring to the knowledge of the formal aspects of the language, and *cognitive control (of linguistic processes)*, corresponding to the ability to pay attention to and to monitor these specific linguistic representations, including in ambiguous or misleading contexts (Bialystok, 1986; Bialystok & Ryan, 1985). These resources are deemed to be present in every metalinguistic task, albeit to various degrees: in the case of a morphological awareness task for instance, Friesen and Bialystok (2012) explain that increasing demands in *analyzed knowledge* can be gradually manipulated by varying the degree of complexity of the linguistic information to be judged, or in asking an individual to locate the (potential) grammatical mistake, correct it or/and justify their answer verbally, rather than "just" asking for a judgment. Different levels of *control* can be set by manipulating the task's cognitive complexity, such as adding salient distracting information that needs to be ignored to perform adequately on the task (Friesen & Bialystok, 2012). While the authors themselves retrospectively qualify the terms *analysis* and *control* as "poor choices" (Bialystok, 2024, p. 1), these terms nevertheless reflect the intertwinement and the importance of both the cognitive and linguistic components at play: Metalinguistic tasks are neither purely linguistic nor purely cognitive, as in grammatical judgment tasks for instance, both representations of the linguistic structures and tuning attention to these representations are arguably required to perform successfully (Bialystok, 2024).

Assuming that these abilities are indeed inherent to any task testing a form of metalinguistic awareness, it is evident that a certain level of linguistic and/or cognitive development may be required to perform successfully (Cummins, 1978; Edwards & Kirkpatrick, 1999). Indeed, these higher-order linguistic skills mature over time, emerging during the later phases of language development and build upon prior linguistic knowledge (Duncan et al., 2009). While some studies identify early signs of metalinguistic awareness in children as young as three years old (Patterson, 2011; Sinclair, 1986), the majority of studies suggest that these skills begin to emerge when children enter primary school at around five to six years old, and continue to develop gradually throughout childhood (Melogno et al., 2022) and even beyond (Edwards & Kirkpatrick, 1999). A pivotal milestone is identified around the age of seven, indicating an important improvement in metacompetence, likely linked to broader general cognitive development (Cummins, 2014; Roehr-Brackin, 2024).

Despite its relevance for successful communication and its ubiquity in everyday life, metalinguistic awareness has been rarely explored in neurodivergent populations, such as Autism Spectrum Disorder, for whom communicative challenges have been specifically identified as a diagnostic criterion in the DSM-5 (American Psychiatric Association, 2013). There have been numerous attempts to better characterize the linguistic profiles of children on the spectrum (Tager-Flusberg, 2006; Tager-Flusberg & Joseph, 2003), which have led to accurate depictions of the heterogenous phonological, lexical, morphosyntactic and pragmatic abilities of autistic individuals (Schaeffer et al., 2023; Silleresi, 2023; Sukenik & Tuller, 2023); however, there is still a gap

in our understanding about whether and how autistic individuals evaluate, manipulate, and reflect upon language at these different levels. Indeed, unlike children with Typical Development (TD) who may develop these later-emerging metalinguistic skills through typical language acquisition processes in interraction with cognitive and educational factors (Melogno et al., 2022), children with ASD often experience atypical language and cognitive development trajectories (Kissine et al., 2023; Tager-Flusberg, 1999), which could potentially impact the growth and integrity of metalinguistic knowledge.

A preliminary study assessing metalinguistic ability in general revealed that twenty autistic children aged nine to seventeen years old performed significantly below their 18 aged-matched neurotypical peers of similar cognitive abilities, in a range of standardized tasks involving complex linguistic skills at the morphosyntactic and semantic levels, such as inferential language understanding and ambiguity resolution tasks (Lewis et al., 2007). While this was taken to suggest that autistic individuals may face difficulties in the realm of metalinguistic abilities, the study did not include any direct assessment of the participants' structural linguistic skills, such as their current receptive vocabulary breadth or receptive morphosyntactic skills. As such, this omission leaves open the possibility that these skills could have influenced the participants' metalinguistic performance, given the reported decisive role of structural linguistic skills in metalinguistic awareness tasks, particularly at the semantic level (Kalandadze et al., 2018), or at the lexical and morphosyntactic levels (Smith & Tager-Flusberg, 1982). Additionally, it is worth noting that half of the tasks in the study by Lewis and colleagues required a verbal response, a modality that could penalize children with language impairment, who are estimated to represent more than two-thirds of the autistic population (Rapin & Dunn, 2003).

In the limited literature on metalinguistic awareness in autistic individuals, *metasemantic* awareness might be the most extensively documented, driven by a substantial body of literature exploring how children with ASD understand figurative language (e.g., sentences with non-literal meaning, irony, metaphors, idioms), where the intended meaning differs from the litteral utterance (e.g., exclaiming "What a lovely day!" when it is raining). Recent reviews and meta-analyses consistently highlight deficits in mastering these complex higher-order skills among autistic individuals (Kalandadze et al., 2018; Melogno et al., 2022; Morsanyi et al., 2020) in favor of a literalist bias (i.e., tendency to interpret figurative language in a literal way) (Vicente & Martín-González, 2021). Yet, Lampri and colleagues (2023) urge researchers to design and use low-verbal tasks (i.e., with minimal linguistic demands) to accurately capture the specific abilities targeted by the assessment, rather than "their verbal competence *per se*" (p. 12), a strategy applied in psycholinguistic research to reduce the linguistic confound in assessing various cognitive skills such as non-verbal reasoning (Silleresi, 2023), Theory of Mind (Burnel et al., 2018), and executive functions (Kaushanskaya et al., 2017; MacDonald & Christiansen, 2002). The need for "purer" assessments, i.e., devoid of potential confounding factors, has been emphasized in the context of metalinguistic awareness as well: Singson and colleagues (2000), for instance, suggest the use of a Grammatical Judgment Task (GJT) (i.e., during which participants are required to decide whether a heard sentence is grammatically correct or not), instead of a sentence completion task to assess morpho-syntactic awareness in school-aged neurotypical children, thereby avoiding any additional burden on verbal short-term memory (Singson et al., 2000). The careful design of a GJT with a non-verbal response from the participant, offers distinct advantages as it enables the assessment of linguistic and metalinguistic competencies with minimal reliance on language resources. Indeed, previous work has underscored the dual nature of these judgment tasks, which involve both mere structural language abilities and meta-cognitive processing skills (Schachter & Yip, 1990): GJTs require a conscious examination of the linguistic structure via a heightened attention towards the linguistic content, and its comparison to the linguistic representations held in memory, in order to make an explicit accurate judgment. These analytical abilities are deemed to belong to a more general non-linguistic cognitive system (Bever, 1970) and to engage extragrammatical factors (Schachter & Yip, 1990; Tremblay, 2005); thus, they might reflect metacompetence beyond solely linguistic knowledge.

However, despite their potential to inform on metalinguistic abilities, these GJTs have seldom been used in the autistic population, except for two studies focusing on older children aged eleven to thirteen (Ambridge et al., 2015) and adolescents aged ten to sixteen (Eigsti & Bennetto, 2009). When employed, the GJT was primarily used as a tool to specifically assess structural language abilities, aiming to identify whether and which specific morphosyntactic structures might be affected in children with ASD. For instance, Eigsti and Bennetto (2009) used a GJT to more precisely pinpoint subtle grammatical structures with which children and adolescents with ASD may struggle (e.g., present progressive markings). Building on this work, Ambridge and colleagues (2015) reached the same conclusion by showing that children with ASD aged 11 to 13 had difficulties detecting specific grammatical errors (e.g. verb argument structure overgeneralization errors, e.g., *Lisa fell the cup off the shelf) which could not be attributed to more global cognitive delays or even to a potential phonological impairments (i.e., their poorer performance does not stem from being

unable to detect grammatical morphemes). Interestingly, the authors acknowledged that due to the dual nature of the task in solliciting both linguistic and metalinguistic abilities, it is possible that children with ASD "might be impaired not on grammar *per se*, but on the particular paradigm used to assess it in this study" (p. 12), namely a GJT.

The current study seeks to gain a more comprehensive understanding of metalinguistic abilities in children with ASD by taking advantage of Bialystok and Ryan's cognitive framework (1985) and experimental GJT design in other work on bilingual populations (Bialystok, 1986; Bialystok et al., 2014; Hermanto et al., 2012) to decipher the respective performance of autistic and neurotypical children in their *metamorphosyntactic* and *metasemantic* skills in a single GJT. To this aim, a novel GJT which limits the impact of grammar *per se* was created, reducing the lexical and morphosyntactic processing demands inherent to the task (i.e., use of short sentences with simple-clause syntactic structure and simple vocabulary notably) as well as reducing verbal short-term memory load (by adhering to short sentences). Proposing such a GJT with a non-verbal response paradigm further avoids penalizing children with ASD for their expressive and socio-communicative impairments. In addition, the task was developed on a tablet, so as to take into consideration the preference of digital technologies exhibited by the autistic population (Scholle et al., 2020). To gain more knowledge on the participants' *metasemantic* abilities at a surface level and its interaction with *metamorphosyntactic* abilities, sentences with anomalous meaning of either correct, or incorrect grammatical structure, were included. These sentences require participants to make grammatical judgments while ignoring their meaning, a *metasemantic* skill mobilized in the very first steps of pragmatic inferencing: in the case of metaphor understanding for instance, the processing of the literal meaning should be repressed, to subsequently (a) analyse the linguistic elements separately and (b) reconcile the literal anomaly with the intended message. This GJT therefore engages both *metamorphosyntactic* and *metasemantic* skills, because it requires the participant to make the distinction between the morphosyntactic and semantic dimensions of the sentence heard to perform accurately.

Thus, this work explores the metalinguistic skills of 6 to 12 years old autistic children, in comparison to age-matched neurotypical peers and taking their socioeconomic status proxy, non-verbal reasoning and overall receptive morphosyntactic skills into account, using a novel digitalized GJT with reduced linguistic complexity and limited burden in verbal short-term memory. Specifically, this observational cross-sectional study with a case-control design will investigate (1) whether the groups differed in the general performance on the task, and (2) whether this performance was differently impacted by the type of sentence. We hypothesized that children with ASD would perform on par with their non-autistic peers on the traditional part of the task (i.e., they would adequately judge the items that are semantically appropriate but that can contain a grammatical mistake), as the linguistic difficulty of the items has been reduced. However, we predict that autistic children may exhibit poorer performance than the neurotypical children on the part of the task engaging additional *metasemantic* resources (i.e., sentences with misleading odd meaning), given the reported difficulties in processing sentences with odd meaning (Kalandadze et al., 2018; Lewis et al., 2007; Morsanyi et al., 2020).

Methods

Participants

Sample

Thirty-eight autistic children aged 6;2–11;11 (Mean = 9;4; SD = 1;8) and ninety neurotypical children aged 6;0–11;7 (Mean = 8;7 SD = 1;8) took part in the study. The neurotypical children did not have any suspicion or diagnosis of Autism Spectrum Disorder or any other neurodevelopmental disorder. All participants had reported no uncorrected vision and hearing. Prior to the study, all autistic participants had received a diagnosis of ASD, established by a professional clinician (e.g., psychiatrist, psychologist). 68% ($N = 26$) of the autistic individuals had been diagnosed with a standardized tool known to the caregivers (*Autism Diagnostic Observation Schedule (ADOS-2)* (Lord et al., 2012): $N = 21$, *Autism Diagnostic Interview Revised ADI-R* (Lord et al., 1994): $N = 3$, *Vineland Adaptive Behavior Scale (VABS)* (McKinlay, 2011): $N = 1$, *Parents' Evaluation of Developmental Status (PEDS)* (Glascoe, 1997): $N = 1$). For the remaining 32% of autistic participants, parents were able to provide an official report stating the Autism diagnosis and/or participants had scored equal to or above the threshold of 15 on the *Social Communication Questionnaire (SCQ)* (Rutter et al., 2003), an adequate cut-off to confirm a diagnosis in 4–18 years old children (Allen et al., 2007). There was an imbalance in the sex ratio between groups, with more male participants in the autistic group.

Socioeconomic Status

Parental educational level was used as an index for socioeconomic status. This is considered a reliable indicator due to its strong correlation with family income (Hauser & Warren, 1997) and association with children's academic

achievement (Sirin, 2005), brain function and cognitive ability (Cermakova et al., 2023). Parents were asked to select the highest degree of education they had completed, which was then transformed into a value on a 5-point Likert scale: (1) elementary school, (2) middle school, (3) high school, (4) post-secondary degree, (5) university. The higher value between the two caregivers was used for analysis.

Origin of the Sample

As part of an international multi-site project, testing took place in Switzerland, Germany, France, the UK and the US. The participants were tested in either English (9.4%), French (31.2%), German (49.2%), or Italian (10.2%). Given the consistent multilingual effects on tasks involving meta(-morphosyntactic) knowledge (Adesope et al., 2010; Bialystok, 2001), we recorded the participants' linguistic background using the Q-BEx (De Cat et al., 2022), a parental questionnaire enabling a thorough and detailed characterization of the participants' linguistic experiences. Around one-third of each group (36%) was exposed to a second language for more than 20% of their lifetime, a cut-off that has been used in research to define the bilingual group (Hantman et al., 2023). Additional languages children were exposed to are presented in Online Appendix A, detailed descriptive statistics of the sample are reported in Table 1.

Table 1 Descriptive statistics of the sample, cognitive and linguistic measures

	Autistic children (N = 38)	Non-Autistic children (N = 90)
Age (months)		
Mean ± SD	112 ± 20.4	103 ± 20.1
Median [Min, Max]	112 [74.0, 143]	102 [72.0, 139]
Sex assigned at birth		
F	3 (7.9%)	46 (51.1%)
M	35 (92.1%)	44 (48.9%)
Parental educational level (min 1 - max 5)		
Mean ± SD	4.21 ± 1.09	4.57 ± 0.90
Median [Min, Max]	5 [1, 5]	5 [1, 5]
Language of administration		
English	5 (13.2%)	7 (7.8%)
French	17 (44.7%)	23 (25.6%)
German	14 (36.8%)	49 (54.4%)
Italian	2 (5.3%)	11 (12.2%)
Linguistic background		
Monolinguals (Exposure to a 2nd language < 20% lifetime)	24 (64%)	58 (64%)
Multilinguals (Exposure to a 2nd language ≥ 20% lifetime)	14 (36%)	32 (36%)
Receptive morphosyntax (TROG, z-score)		
Mean ± SD	-0.44 ± 1.37	0.12 ± 1.32
Median [Min, Max]	-0.30 [-3.00, 1.60]	0.20 [-3.00, 2.80]
Non-verbal IQ (Raven's 2 score)		
Mean ± SD	98.3 ± 15.5	99.7 ± 12.2
Median [Min, Max]	96.5 [77, 133]	102 [71, 122]

Procedure and Measures

The tasks were part of a larger protocolaiming to test the linguistic and cognitive development of children with ASD. Each participant was individually tested in a quiet room, always accompanied by an experimenter to guide them through the tasks. All tests were administered in one of four language versions (English, French, German and Italian), to enable testing in different regions, and all children were tested in their most proficient language, which they all acquired before the age of three. In addition to the newly created *Grammatical Judgment Task*, participants nonverbal reasoning and receptive morphosyntactic skills were tested.

Grammatical Judgment Task (GJT)

To test metalinguistic abilities at the morphosyntactic and semantic levels, a new GJT was created, inspired by Atchley and colleagues (2006) and later by Bialystok and colleagues' "sentence-judgment task" (Atchley et al., 2006; Bialystok et al., 2014). The GJT was embedded in a so-called serious game designed for tablet use. Tablet assessment was preferred because (1) it fosters *systematic and reproducible testing* by using of pre-recorded instructions, items, and feedback, and enabled control of the quantity and quality of instructions provided to each participant and across language versions; (2) it improves *accuracy* (Germine et al., 2019) by eliminating human error during scoring, as the process was automatized; (3) it allowed the experimenter to act as a partner of the session rather than a "judge" of the participant's abilities, thus circumventing social challenges and additional distress face-to-face interaction impose on autistic individuals (Pinchevski & Peters, 2016); (4) tablet-based interventions and assessments have been proven effective in children with ASD (Alzrayer et al., 2014), who tend to be particularly drawn to digital technologies (Scholle et al., 2020). Participants were presented with a virtual classroom where a human-like 3D female teacher character with natural human voice introduced the task. A friendly little monster appeared on the screen, and participants were told that the monster was a new pupil trying to learn their language, and that they had to help the monster to improve. Participants had to listen to a pre-recorded sentence enunciated by the monster and to select either a picture of a sweet to feed

them (i.e., if the sentence was grammatically correct) or a sock (i.e., if it was grammatically incorrect). It was specified that the monster disliked socks but that it should be corrected when making mistakes so that it could improve. To simplify the instructions and avoid biasing or confusing younger children unfamiliar with the concept, we decided to not use the term "grammatically correct" or "grammar" throughout the task's explanations. Experimenters were allowed to repeat or rephrase the instructions, as close as the given instructions, and to answer the participants' clarification questions. The task started with a familiarization phase of three to six practice items (depending on the participants' performance) with corrective and explanatory feedback, to ensure that the participants understood that the judgment had to be made based on the grammar of the heard sentence. Thirty-two test items arranged in random order were then presented.

GJT Stimuli Specifications

Half of the 32 trials constituted a traditional GJT, with sentences being either grammatically correct ($N=8$) or incorrect ($N=8$), but all semantically appropriate ($N=16$). The grammatical errors could be either of a syntactic nature (i.e., determiner-noun reversal, e.g., "she is picking flowers in *garden the*"), or of a morphological kind (i.e., subject-verb agreement, e.g., "the children buys"). These two errors were selected as they were easily reproducible in all four languages in which the task was created. Moreover, as syntactic errors are easier to detect than morphological ones, by including errors of both types we were able to devise a task that was of alternating levels of difficulty. The other half of the sentences ($N=16$) were either grammatically correct ($N=8$) or incorrect ($N=8$), but semantically anomalous. As in the study by Bialystok et al. (2014), semantic anomaly was created by an impossible or unrealistic pairing of the action with the agent (e.g., "the *shoe* is *cooking*"). Moreover, a considerable effort was made to reduce the linguistic complexity of the task, to avoid penalizing children with linguistic impairments, and to tap into metacompetence rather than linguistic abilities. The sentences were kept short (i.e., between nine to twelve syllables) to limit length effects, which have been reported to have a greater impact on performance in the autistic population (Eigsti & Bennetto, 2009). The sentences were also restricted to a simple clause syntactic structure and contained only verbs in the present tense, as autistic children have been shown to experience difficulties with past tense (Durrleman & Zufferey, 2009; Roberts et al., 2004). Finally, the lexical items were selected from the Mac-Arthur Bates Checklist Inventory MB-CDI (Fenson et al., 1994) and its respective adaptations in all targeted languages i.e., French (Kern et al., 2010), German (Szagun et al., 2014), Italian (Rinaldi et al., 2019), in order to reduce the lexical difficulty to words emerging in the first years of life. The instructions and stimuli were recorded for each language by a native speaker in a sound-proof room, then edited with Audacity software (Audacity Team, 2014) for normalization and voice pitch increase to create a slightly robotic, higher-pitched yet natural voice corresponding to a monster's voice. An example of audio stimulus in each language is available under https://osf.io/wnsdc/?view_only=4baca7db03d24759b4d695b59990c112.

Language Versions

An initial 40-items GJT was created in French (i.e., 10 sentences per sentence type), which was then consequently adapted into English, German, and Italian with the same structure and characteristics to yield comparable GJTs across the four languages. Some lexical items (nouns and verbs) varied between languages, however, to fulfill the criterion of a maximum 12 syllables per sentence. Prior to the study, ten healthy native speakers of the four languages and aged 18–35, with no known neurological history, piloted the task and performed at ceiling, as expected. Consequently, two items per sentence type were removed, resulting in the final 32-item GJT now available in the four languages of interest. All instructions were translated from French, ensuring that the same amount of information was provided to all participants in each language. An example of stimuli is presented in Table 2, and a complete item list in all languages is available in Online Appendix B. One item of the English version was removed from all analyses due to an error subsequently identified in the wording[2].

GJT Scoring

Scoring was automatically collected by the tablet device and stored in a csv file. For each item individually, a score of "1" was allotted to a correct response (i.e., the participant accurately selected the *candy* when the sentence was grammatically correct or the *sock* picture when it was grammatically incorrect, irrespective of the meaning) and "0" for an incorrect response. Only participants who completed all 32 items were considered in the analyses ($N=38$ children with ASD, $N=90$ children with TD). The overall performance for a participant therefore corresponded to the sum of correct responses (i.e., where the value for an item worth "1") on all items, yielding a maximum score of 32 (8 items per sentence type). As judgment had to be made on the grammatical correctness only, there were equal opportunities to select the candy (50% of the trials) and the sock (50%).

[2] We thank an anonymous reviewer for drawing this to our attention.

Table 2 Examples of the four sentence types of the 32-item GJT task, made equivalent in French, English, German, and Italian. There were 8 items per sentence type. Sentences appeared in a random order

	(a) grammatically correct, semantically appropriate	(b) grammatically incorrect, semantically appropriate	(c) grammatically correct, semantically odd	(d) grammatically incorrect, semantically odd
	G + S+	G- S+	G + S-	G- S-
English	Mark goes to the swimming pool with a friend.	Tonight there are clouds and stars in sky *the*.	The *broom* wakes up every morning.	The rain *climb* tonight in the sandbox.
French	Marc va à la piscine avec un ami.	La nuit il y a nuages *des* dans le ciel.	Le *balai* se réveille tous les matins.	La pluie *grimpons* ce soir dans le caillou.
German	Mark geht mit einem Freund ins Schwimmbad.	Es gibt in Nacht *der* Wolken am Himmel.	Der *Besen* wacht jeden Morgen auf.	Der Regen *klettern* heute Nacht in den Stein.
Italian	Marco va al mare con un amico.	Di notte sono stelle *ci* in cielo.	La *scopa* si sveglia la mattina.	La pioggia si *arrampicare* sul sasso

Morphosyntactic Abilities Assessment

The participants were administered the *Test For Reception of Grammar (TROG)* version 2 (Bishop, 2003) and its respective adaptations in French (Lecocq, 1996), German (Fox-Boyer, 2006), and Italian (Suraniti et al., 2009), to assess their general receptive morphosyntactic skills in the language of test. The children listened to pre-recorded sentences of gradually increasing complexity involving various syntactic structures (e.g., negative sentences, "X but Y", "neither nor", relative clause in the subject and in the object, "not only X but also Y", pronoun gender/number, etc.) and were asked to select the appropriate image from four choices displayed on screen. None of the items of the TROG assessed word order reversal nor subject-verb agreement. Given the variations in scoring systems, target structures, and total item numbers across the different language versions, Z-scores were used to allow for comparisons between participants of all languages.

Non-Verbal Reasoning Assessment

A non-verbal IQ score (Mean = 100, SD ± 15) reflecting fluid reasoning was obtained through the short version of the digitalized *Raven's Progressive Matrices Second Edition* (Raven's 2) (Raven et al., 2018). This reliable, relatively short task of graduated complexity requires the participant to select, amongst five choices, the piece of the puzzle that best fits the pattern of a big picture displayed on the screen in which one piece was missing. It has been shown to accurately reflect the non-verbal reasoning skills of autistic individuals across different intellectual profiles (*see* Silleresi, 2023 *for an informative discussion on why this tool is particularly appropriate when testing children with ASD*). The performance of each group on the linguistic and non-verbal measures are presented in Table 1.

Statistical Analyses

To assess whether groups differed in their overall performance, and whether their accuracy was differently impacted by the sentence types, a binomial generalized mixed-effects model with a logit function was implemented and was estimated using LM and BOBYQA optimizer. All statistical analyses were performed in R using R Studio (Version 2023.12.0 + 369) with the lme4 package (Bates et al., 2015).

Model Specifications

Group (children with ASD/children with TD), grammatical correctness (grammatically correct versus incorrect) and semantic appropriateness (semantically appropriate versus semantically odd) were entered as fixed effects, together with two- and three- way interaction between these three factors. The goal was to investigate (1) whether the groups differed in their overall performance, (2) whether the fact that a sentence is either grammatically correct or incorrect *(i.e., grammaticality effect)* or semantically appropriate or inappropriate *(i.e., effect of semantic appropriateness)* impacted the performance, and (3) whether these effects of grammaticality and semantic appropriateness differed between the groups. To ensure that the results were not driven by differences between groups in key variables, the following factors were entered as covariates: biological age (in months), non-verbal IQ (Ravens' 2 score), general receptive morphosyntactic skills (TROG z-score), socio-economic status proxy (Likert scale score 1–5), language of administration (English, French, German or Italian) as well as bilingual status (monolingual/bilingual). The model also had by participant and by item random intercepts, a by item random slope for the effect of group and by participant random slopes for the effects of grammaticality and semantic appropriateness to account for their variability beyond the fixed effects. Additional information on the model selection, contrast coding, and model checks is available in Online

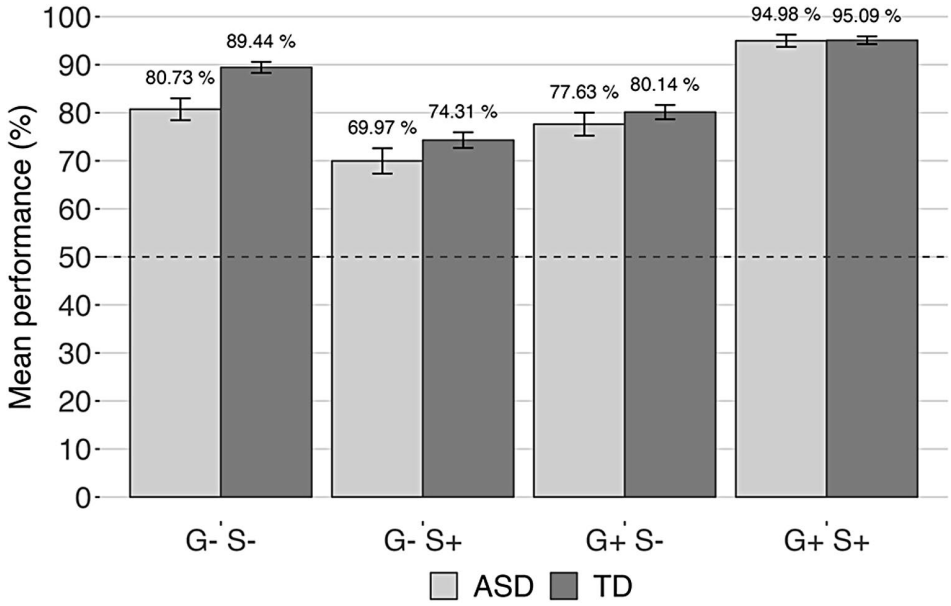


Fig. 1 Performance (i.e., mean of correct responses) per groups and sentence types. G+/G- is used for grammatically correct/incorrect sentences, S+/S- for semantically appropriate/odd sentences. Exact percentages of correct responses are displayed above each bar

Table 3 Fixed effects of the GLMM output

	Performance					
	Odds Ratios	CI	β	Std. Err	Z value	*p*
(Intercept)	15.97	10.13–25.16	2.77	0.23	11.94	**< 0.001**
Group	0.70	0.39–1.26	-0.36	0.30	-1.19	0.24
Gramm_correctness	**0.32**	**0.18–0.59**	**-1.14**	**0.31**	**-3.68**	**< 0.001**
Sem_appropriateness	**0.61**	**0.38–0.96**	**-0.50**	**0.23**	**-2.15**	**0.03**
Group*gramm	0.47	0.17–1.25	-0.76	0.50	-1.51	0.13
Group*sem	0.57	0.31–1.05	-0.56	0.31	-1.81	0.07
Gramm*sem	**29.49**	**10.72–81.11**	**3.38**	**0.52**	**6.56**	**< 0.001**
Age	**2.88**	**2.20–3.77**	**1.96**	**0.14**	**7.74**	**< 0.001**
SES	1.30	0.99–1.70	0.26	0.11	1.90	0.06
Non-verbal IQ	**1.78**	**1.33–2.37**	**0.58**	**1.31**	**3.92**	**< 0.001**
Rec. morphosyntax	1.22	0.99–1.52	0.20	0.92	1.86	0.06
Language_English	0.06	0.00–0.75	-2.84	0.86	-2.18	0.03
Language_French	4.82	0.79–29.26	1.57	0.92	1.71	0.09
Language_German	1.45	0.27–7.79	0.37	0.86	0.44	0.66
Multilingual_status	0.87	0.52–1.48	-0.13	0.27	-0.50	0.62

Lines in bold correspond to significant predictors ($p < .05$)

Appendix C. Complete model formulas are available under https://osf.io/wnsdc/?view_only=4baca7db03d24759b4d695b59990c112.

Results

The two groups seemed to perform above chance level on all sentence types. The group of children with ASD produced on average 19.22% of incorrect responses, while the mean proportion of incorrect response was of 15.24% for the group of children with TD (Fig. 1 – see Online Appendix D for the distribution of performance by group and sentence type).

The model did not show any significant effect of group (β= - 0.36, SE = 0.30, $p > .05$) when accounting for socio-economic status, non-verbal IQ, receptive morphosyntactic skills and the language of test (Table 3). However, age (β = 1.06, SE = 0.14, $p < .001$) and non-verbal reasoning (β = 0.58, SE = 0.15, $p < .001$) were significant positive predictors of the performance. Receptive morphosyntactic skills approached significance level (β = 0.21, SE = 0.11, $p = .05$).

Additionally, a significant main effect of grammatical correctness was found (β = - 1.14, SE = 0.31, $p < .001$), with grammatically correct sentences yielding better performance than grammatically incorrect sentences, be they semantically odd or not. Similarly, a significant effect of

semantic appropriateness was found (β= -0.50, SE = 0.23, $p < .05$), with semantically appropriate sentences exhibiting better performance than sentences with anomalous meaning, irrespective of their grammatical status (Online Appendix E). The non-significant interactions between groups and the effect of grammatical correctness (β= - 0.76, SE = 0.50, $p > .05$) as well as between groups and the effect of semantic appropriateness (β=-0.56, SE = 0.31, $p = .07$) does not enable us to conclude whether groups were differently impacted by these effects. However, the interaction between the effect of grammatical correctness and semantic appropriateness was significant (β = 3.38, SE = 0.51, $p < .001$), suggesting that the effect of grammatical correctness varies depending on the semantic status of the sentence, and vice-versa. In other terms, this translates to a congruency effect, where sentences that are both grammatically correct and semantically appropriate (G + S+) or grammatically incorrect and semantically odd (G - S -) are performed better than incongruent sentences where the two linguistic dimensions are conflicting, i.e., sentences that are grammatically correct but semantically odd (G + S-) and sentences that are grammatically incorrect but semantically appropriate (G - S +). Controlling for all other demographic, cognitive and linguistic variables, the English-speaking participants displayed significantly lower performance than the overall performance of all language groups (β= - 2.84, SE = 1.31, $p < .05$). The English-speaking group indeed exhibited an overall mean performance of 76,7%, while the French-speaking group produced 84.2% of correct response, the German-speaking group 85.2% and the Italian-speaking 79.9%. Post-hoc investigations show that, as expected, sentences containing a syntactic error (i.e., determiner-name reversal) were generally better identified as ungrammatical, in comparison to sentences containing a subject-verb agreement mismatch. This effect was however particularly striking for the English-speaking group, which performed on average below chance level on sentences containing morphological disagreement but not on sentences with syntactic reversal (Online Appendix F).

Discussion

This study explored the metalinguistic awareness skills of 6-to-12 year-old autistic children, by examining their performance in a low-verbal GJT engaging two dimensions of metalinguistic skills (i.e., *metasemantic* and *metamorphosyntactic awareness*) in comparison to age-matched neurotypical peers of comparable receptive morphosyntactic abilities, non-verbal reasoning skills, and socioeconomic status. A logistic mixed effects analysis was conducted to evaluate (1) whether variations in performance between groups were present and (2) whether the type of sentence differently affected their accuracy. Accounting for age, receptive morphosyntactic skills, non-verbal reasoning, and socio-economic status in addition to the language of administration, the model did not show a significant effect of group, neither on the traditional part of the task, engaging *metamorphosyntactic* skills, nor more surprisingly on the part involving an additional demand in *metasemantic* abilities (i.e., sentences with anomalous meaning). These results could suggest a comparable pattern of performance on a metacognitive task between children with ASD and their peers with TD, possibly thanks to being minimally linguistically and cognitively taxing, but it is important to remain cautious given that such an interpretation cannot be confirmed by the absence of significant difference between the groups. Nevertheless, in our task, autistic participants were able to mobilize metacognitive resources, and this ability to judge sentences based on grammatical correctness aligns with previous work conducted in older children with ASD and adolescents (Ambridge et al., 2015; Eigsti & Bennetto, 2009). This ability was primarily observed for shorter sentences, sentences with less subtle grammatical errors, such as word order manipulations, yes/no questions violations, and determiners substitutions and omissions (Eigsti & Bennetto, 2009). Our findings also show that autistic participants can access form as distinct from meaning.

Pertaining to semantic awareness, no difference in comparison to neurotypical peers could be demonstrated on sentences with anomalous meaning, which contradicts the existing literature showing difficulties for autistic individuals in understanding sentences with odd meaning, and dealing with figurative language in general (see Kalandadze et al., 2018; Lampri et al., 2023; Morsanyi et al., 2020). We argue that these seemingly contradictory findings may in fact be the result of methodological differences: as participants in our task were asked to judge the items based on their grammatical content only, and not on their semantic appropriateness, the current task arguably relies less on *metasemantic* resources compared to other tasks used in the previous studies. For instance, formulating two distinct interpretations to resolve the ambiguity in a sentence heard in Lewis et al. (2007)' *ambiguous sentences* subtest might impose a high demand in linguistic skills to understand the sentence and justify one's answer verbally, in addition to an effort in conceptualization and potentially cognitive flexibility to conceive two alternate, plausible solutions. Similarly, processing figurative language such as metaphors is known to require the coordination of complex linguistic and cognitive skills i.e., in (1) processing the actual literal meaning of the sentence, (2) detecting the ambiguity and (3) mapping it with the intended message. Instead, the current GJT mobilized *metamorphosyntactic* and *metasemantic* skills in

having to distinguish form from meaning. In order to more equally flag both linguistic levels in future work, the task should include instructions to judge the sentences based on the meaning, irrespective of the sentences' grammatical status, thus soliciting judgments on both the morphosyntactic and semantic dimensions alternately. Moreover, as our task implicated ignoring potentially misleading meanings in half of the trials, it would have been interesting to explore the extent to which the participants' performance specifically in sentences that are grammatically correct but semantically anomalous is associated with their executive function abilities (i.e., set of higher-order cognitive skills enabling to achieve a goal such as e.g., cognitive flexibility, inhibitory control, working memory (Diamond, 2013), as shown in previous studies investigating multilingual effects on similar tasks targeting metalinguistic awareness (Bialystok & Ryan, 1985; Friesen & Bialystok, 2012). As executive functions have been shown to be impaired in the autistic population (Hill, 2004), exploring their association with metalinguistic awareness might shed light on the underlying mechanisms used by the groups to perform the task. Our findings of seemingly comparable performance on these sentences displayed by our participants with ASD in comparison to TD peers could be explained by relatively high executive functions exhibited by our sample, that could have compensated for difficulties in metacognition – an assumption that would need to be experimentally measured and tested to be ascertained. In addition, the formal, rule-based nature of the semantic anomaly involving the recognition of an animacy disagreement in most of the semantically odd sentences (i.e., as in "the *blanket* is *jumping*"), could have enhanced the autistic participants' preserved accuracy in these sentences[3]. Future research is warranted to specifically investigate this possibility.

For both groups, sentence types were found to play a significant role on the performance: firstly, there was an effect of grammaticality, implying that grammatically correct sentences were better performed than ungrammatical sentences, irrespective of their meaning being appropriate or not. Secondly, an effect of semantic appropriateness was also identified, suggesting that semantically appropriate sentences were better performed than sentences with semantically odd meanings, be they grammatically correct or incorrect. Crucially, the interaction between these two effects resulted in a congruency effect, a well-known effect in psycholinguistic experiments: congruent sentences (i.e., sentences correct in both their grammatical and semantic dimensions (G + S+), or incorrect in both dimensions (G - S -) generated better scores than incongruent sentences (i.e., sentences containing conflicting dimensions where only one dimension is incorrect, as in G + S- and G - S + sentences). This lower performance on incongruent sentences likely highlights the complexity of this task imposed by the intertwinement of the *metasemantic* and *metamorphosyntactic* dimensions. This aligns with the positive main effect of non-verbal reasoning, which was identified as a significant predictor of performance: participants with higher IQ also had better performance in the task. Crucially, both underscore that participants did engage in the task and did not reply randomly, as the scores consistently exceeded chance level[4]. Consistent with previous studies ascertaining a gradual development of metalinguistic awareness (Edwards & Kirkpatrick, 1999; Melogno et al., 2022; Sinclair, 1986), the performance on the task significantly improved with age, after accounting for all other variables.

Despite our best efforts to make the GJT's instructions, structure, and stimuli as similar as possible across all languages of administration, the English-speaking participants did exhibit lower performance in comparison to the other language groups. Beyond the plausible presence of individual differences not captured by the model which could lead to differences in performance, the lower performance of the English-speaking participants could be potentially linked to the experimental material (i.e., the audio stimuli): as compared to the other languages, the English native speaker who recorded the audio stimuli could have spoken faster, plausibly resulting in a greater difficulty to keep track of the information in the sentences and, more specifically, to detect the grammatical errors that were short in duration (i.e., morphological verb-agreement mismatch and syntactic noun-determiner reversal). A more convincing explanation pertains to the lack of detection of the morphosyntactic mistakes in the grammatically incorrect sentences by the English-speaking participants: specifically, post-hoc investigations revealed that English participants did not identify sentences with morphological disagreement above chance level. This can be due to the fact that the -s agreement marker shows variation in its use across different varieties of English where it can be absent (Patrick, 2008; Sedlatschek, 2009; Wolfram & Schilling, 2015), and, when present, is likely to be omitted in language impairment (Brown, 1973; Rice & Wexler, 1996)[5]. This limitation could have only a minimal repercussion on the current findings, and therefore does not cast doubt on their robustness, as the language version was controlled for in being entered as a covariate in the statistical

[3] We thank an anonymous reviewer for evoking this possibility.

[4] A reviewer raised the possibility that some children could have adopted a candy-heavy approach (i.e., systematically selecting the candy instead of the sock to please the monster). Post-hoc analyses revealed that only 3 participants (2 in the group of children with ASD, 1 in the group of children with TD) might have adopted this approach.

[5] We thank the reviewers for their expertise in suggesting this explanation.

model. It nevertheless underscores the challenges of testing in multiple languages (Hambleton & Patsula, 1998; Iliescu, 2017), although this is essential to promote scientific collaborations to achieve larger cohorts and consequently to gain more statistical power *(see* Prévost & Tuller, 2022*for an in-depth discussion of this endeavor in studies on autism)*.

The study's main limitation might stem from the sample constituting the ASD groups: firstly, there were only 38 participants included in the autistic group, as participants had to meet sufficient criteria in terms of linguistic and cognitive (e.g., attentional) resources to complete the entire assessment (GJT, non-verbal IQ test, receptive morphosyntactic assessment). Consequently, only a few participants in our sample presented an intellectual impairment, resulting in a possible selection bias, a common issue ubiquitous in autism research (Russell et al., 2019). Secondly, most of these children were recruited from higher socioeconomic backgrounds, constituting a WEIRD (Western, Educated, Industrialized, Rich and Democratic) sample, limiting its generalizability across diverse cultures and contexts (Henrich et al., 2010). Altogether, these points also raise the question about the representativeness of our sample with respect to the heterogeneity of the linguistic, social, and cognitive profiles in autistic individuals.

Nevertheless, this work offers interesting perspectives in both the educational and research fields: the instruction of morphosyntactic awareness has demonstrated positive effects on literacy development and vocabulary knowledge (Goodwin & Ahn, 2010; Ramirez et al., 2014), even benefiting struggling learners (Deacon et al., 2008) in the neurotypical population. By extending these strategies to children with ASD, who seem to possess a baseline level of morphosyntactic awareness, our study suggests potential advantages for the ASD population. As multilingual effects on metalinguistic awareness have been reliably found in the neurotypical population (Adesope et al., 2010) with bilinguals outperforming monolinguals in a range of tasks of *metamorphosyntactic* and *metasemantic* nature (Ben-Zeev, 1977; Bialystok, 2001; Hermanto et al., 2012), investigating these effects in the autistic population could provide valuable insights into the underlying linguistic and cognitive strategies at play in this growing but understudied population (Beauchamp & MacLeod, 2017; Prévost & Tuller, 2022). Proposing multilingual tools such as the GJT developed for the sake of this study might be particularly suitable to achieve higher cohorts and enable testing in different regions children with various linguistic backgrounds.

To our knowledge, this study is the first to explore *metamorphosyntactic* and *metasemantic* competence of school-aged autistic children in comparison to aged-matched neurotypical peers of comparable non-verbal reasoning and receptive linguistic skills, in a gamified task of reduced linguistic complexity that does not require a verbal response. The current findings seem to suggest that autistic children may be as able as their neurotypical peers to mobilize metalinguistic skills at the morphosyntactic and semantic levels in a task of reduced linguistic complexity.

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Author Contributions PW: Study conception, material creation, data collection, statistical analyses and interpretation, manuscript drafting and writing. FB: material creation, data collection, manuscript review. NR, GC and LN: data collection, manuscript review. SD: project conception, funding acquisition, material creation, data collection, manuscript review. All authors reviewed and approved the manuscript for publication.

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Data and Code Availability Data and code are available on OSF repository, under: https://osf.io/wnsdc/?view_only=4baca7db03d24759b4d695b59990c112.

Declarations

Ethical Approval and Informed Consent All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. This study was approved by the Swiss Association of Research Ethics Committees *Swissethics* (Project ID-2022-00878). All parents provided informed consent their child's participation prior to their inclusion in the study.

Conflict of Interest The authors declare that they have no conflict of interest and have no relevant financial or non-financial interests to disclose.

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Supplementary Material – Online Appendix

Appendix A. Languages multilingual children were exposed to (more than >20% of their lifetime), in addition to the language in which they were tested.

Language of test	**English N=3**	**French N=16**	**German N=23**	**Italian N=4**
Additional languages multilingual participants were exposed to…	German (N=3)	Arabic (N=1)	Chinese (N=1)	Dutch (N=1)
		English (N=4)	Czech (N=1)	German (N=1)
		German (N=4)	Dutch (N=1)	Macedonian (N=1)
		Hungarian (N=1)	English (N=2)	Serbo-Croatian (N=1)
		Italian (N=1)	Italian (N=4)	
		Japanese (N=2)	Portuguese (N=1)	
		Malagasy (N=1)	Russian (N=1)	
		Spanish (N=1)	Spanish (N=11)	
		Swiss-German (N=1)	Swiss-German (N=1)	

Appendix B. Item list in all languages. Blanks refer to initial stimuli that have been removed after the pilot phase with neurotypical adults, so as to keep 4*8 items per language. Original stimuli names have been kept for transparency reasons, to be able to better compare the languages. The item "gramm_sem_8" has been removed from all analyses after a reviewer's suggestion (see footnote 2).

Item	French	English	German	Italian
practice	Tu bois du thé.	You drink tea.	Du trinkst Tee.	Tu bevi il tè
practice	La dame dort.	The woman sleeps.	Die Dame schläft.	La signora sta dormendo
practice	Elle fromage mange.	She cheese eats.	Sie Käse isst.	Lei formaggio mangia
practice	Il pain coupe.	He bread cuts.	Er Brot schneidet.	Lui pane taglia
practice	La balle chante.	The ball is singing.	Der Ball singt.	La palla canta
practice	La table marche.	The table is walking.	Der Tisch läuft.	ll tavolo cammina
gramm_sem_1	Le grand-père jette le mouchoir à la poubelle.		Der Großvater wirft das Tuch in den Mülleimer.	
gramm_sem_2	Le bébé fait la sieste dans le lit.	The baby is taking a nap in a bed.	Das Baby schläft heute im Schlafzimmer.	Il bambino dorme sul' letto
gramm_sem_3	La fille écrit des histoires dans un livre.	The girl is writing stories in a book.	Das Mädchen schreibt Geschichten in ein Buch.	La donna scrive storie in un libro
gramm_sem_4	Tu laves le pyjama dans la machine.	You wash the pyjamas in the machine.	Du wäschst das Hemd in der Waschmaschine.	Tu lavi la giacca in lavatrice
gramm_sem_5			Im Wald gibt es Hasen und Füchse.	C'è un coniglio nel giardino
gramm_sem_6	La grand-mère lit un livre sur un banc.	Grandmother is reading a book on a bench.	Die Großmutter liest ein Buch auf einer Bank.	La ragazza legge un libro
gramm_sem_7	Le docteur fait un sourire au garçon.	The doctor is smiling at the boy.		Il dottore saluta il ragazzo.
gramm_sem_8		~~**The lady raises the hand to say Hello.**~~		
gramm_sem_9	Marc va à la piscine avec un ami.	Mark goes to the swimming pool with a friend.	Mark geht mit einem Freund ins Schwimmbad.	Marco va al mare con un amico.
gramm_sem_10	J'allume la lumière dans le couloir.	I am turning the light on in the hallway.	Ich schalte das Licht im Wohnzimmer ein.	Accendo la luce nella casa
agramm_sem_1 *(agreement)*	Tu préparont une soupe pour le diner.	The man open the door of the house.	Der Herr kochen eine Suppe am Abend.	Tu cucinate la carne la sera.
agramm_sem_2 *(agreement*)		The hen lay eggs every morning.		Le scimmie mangia delle banane
agramm_sem_3 *(agreement)*	Le poisson et le canard nageons dans l'eau.	The duck are swimming in the water.	Die Ente und der Fisch schwimmt im Wasser.	La rana nuotiamo nell'acqua

agramm_sem_4 *(agreement)*	L'enfant achetons des pommes et des bananes.	The children buys bananas.	Das Kind kaufen Eis im Supermarkt.	Il bambino comprano frutta
agramm_sem_5 *(agreement)*	Le pompier conduire le camion sur la route.		Der Feuerwehrmann fährst mit dem Lastwagen.	
agramm_sem_6 *(reversal)*	Tu nettoies la baignoire dans salle la de bains.		Mädchen das spielt vor dem Haus mit dem Ball.	Ragazza la gioca a palla
agramm_sem_7 *(reversal)*		You are cleaning bathtub the in the bathroom.		Maria pulisce cucina la
agramm_sem_8 *(reversal)*	Marie cueille des fleurs dans jardin le.	Mary is picking flowers in garden the.	Theresa fährt mit Zug dem in die Stadt.	
agramm_sem_9 *(reversal)*	Elle porte une robe et chaussures des.	She is wearing scarf a and a dress.	Sie trägt Strumpfhose eine und Kleid ein.	Porta una gonna e scarpe delle
agramm_sem_10 *(reversal)*	La nuit il y a nuages des dans le ciel.	Tonight there are clouds and stars in sky the.	Es gibt in Nacht der Wolken am Himmel.	Di notte sono stelle ci in cielo.
gramm_asem_1	Le balai se réveille tous les matins.	The broom wakes up every morning.	Der Besen wacht jeden Morgen auf.	La scopa si sveglia la mattina
gramm_asem_2				
gramm_asem_3	La chaussure cuisine des spaghettis.	The shoe is cooking spaghetti and eggs.	Der Schuh kocht Spaghetti mit Käse.	La scarpa cucina gli spaghetti
gramm_asem_4	La brosse à dent est fatiguée ce soir.	The toothbrush is tired and wants to sleep.	Die Zahnbürste ist heute Abend müde.	Il telefono è stanco stasera
gramm_asem_5	Les fourchettes et les couteaux jouent dans le parc.	Forks and knives are playing in the park.	Die Gabeln und Messer spielen im Park.	Piatti e tazze giocano nel mare.
gramm_asem_6	Le magasin chante à la radio.	The shop is singing on the radio tonight.	Der Staubsauger singt im Radio.	Il negozio canta alla radio
gramm_asem_7	La bouteille se dépêche et court dehors.	The bottle hurries and runs in the bedroom.	Die Flasche beeilt sich und läuft nach draussen.	La scopa si sbriga e corre fuori
gramm_asem_8				
gramm_asem_9	Aujourd'hui le frigo coupe un gâteau.	Today the fridge is cutting a cake.	Der Kühlschrank schneidet heute eine Torte.	Oggi il forno taglia una torta
gramm_asem_10	Les compotes de fruits écoutent la maitresse.	The kitchen listens to the teacher.	Die Küche hört der Lehrerin zu.	La cucina ascolta la pediatra
agramm_asem_1 *(agreement)*			Die Garage schüttelst die Suppe.	Il bar baciare la caramella
agramm_asem_2 *(agreement)*	L'éléphant dormons avec le bateau.	The elephant sleep with the boat.	Der Elefant schlafen mit dem Boot.	L'elefante dormono con la barca

agramm_asem_3 *(agreement)*	La piscine recevoir un savon au cirque.	The pool is get a soap at the circus.	Der Teich kriegen eine Seife im Zirkus.	La doccia dare un libro al circo.
agramm_asem_4 *(agreement)*	La pluie grimpons ce soir dans le caillou.	The rain climb tonight in the sandbox.	Der Regen klettern heute Nacht in den Stein.	La pioggia si arrampicare sul sasso
agramm_asem_5 *(agreement)*	Les lunettes donnons un genou à la plage.	The glasses gives a knee at the beach.		
agramm_asem_6 *(reversal)*	Le panier attend train le à l'école.	Basket the is waiting for the train at school.	Der Korb wartet auf Zug den in der Schule.	La scopa aspetta treno il
agramm_asem_7 *(reversal)*	La couverture saute sur pommes de les terre.	The blanket is jumping on potato the.	Die Decke springt auf Kartoffeln die.	La coperta salta patate sulle
agramm_asem_8 *(reversal)*	Le facteur glisse fleur la dans le ciel.	The mailman slides flowers in sky the.	Der Briefträger rutscht Blumen in Himmel den.	La parrucchiere si siede cielo nel
agramm_asem_9 *(reversal)*				
agramm_asem_10 *(reversal)*	La veste attend biberon le dans l'escalier.	The jacket waits for the box in staircase the.	Die Jacke wartet auf Flasche die.	La giacca aspetta bottiglia la

Appendix C. Additional information on the statistical approach, including contrast coding, model specifications, checks and assessment.

Variable scaling. All continuous variables were centered around the mean.

Missing data. There was no missing data in the variables age, non-verbal IQ, receptive morphosyntactic score, socioeconomic status, language, and GJT scores: only the participants who completed these tasks entirely were included.

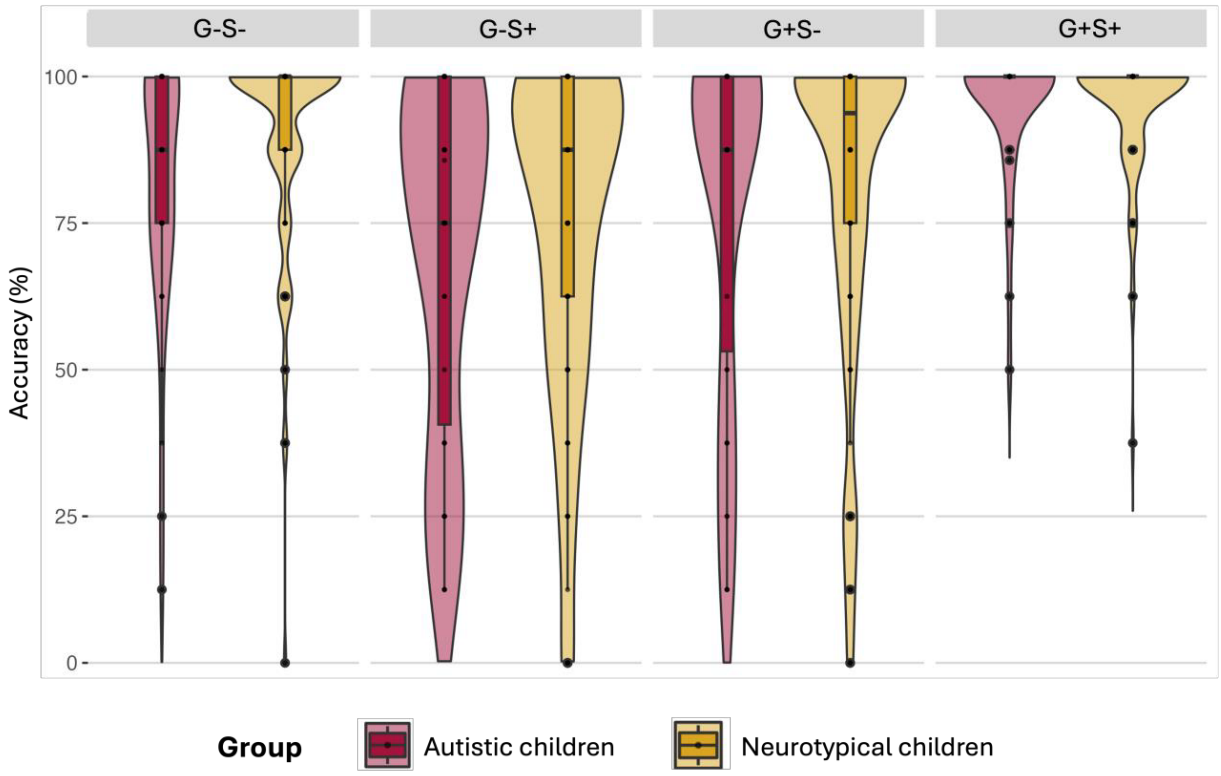
Model checks. Prior to conducting the model, we ensured that there was no potential harmful collinearity between the variables: all variance inflation factors were below 5.

Contrast coding. The group variable was recoded using a scaled sum contrast: children with TD were assigned a value of -0.5, while the group of children with ASD was assigned a value of 0.5; thus, a negative estimate for this variable suggests that the autistic group exhibited lower performance. For the variable *effect of grammaticality*, grammatically correct sentences were assigned a value of -0.5, and 0.5 to grammatically incorrect sentences. Similarly, a value of -0.5 was allocated to sentences with appropriate meaning, while 0.5 was assigned to sentences with odd meaning, for the variable *semantic appropriateness*. In this way, positive estimates for these variables reflect better performance for grammatically correct and semantically appropriate sentences, respectively. Finally, a scaled sum contrast was set to recode the variable *language of administration,* reflecting the language in which the child performed the task to account for different language versions; it allowed for the comparison of each language group against the overall mean of performance in all languages.

Model selection. A first model containing the variables mentioned (i.e., biological age (in months), non-verbal IQ (Ravens' score), general receptive morphosyntactic skills (TROG z-score), socioeconomic status proxy (Likert scale score 1-5), language of administration (English, French, German or Italian) as well as bilingual status (monolingual/bilingual)), as well as a 3-way interaction term between group, grammatical correctness and semantic appropriateness was conducted. The 3-way interaction term was not significant and was therefore removed. The model with two ways interactions did not converge and was simplified by removing the correlations between random intercepts and random slopes, yielding the final model used.

Model assessment. The model's total explanatory power was substantial (conditional R2 = 0.55), and its part related to the fixed effects alone (marginal R2) accounted for 0.34.

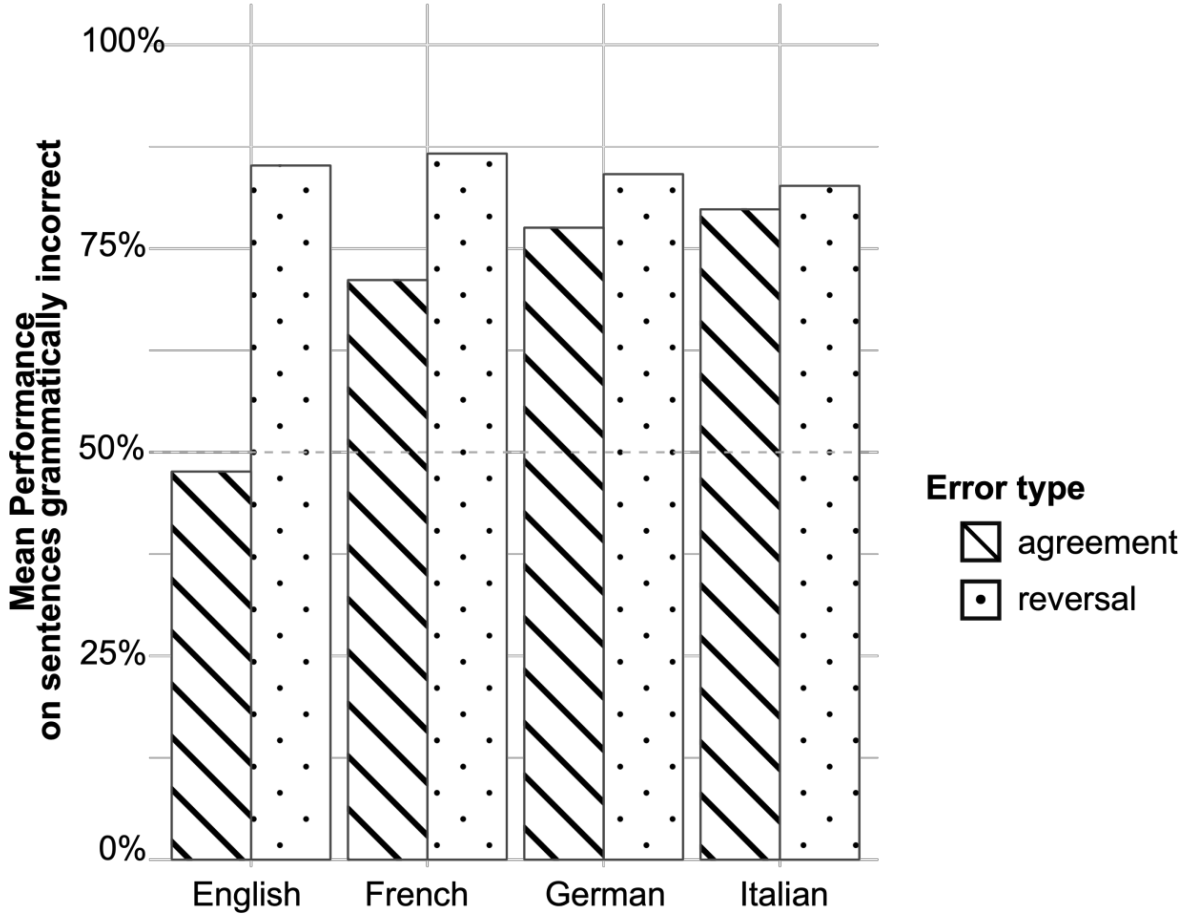
Appendix D. Groups' performance on the four sentence types. G+/G- hold for grammatically correct or incorrect, S+/S- for semantically appropriate or odd, respectively.



Appendix E. Percentage of errors per groups depending on semantic appropriateness and grammatical correctness. G+/G- hold for grammatically correct or incorrect, S+/S- for semantically appropriate or odd, respectively

	G +	**G -**	**S +**	**S -**
Children with TD	12.4%	18.1%	15.4%	15.2%
Children with ASD	13.8%	24.7%	17.6%	20.8%
All children	12.8%	20.1%	16.0%	16.9%

Appendix F. Language groups' performance on grammatically incorrect sentences (N=8 semantically appropriate and N=8 semantically odd), as a function of the type of error it contains (reversal or agreement).



5.2 BILINGUALISM EFFECTS ON METALINGUISTIC AWARENESS IN AUTISTIC AND NEUROTYPICAL CHILDREN

In the previous section, we saw that the modified Grammaticality Judgment Task (GJT) allowed for an examination of metalinguistic ability in autistic individuals at the morphosyntactic and semantic levels. Findings revealed that participants could reliably focus on the morphosyntactic dimension, even in cases where meaning was potentially misleading.

Notably, modified GJTs have also been used in neurotypical bilingualism research to investigate how bilingualism may differentially influence the *cognitive* and *linguistic* abilities involved in the task. Some hypotheses have been proposed about which aspects of the bilingual experience most strongly influence the *linguistic* versus *cognitive* aspects of metalinguistic awareness. For instance, it has been argued that *proficiency in the second language* (L2) plays a crucial role in sentences relying on linguistic knowledge. Conversely, bilingual individuals have also been shown to outperform monolingual peers on sentences requiring cognitive control, irrespective of their L2 proficiency. However, these claims have not been tested directly with a *continuous* measure of L2 proficiency; past studies have relied on group comparisons comparing monolinguals to bilinguals, making it difficult to determine whether proficiency *itself* was the key factor driving the observed effects.

The following study aims to fill this gap by investigating whether the bilingual effects of L2 proficiency on GJT performance observed in neurotypical children can be replicated in our study, and whether these effects also manifest in autistic children. No study to date has examined bilingualism effects on metalinguistic awareness in autistic children, making this investigation a pioneering contribution to the field.

The version presented in this section has been submitted for publication.

Bilingualism effects on metalinguistic awareness: Revisiting the two-dimensional Grammaticality Judgment Task in neurotypical and autistic children

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CrediT author contributions

PW: Conceptualization, Data Curation, Formal Analysis, Investigation, Methodology, Resources, Supervision, Visualization, Writing – Original draft. FB: Conceptualization, Methodology, Data Curation, Investigation, Resources, Supervision, Writing – Review & Editing. SD: Conceptualization, Methodology, Resources, Supervision, Writing – Review & Editing, Project Administration, Funding Acquisition. All authors reviewed and approved the manuscript for publication.

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Declaration of Interest statement

The authors have declared that no competing interests exist.

Compliance with ethical standards

This study was approved by the Swiss Association of Research Ethics Committees *Swissethics* (Project ID-2022-00878), the Institutional Review Board of the University of Connecticut (US), the Research Ethics Board Office at McGill University in Montreal (Canada), the Psychology Research Ethics Committee of the University of Edinburgh (UK), the Institutional Review Board of Emerson College Boston (US), and the Research Ethics Committee of the Unio Catalana Hospitals Foundation (Spain). All parents provided informed written consent for their child's participation prior to their inclusion in the study. All work has been carried out in accordance with The World Medical Association's Declaration of Helsinki for experiments involving humans.

Data availability statement

Data, analysis scripts, and stimulus video examples are openly available at: https://osf.io/kbyc6/ [DOI 10.17605/OSF.IO/KBYC6]

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the author(s) used ChatGPT to assist with revision and proofreading. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.

Abstract

Bilingualism has been associated with enhanced metalinguistic awareness (MA), the ability to reflect upon language. However, findings remain mixed. Little is known about how proficiency in the most proficient language (L1) and second language (L2) contributes to MA, or how these effects generalize across individuals with differing cognitive and linguistic abilities. This study re-examined bilingualism effects on MA in neurotypical children, controlling for L1 proficiency and assessing the role of L2 proficiency, and further tested whether these effects extend to autistic children, who often show greater variability in language and cognition. We tested 270 children aged 5–12 (180 neurotypical; 90 autistic) using a two-dimensional Grammaticality Judgment Task (GJT) requiring two MA components: *analyzed knowledge* (understanding of grammatical rules) and *cognitive control* (suppression of irrelevant semantic cues). Bilingualism was operationalized both categorically (monolingual vs. bilingual) and continuously (L2 proficiency). Generalized linear mixed-effects models controlled for age, non-verbal IQ, and language skills. Among neurotypical children, no bilingual advantage emerged on items requiring *cognitive control*. L2 proficiency did not significantly predict performance, despite a positive trend for items requiring *analyzed knowledge*. In contrast, bilingual autistic children as a group significantly outperformed monolingual peers on items requiring *cognitive control*. L2 proficiency predicted better overall GJT performance in autistic children. These findings refine our understanding of how bilingualism interacts with MA, demonstrating that its effects may vary across cognitive and linguistic profiles. They further underscore the importance of combining categorical and continuous measures of bilingual experience to more precisely capture its cognitive consequences.

Keywords

Bilingualism; Metalinguistic Awareness; Grammaticality Judgment Task; Autism Spectrum Disorder

1. Introduction

Metalinguistic awareness is one of the earliest topics investigated in bilingualism research. Already decades ago, researchers observed that bilingual children tended to outperform their monolingual peers on a range metalinguistic tasks, such as word awareness and grammaticality judgment (Adesope et al., 2010). It has been hypothesized that exposure to multiple language systems may make bilingual children more attuned to the abstract properties of language than their monolingual peers (Ben-Zeev, 1977; Bialystok, 1988). This heightened awareness and focus is thought to train bilinguals to consider language as a formal system, and to examine its properties more closely (Bialystok, 2001; Galambos & Goldin-Meadow, 1990).

1.1. A two-dimensional framework to examine metalinguistic awareness

Metalinguistic awareness – the ability to consciously reflect on language as an object of thought (Tunmer & Herriman, 1984)– plays a central role in linguistic and cognitive development (Patterson, 2011; Pratt & Grieve, 1984). It is essential for effective communication, allowing individuals to adjust their language to different contexts, and repair miscommunications (Patterson, 2011). It is also important for literacy development, as it underpins pivotal skills such as phonological awareness, reading comprehension, and spelling (Apel et al., 2012; Apel & Masterson, 2001; Nagy et al., 2003; Tunmer & Herriman, 1984).

Because 'metalinguistic awareness' represents "*a highly diversified array of knowledge and skills*" (Bialystok, 2024; Scribner & Cole, 1981) the construct generally remains only vaguely defined at a conceptual level. Bialystok and Ryan (Bialystok & Ryan, 1985) introduced a two-dimensional framework to analyze the abilities mobilized in any metalinguistic task more concretely. According to their framework, metalinguistic awareness reflects the interplay between the linguistic knowledge dimension (i.e., called *analyzed knowledge*) that individuals possess in a given language, and the control dimension (i.e., *cognitive control*), corresponding to the individual's control of attentional procedures to attend to these linguistic features, process and manipulate them (Bialystok & Ryan, 1985).

This cognitive framework has been widely adopted in studies comparing monolingual and bilingual school-aged children, aged 5 to 10 (Bialystok, 1986, 1988; Bialystok & Barac, 2012; Bialystok & Majumder, 1998; Cromdal, 1999). In these studies, the traditional grammaticality judgment task (GJT) was modified to impose varying demand in either the *analyzed knowledge* or the *cognitive control* dimensions. Specifically, participants were requested to judge the grammaticality of an auditorily presented sentence (i.e., indicate if the sentence heard was grammatically correct, or incorrect).

In addition, sentences with anomalous meaning were also introduced, resulting in the presentation of four types of sentences, each imposing varying demands on the two dimensions (*analyzed knowledge* or *cognitive control*):

- (1) Sentences that are grammatically correct, and meaningful (i.e., further mentioned as GM). These sentences are considered the easiest because they are congruent (i.e., both the grammar and the meaning are correct), and no error had to be detected.
- (2) Sentences that are grammatically incorrect, and contain a semantic anomaly (i.e., gm).
  While also congruent, these sentences are considered more complicated to parse than the GM sentences, as detecting a grammatical mistake has been shown to be more difficult than identifying grammatically correct sentences (Hakes, 1980; Ryan & Ledger, 1979).
- (3) Sentences that are grammatically correct, but contain a semantic anomaly (i.e., Gm).
  These sentences are considered to impose a higher demand on the *cognitive control* dimension, as they require the participant to ignore the misleading meaning of the sentence to succeed, and to indicate that the sentence is grammatically correct. Processing the meaning of a sentence is indeed automatic and irrepressible (Hakes, 1980).
- (4) Sentences that are grammatically incorrect, but meaningful (i.e., gM).
  These sentences place a greater demand on the *analyzed knowledge* dimension than the other sentences, as they require spotting the grammatical mistakes, without having to ignore the meaning, which is not misleading.

Individual differences in metalinguistic performance can reflect variability in children's proficiency in the language of testing. For bilingual children, proficiency in the test language has been shown to support metalinguistic tasks such as grammaticality judgments, where a stronger linguistic foundation allows for more accurate analysis of sentence structure (Bialystok & Barac, 2012). This perspective aligns with the *Interdependence Hypothesis* (Cummins, 1991), which posits that linguistic and conceptual knowledge can transfer across languages, provided there is sufficient exposure and motivation. Proficiency in one language may therefore support metalinguistic awareness in another through a shared underlying proficiency. Importantly, this transfer is bidirectional, allowing for cross-linguistic development in both languages (Verhoeven, 2007). Metalinguistic awareness, therefore, is not confined to L1 or L2 in isolation, but develops through dynamic interaction between the two. Linguistic knowledge involves increasingly explicit representations of language rules, a knowledge that strengthens with language development and can be enriched through exposure to multiple linguistic systems (Bialystok, 1988; Tunmer & Herriman, 1984). Metalinguistic skills therefore emerge not only from the proficiency in a single language, but also from the comparative insights gained by navigating structural differences between languages (Kuo & Anderson, 2006). Together, these perspectives suggest that

language skills in each language may contribute to the development of metalinguistic awareness, and that variability in either may help explain individual differences in performance.

1.2. Bilingualism effects on GJT

1.2.1. Bilingualism effects in neurotypical children

Findings from the two-dimensional paradigm suggest that effects of bilingualism on metalinguistic awareness may be different depending on the dimension under consideration (*analyzed knowledge* versus *control*), and the participants' 'degree of bilingualism', in the sense of their proficiency in their second language (L2).

Pertaining to the *cognitive control* dimension (i.e., performance in Gm sentences), bilingual children have been reliably shown to outperform monolinguals across studies (Bialystok, 1986, 1988; Bialystok & Majumder, 1998; Cromdal, 1999). This advantage appeared regardless of the bilingual's level of second-language (L2) proficiency in a study (Bialystok & Majumder, 1998), while another work showed that only bilinguals with high proficiency in their L2 (and not bilinguals with lower L2 proficiency), outperformed monolingual peers (Cromdal, 1999). Notably, bilingual children have been found to perform better on Gm sentences, placing higher *cognitive demand,* than on gM sentences involving more *analyzed language* (Bialystok, 1986). For monolingual participants, however, the opposite pattern has been reported (i.e., better performance on gM sentenced than Gm sentences), suggesting a tendency to prioritize the processing of meaning and a reduced ability to inhibit semantic interference. These findings suggest that monolingual and bilingual children may adopt different strategies when performing the task (Bialystok, 1986). Researchers hve suggested that the confrontation and management of multiple languages would lead to the better performance in Gm sentences (Barac & Bialystok, 2012).

Bilingualism effects on gM sentences (i.e., engaging more *analyzed knowledge*) are relatively mixed. Some studies have reported no significant differences between bilingual and monolingual groups on gM sentences (Bialystok, 1986; Bialystok & Majumder, 1998), suggesting that bilingualism *per se* does not necessarily confer an advantage in those items. In contrast, some studies have reported bilingual advantages on gM sentences, particularly when bilingual children demonstrate high L2 proficiency: In Bialystok (Bialystok, 1988), 6-7 year-old bilingual children significantly outperformed monolingual peers on gM items (Bialystok, 1988). Cromdal (1999) further showed that *balanced bilinguals* with high proficiency in both languages, outperformed not only monolinguals but also *partially bilinguals* with lower L2 proficiency (Cromdal, 1999), suggesting a positive impact of L2 proficiency on *analyzed knowledge*. According to Bialystok (Bialystok, 1988), possessing '*some sufficient*' level of linguistic knowledge in the L2 is required to see an effect emerge on sentences involving greater demand on *analyzed knowledge.* As the author mentions: "*knowing 'more' of the second language is a necessary condition*' [leading to advances in linguistic analysis](Bialystok, 1988). Yet, it remains unclear what

minimal level of L2 proficiency is required to find an advantage for sentences with additional *analyzed knowledge* demands relative to monolinguals.

While previous research has often highlighted the role of L2 proficiency in metalinguistic performance, its impact has not been directly tested. Instead, children were typically divided into monolingual and bilingual groups based on the presence of a second language. Bilinguals were further categorized as 'highly bilingual' or 'partially bilingual' according to their L2 proficiency, generally indexed by receptive vocabulary scores (Bialystok, 1988; Cromdal, 1999). However, such categorical grouping could mask important interindividual variability in L2 proficiency. Methodological variability in previous studies may have further obscured the role of L2 proficiency. In some cases, subgroups of children were tested in their weaker language (Bialystok & Majumder, 1998); in others, results from the GJT conducted in both L1 and L2 were merged (Bialystok, 1988); sometimes, effects were found only in the weaker language but not in the most proficient one (Cromdal, 1999). Such inconsistencies may limit the ability to isolate the impact of L2 proficiency on performance in tasks administered in the most proficient language (L1).

Reflecting these methodological concerns, researchers advocate for adopting continuous measures or group-based approaches when appropriate, emphasizing that methodological choices should be theoretically justified, hypothesis-driven, and grounded in existing literature to provide a more nuanced understanding of bilingualism's effects on cognition and language (De Houwer, 2023; Kremin & Byers-Heinlein, 2021; Luk, 2015).

1.2.2. Bilingualism effects in autistic children

While bilingualism is often associated with advantages in MA, how these effects manifest across individuals with varying linguistic and cognitive profiles remains an open question. Children with autism spectrum disorder (ASD) experience reportedly challenges in both linguistic and cognitive domains (American Psychiatric Association, 2022; Silleresi, 2023), making them an informative group for investigating if bilingualism can influence MA despite these challenges. While autistic children often present language impairments (Rapin & Dunn, 2003; Schaeffer et al., 2023; Silleresi, 2023) and executive function deficits (Craig et al., 2016; Leung et al., 2016), their metalinguistic abilities in fact remain underexplored. A preliminary study found that autistic children aged 9 to 17 year-old presented difficulties in comparison to NT peers, in a range of tasks assessing metalinguistic competence including the understanding of inferential language and the resolution of ambiguity (Lewis et al., 2007). More recent work using a two-dimensional GJT requiring non-verbal answers showed no difference between autistic school-aged children and their age-matched NT peers, suggesting that children with ASD may be able to mobilize metalinguistic knowledge when language complexity is reduced (Wolfer et al., 2024).

Investigating bilingualism in both autistic and NT children provides an opportunity to assess whether previously established patterns of results hold across populations with distinct cognitive and linguistic profiles. It would allow for a broader understanding of how linguistic and cognitive variability

influence metalinguistic skills, by clarifying the role of individual differences in language proficiency and cognitive abilities. This perspective aligns with recent theoretical recommendations emphasizing the need to consider bilingualism as a heterogenous rather than uniform experience (de Bruin, 2019; de Bruin & Hayiou-Thomas, 2022). Finally, it would provide valuable insights into the impact of bilingualism on autism, which also had practical societal applications as parents often fear that dual language exposure may exacerbate the linguistic, cognitive, and communicative challenges their children face (Drysdale et al., 2015; Howard et al., 2021; Yu, 2013).

1.3. The present study

1.3.1. Purpose

In the current work, we aim to refine previous work investigating the effects of bilingualism on metalinguistic awareness in school-aged NT children, to clarify the role of L2 proficiency. We also extend this investigation to children with ASD, presenting greater variability in their cognitive and linguistic profiles. Specifically, we adopt the *cognitive framework*, so far applied exclusively to NT children to (1) confirm whether the reported effects of bilingualism are replicated in a sample of NT children aged 5 to 12, (2) examine the direct effect of L2 proficiency on metalinguistic performance, and (3) determine whether these effects also apply to their age-matched peers with ASD. The age range of 5 to 12 years was selected to cover the years in which children develop their metalinguistic skills (Bialystok, 1986; Edwards & Kirkpatrick, 1999; Melogno et al., 2022), corresponding to the primary school years.

1.3.2. Research questions

Specifically, three research questions (RQ) will be examined, both in autistic and neurotypical children.

- ***RQ1****: Do NT and autistic bilinguals outperform monolinguals peers in MA requiring cognitive control (i.e., Gm sentences)?*

According to Bialystok and Majumder (Bialystok & Majumder, 1998), NT bilinguals would outperform their monolinguals peers, regardless of their L2 proficiency, that is: participants exposed to a second (and even third) language would obtain better Gm performance than participants exposed to only one language. A bilingual advantage in Gm sentences over monolinguals would be also consistent with work by Bialystok (Bialystok, 1986, 1988).

In order to more directly and precisely assess the impact of L2 proficiency on MA requiring *cognitive control*, we addressed the second research question as follows:

- ***RQ2****. How does L2 proficiency impact performance on MA requiring cognitive control (i.e., Gm sentences) in NT and autistic children?*

This approach follows contemporary recommendations of bilingual operationalization (De Houwer, 2023; Kremin & Byers-Heinlein, 2021; Rothman et al., 2023), and enables to capture inter-individual differences on the proficiency dimension, that former group comparisons of *high*- and *low*- *L2-proficiency* children may have masked. We predicted that children with greater L2 proficiency would outperform

children with lower L2 proficiency on Gm sentences, according to the study by Cromdal et al. (Cromdal, 1999) showing that only bilinguals with high L2 proficiency, but not those with lower L2 proficiency, performed better than monolinguals.

Finally, to clarify the role of L2 proficiency on *analyzed knowledge*, so far also only indirectly tested with monolingual vs. *high-* and *low-L2* bilingual groups comparisons, we asked:

- ***RQ3****. How does L2 proficiency impact performance in MA requiring analyzed knowledge (i.e., gM sentences) in NT and autistic children?*

In the neurotypical group, we predicted that L2 proficiency would positively impact performance in analyzed knowledge (Bialystok, 1988): Greater L2 proficiency would lead to better performance on gM sentences. Alternatively, an absence of effect of L2 proficiency is also possible (Bialystok, 1986; Bialystok & Majumder, 1998).

To date, this is the first study to examine the effects of bilingualism on metalinguistic awareness in children with ASD. Given the novelty of this research, our investigation was exploratory, and no specific predictions were made. However, we anticipated greater variability in performance among autistic children compared to their neurotypical peers. This expectation reflects the considerable heterogeneity in ASD (American Psychiatric Association, 2022), particularly in non-verbal IQ (Silleresi, 2023) and executive functioning (Craig et al., 2016; Demetriou et al., 2019), which are likely to influence performance on tasks requiring *cognitive control* (Bialystok & Barac, 2012), and in language skills (Schaeffer et al., 2023), which may affect performance in *analyzed knowledge* (Bialystok & Barac, 2012).

2. Method

2.1. Participants

2.1.1. Groups

Participants were prospectively recruited between 3 January 2023 and 31 August 2024. All parents provided written informed consent for their child's participation.

The data of N = 270 children between 5 and 12 years old were analyzed in this study (see *Table 1* for the sample characteristics); N = 90 autistic children (9;1 ± 1;9 years), and N = 180 NT children (8;6 ± 1;11 years). In the autistic group, the median socioeconomic status score was 4 on a 5-point Likert scale, indicating that most parents had completed postgraduate education. In the NT group, the median socioeconomic status score was 5, suggesting that most caregivers had attended university. None of the children had any visual or auditive impairment.

Autistic participants had an official diagnosis of autism spectrum disorder established by a certified professional prior to the study inclusion with standardized tools (e.g., *Autism Diagnosis Observation Schedule 2nd Edition*; *ADOS-2* (Lord et al., 2012), *Autism Diagnosis Interview-Revised;* ADI-R (Lord et al., 1994)). Neurotypical children had no diagnosis or suspicion of neurodevelopmental disorder

of any kind. All caregivers filled in the *Social Communication Questionnaire* (SCQ; Rutter et al.,(Rutter et al., 2003)), a 40-items parental questionnaire enabling to screen for autistic traits. Neurotypical children all scored below the 15 cut-off and presented, as expected, a lower average score than their autistic peers (W = 14924, *p* <.001). There was an imbalance in the sex ratio between groups, with a greater proportion of males in the autistic group (84%) compared to the neurotypical group (49%), which is consistent with the higher prevalence of autism in males typically observed in ASD research. On average, neurotypical participants were younger than their autistic peers (Mean age in ASD: 9;1 ± 2;10, NT: 8;6 ± 1;11; W = 9399, p = .03), and presented higher receptive vocabulary skills (measured with the *Peabody Picture Vocabulary Test* (Dunn & Dunn, 2007); see Methods section) in the language of testing (i.e., their most proficient language; W = 3615.5, *p* <.001). The NT group presented higher non-verbal IQ score than the autistic group (W = 5492, p < .001), as measured with the *Raven's Progressive Matrices* (*Raven's-2*; Raven et al., 2018). Sample characteristics are presented in Table 1.

2.1.2. Language of testing

All participants were tested in their L1, which was the language in which their caregivers reported them to be the most proficient. It corresponded to the society language in which the data were collected (i.e., USA, UK, France, Switzerland, Germany, Spain, Canada), either English, French, German, Italian or Spanish.

Table 1. Characteristics of the sample

	Autistic children (*N* = 90)	**Neurotypical children (*N* = 180)**
Age (months)		
Mean (SD)	109 (21.7)	102 (23.7)
Median [Min, Max]	112 [61, 143]	103 [61, 143]
Sex assigned at birth		
Female	14 (15.6%)	92 (51.1%)
Male	76 (84.4%)	88 (48.9%)
Parental educational level (Min 1 - Max 5)		
Mean (SD)	4.00 (1.11)	4.60 (0.70)
Median [Min, Max]	4 [1, 5]	5 [2, 5]
Receptive vocabulary (PPVT, z-score)		
Mean (SD)	-0.57 (1.67)	0.67 (1.11)
Median [Min, Max]	-0.60 [-4.00, 3.27]	0.64 [-2.87, 4.00]
Non-verbal IQ (Raven's 2, IQ score)		
Mean (SD)	95.4 (14.6)	102 (12.1)
Median [Min, Max]	93 [69, 131]	103 [71, 133]
SCQ score		
Mean (SD)	19.5 (7.07)	4.06 (2.99)
Median [Min, Max]	20 [3, 34]	4 [0, 14]
Language of testing (L1) *(N; proportion of the whole sample)*		
English	9 (10.1%)	38 (21.1%)
French	37 (41.1%)	41 (22.8%)
German	19 (21.1%)	66 (36.7%)
Italian	3 (3.3%)	18 (10.0%)
Spanish	22 (24.4%)	17 (9.4%)

NOTE. For the PPVT, there were 5 missing values in the autistic group, and 20 in the NT group. Z-scores were calculated against the reference norms for each language versions. For the non-verbal IQ, there was 1 missing value for the autistic group, and 8 in the NT group. For the SCQ variable, there were 5 missing values in the autistic group, and 1 in the NT group.

2.1.3. Bilingualism operationalization

Information regarding the linguistic background of the children were accessed via the *Quantifying Bilingual Experience* questionnaire (Q-BEx; De Cat et al., 2022). Caregivers replied to a series of questions about their child's experience in up to three languages, such as their amount of exposure to the languages, use of the languages in different contexts, estimated proficiency in the languages, among others.

For RQ1, participants were divided based on their '*bilingual status*' into 'bilinguals' and 'monolinguals': children were considered *bilinguals* when (a) their parents indicated that they had contact with a second language, and (b) children had even minimal proficiency in *understanding*, *speaking*, *writing* or *reading* this second language, as estimated by their caregivers. In total, four groups for RQ1 were created: bilingual children with ASD (N = 66), monolingual children with ASD (N = 24), bilingual NT children (N = 121), monolingual NT children (N = 59). The presentation of the diversity of languages to which participants were exposed is available in Appendix S1.

To index the participant's L2 proficiency for RQ2 and RQ3, we selected the parents' estimate of their child's proficiency in their second-best language. Specifically, parents indicated on a 4-point Likert-scale the level of proficiency of their child in *speaking*, *understanding*, *writing* and *reading* any language to which the child was exposed. Scores on these subindices were averaged per language. The result was a percentage indicating the proficiency in that language, from 0% (no proficiency in that language) to 100% (excellent proficiency). Hence, the percentage corresponding to the second-best language other than the language of testing (L1) indicated L2 proficiency. For participants whose parents reported no L2 (i.e., 'true' monolinguals), L2 proficiency was set to 0.

2.2. Measures

All participants were tested individually in a quiet room by a trained experimenter. Children were allowed to take as many breaks as they wished during the protocol. The assessment was entirely screen-based and required non-verbal responses only, to avoid disadvantaging children with ASD due to potential difficulties with verbal expression and to ensure systematic instructions across participants and language versions. Assessment included a grammaticality judgment task (GJT)(Wolfer et al., 2024), a non-verbal IQ test (Raven et al., 2018) and a measure of receptive vocabulary to account for the proficiency in the testing language (Dunn & Dunn, 2007).

2.2.1. Grammaticality Judgment Task (GJT)

The same two-dimensional GJT as in Wolfer et al. (Wolfer et al., 2024) was used in the current work. This task, inspired by previous work (Atchley et al., 2006; Bialystok, 1986), required participants to judge pre-recorded sentences based on their grammatical well-formedness. Participants provided their judgment by either giving a piece of candy (when the sentence heard was judged to be well-formed) or a sock (when judged incorrect) to a friendly monster on screen.

The GJT material consisted of four types of sentences with reduced linguistic difficulty:

(1) GM sentences, that were grammatically correct and semantically appropriate. These sentences corresponded to baseline performance.

(2) gm sentences, that were grammatically incorrect and semantically anomalous.

(3) Gm sentences, that were grammatically correct but contained a semantic anomaly, thereby imposing a greater demand on the *cognitive control* dimension to ignore the misleading meaning.

(4) gM sentences, that contained a grammatical mistake but had appropriate meaning, considered to engage greater resources on the *analyzed knowledge* dimension.

The grammatical mistakes in gm and gM sentences consisted of determiner-noun reversal and morphological disagreement between the verb and the subject. The semantical anomaly in gm and Gm sentences resulted from an unrealistic pairing between the agent and the action described by the verb. Sentences were kept short and with minimal morphosyntactic complexity to inclusively test children with and without ASD (see Wolfer et al., 2024 for additoinaldetails on the task structure). There were 8 unique sentences of each type, resulting on a 32-items task (see Table 2 for examples). Each correct attribution of a candy or a sock was rewarded 1 point, each incorrect response 0. Therefore, the total possible score to the task was 32, while the total score for gM or Gm sentences separately was each 8 points. Most participants completed the tasks entirely, except for N = 3 children with ASD (completing 28, 30 and 31 items of 32 possible) and N = 2 neurotypical participants (completing 31 items on 32).

Table 2. Examples of sentences in the different languages

	GM	**gM** *Analyzed knowledge*	**Gm** *Cognitive control*	**gm**
	Grammatically correct, Semantically appropriate	Grammatically incorrect, Semantically appropriate	Grammatically correct, Semantically odd	grammatically incorrect, Semantically odd
ENGLISH	Mark goes to the swimming pool with a friend.	Tonight there are clouds and stars in sky *the*.	The *broom* wakes up every morning.	The rain *climb* tonight in the sandbox.
FRENCH	Marc va à la piscine avec un ami.	La nuit il y a nuages *des* dans le ciel.	Le *balai* se réveille tous les matins.	La pluie *grimpons* ce soir dans le caillou.
GERMAN	Mark geht mit einem Freund ins Schwimmbad.	Es gibt in Nacht *der* Wolken am Himmel.	Der *Besen* wacht jeden Morgen auf.	Der Regen *klettern* heute Nacht in den Stein.
ITALIAN	Marco va al mare con un amico.	Di notte sono stelle *ci* in cielo.	La *scopa* si sveglia la mattina.	La pioggia si *arrampicare* sul sasso
SPANISH	Marcos va a la piscina con amigos.	Esta noche hay nubes en cielo el.	La escoba se levanta cada día.	La lluvia subir ayer en el castillo.

2.2.2. Receptive vocabulary

Participants' receptive vocabulary in their L1 was assessed with the *Peabody Picture Vocabulary Test (PPVT)* and its respective adaptations in the different language of testing: English (Dunn & Dunn, 2007), French (Dunn et al., 1993), German (Lenhard et al., 2015), Italian (Stella et al., 2000) and Spanish (Dunn et al., 2006). Participants listened to pre-recorded words of and selected, among four choices, the picture that corresponded. Z-scores were calculated using the reference norms from each language version's manual to ensure comparability across participants and language versions.

2.2.3. Non-verbal IQ

Non-verbal IQ was determined by the *Raven's-2* (Raven et al., 2018), a non-verbal assessment requiring participants to select, among five choices, the missing piece matching a visual pattern. This task is commonly considered to reflect fluid intelligence. Standardized IQ scores were used in the analyses.

2.3. Analysis plan

Generalized mixed-effects models with a logit-link function were fitted for each research question independently, using the *glmer* function of the *lme4 package* (Bates et al., 2015) in *R* and R Studio version 2024.04.2+764 (R Core Team, 2020). A separate model was created for each RQ, with performance at the item level (0 or 1) as the dependent variable. Two planned comparisons - operationalized as contrast codes - were created to examine performance depending on the *sentence type*: the first contrast corresponded to the *cognitive control* dimension and compared performance on Gm sentences to performance on GM sentences (referred to as "comparison [a]"). The second contrast reflected performance on *analyzed knowledge* and compared gM sentences to GM sentences ("comparison [b]").

For RQ1, we specified the main effects and full three-way interactions between *diagnostic group* (ASD/NT, sum-coded), *bilingual status* (monolingual/bilingual, sum-coded) and *sentence type.* For RQ2

and RQ3, we specified the main effects and full three-way interactions between *diagnostic group* (ASD/NT, sum-coded), *L2 proficiency* (scaled proficiency in the L2) and *sentence type*.

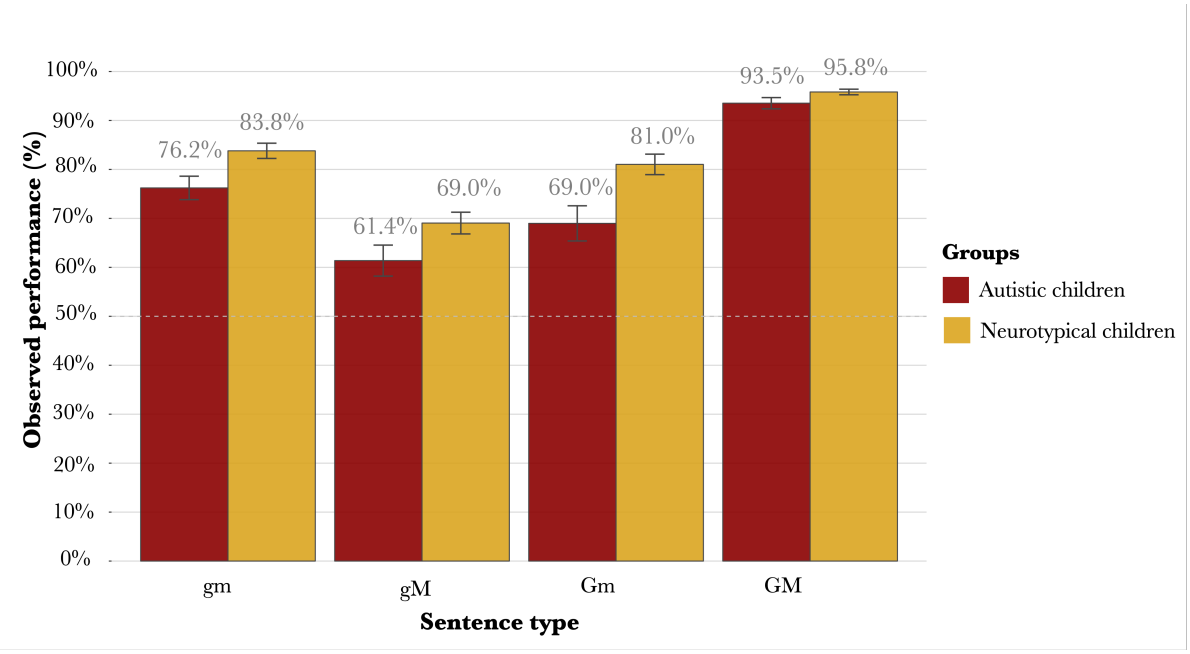
In addition, all models contained *age* (scaled) and *language of testing* (sum-coded) as covariates, as well as *non-verbal IQ* (scaled) and *receptive vocabulary z-score*. These covariates were added as fixed effects because of their reported impact on GJT performance (Bialystok, 1986; Schachter & Yip, 1990; Tremblay, 2005; Wolfer et al., 2024). *Participants* and *items* were entered as random intercepts. All continuous variables were scaled, and prior model checks revealed no harmful multicollinearity between the predictors (VIF ≤ 5). Significant interactions were resolved hierarchically.

3. Results

3.1. Descriptive performance

Both groups performed relatively well on the task: The group of children with ASD obtained a mean accuracy score of 75.03% (±1.5 SEM) across sentence types, while the group of neurotypical children presented a mean accuracy score of 82.42% (± 1.50 SEM) across sentence types. Descriptively, both groups obtained a similar pattern of performance (Fig 1). Precisely, performance was better for GM sentences than for gm sentences; for gm sentences than for Gm; and for Gm sentences than for gM.

Figure 1. Observed mean accuracy scores (%) across participants, by group and sentence type. The grey dotted line represents the chance-level accuracy (50%). Exact accuracy percentages are displayed above each bar. Error bars indicate the Standard Error of the Mean (SEM).



3.2. Generalized Mixed effects models

3.2.1. RQ1: Bilinguals versus Monolinguals comparison on MA requiring cognitive control (i.e., Gm sentences relative to GM sentences; comparison [a])

The model revealed a significant 3-way interaction between group, bilingual status and sentence type Gm relative to GM (comparison [a]; Estimate = 0.825, SE = 0.249, z = 3.314, p = <.001; see Table 3 for the model output).

Table 3. Output of the GLMM model for RQ1

	Estimate	Std. Err	Z value	*p*
(Intercept)	1.794	0.131	13.673	< .001
Group	-0.676	0.186	-3.638	< .001
Bilingual status	0.348	0.170	2.052	.040
Gm vs. GM [a]	-0.539	0.172	-3.139	.002
gM vs. GM [b]	-1.111	0.170	-6.525	< .001
Sentence type [omnibus]	0.015	0.210	0.074	.941
Age	0.839	0.074	11.375	< .001
Non-verbal IQ	0.180	0.077	2.332	.020
Receptive vocabulary in L1 (PPVT)	0.317	0.056	5.625	< .001
Language_English	-2.675	0.730	-3.664	< .001
Language_French	2.827	0.644	4.389	< .001
Language_German	1.764	0.674	2.616	.009
Language_Italian	-0.807	0.980	-0.823	.410
Group: Bilingual status	0.623	0.321	1.943	.052
Group: Gm vs. GM [a]	-0.337	0.124	-2.710	.007
Group: gM vs. GM [b]	0.445	0.124	3.576	< .001
Group: Sentence type [omnibus]	-0.165	0.150	-1.103	.270
Bilingual status : Gm vs. GM [a]	0.110	0.125	0.880	.379
Bilingual status :Gm vs. GM [b]	0.009	0.124	0.070	.944
Bilingual status: Sentence type [omnibus]	0.022	0.150	0.146	.884
Group: Bilingual status: Gm vs. GM [a]	0.825	0.249	3.314	< .001
Group : Bilingual status: gM vs. GM [b]	-1.091	0.249	-4.387	< .001
Group: Bilingual status: Sentence type [omnibus]	0.571	0.299	1.910	.056

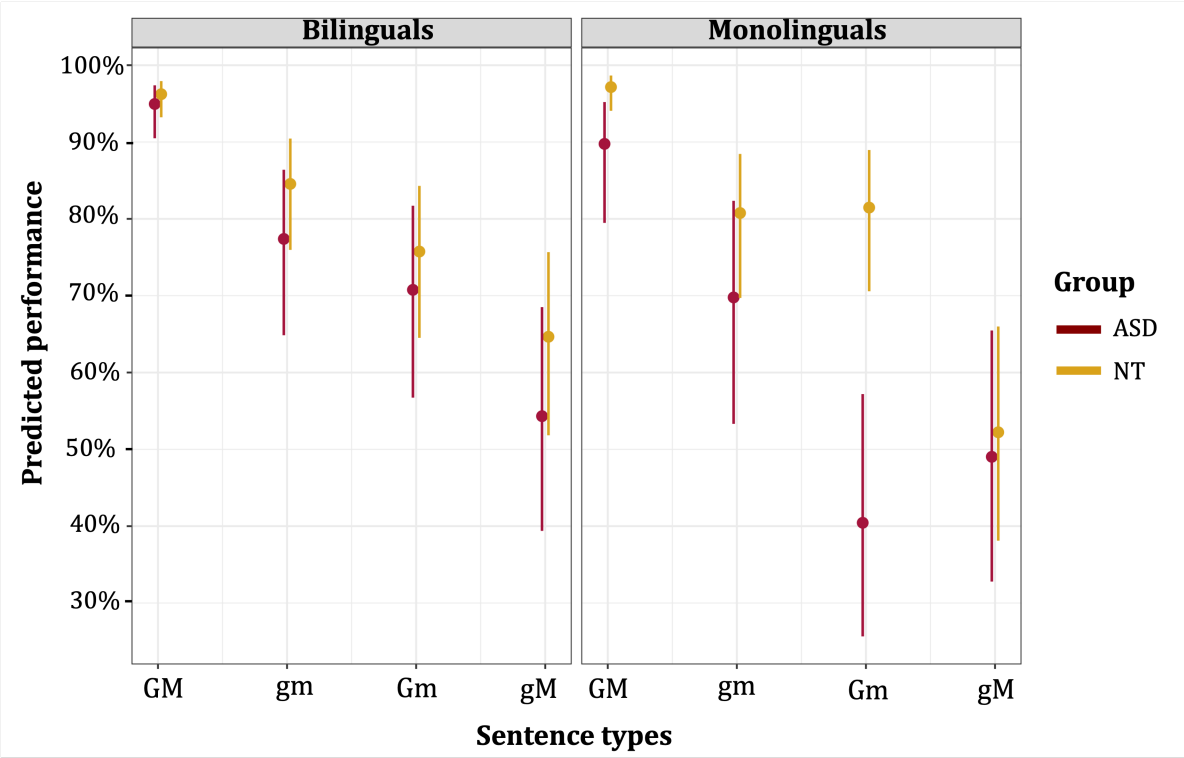
NOTE. [a] : planned comparison [a] between Gm and GM sentences; [b]: planned comparison [b] between gM and GM sentences; [omnibus] corresponds to the overall effect of sentence type.

Further investigations were therefore conducted in the two groups separately to locate the source of the interaction. In neurotypical children, the two-way interaction between bilingual status and comparison [a] was not significant (Estimate = -0.302, SE = 0.166, z = -1.823, p = .068; Table A in Appendix S2), indicating no significant difference between monolinguals and bilingual NT children. In contrast, in autistic children, the two-way interaction between bilingual status and comparison [a] was significant (Estimate = 0.533, SE = 0.187, z = 2.854, p = .004; Table C in Appendix S2): Bilingual children with ASD significantly outperformed their monolinguals peers in Gm sentences (Estimate = 1.755, SE = 0.638, z = 2.2753, p = .006; Table C in Appendix S2), and in the baseline GM sentences (Estimate = 1.195, SE = 0.491, z = 2.435, p = .015; Table D in Appendix S2). The predicted probability to provide a correct response on

Gm sentences was estimated at 80.5% (95% CI: 71.0 – 87.5) for monolingual autistic children and 53.7% (95% CI: 38.0 – 68.7) for bilingual autistic children.

Investigations in bilingual children (both NT and with ASD) revealed no effect of group, either as an individual predictor or in interaction with sentence type, indicating that there was no difference in performance between bilingual autistic and NT children (Table E in Appendix S2). In monolinguals, however, the interaction between group and sentence type Gm relative to GM (comparison [a]) was significant (Estimate = 0.983, SE = 0.211, z = -3.644, p < .001; Table F in Appendix S2), further revealing that NT monolingual children significantly outperformed monolingual autistic children on Gm sentences specifically (Estimate = -3.126, SE = 1.039, z = -3.010, p = .003; Table G in Appendix S2). Figure 2 presents the predicted performance in each sentence type for monolingual and bilingual autistic and NT children.

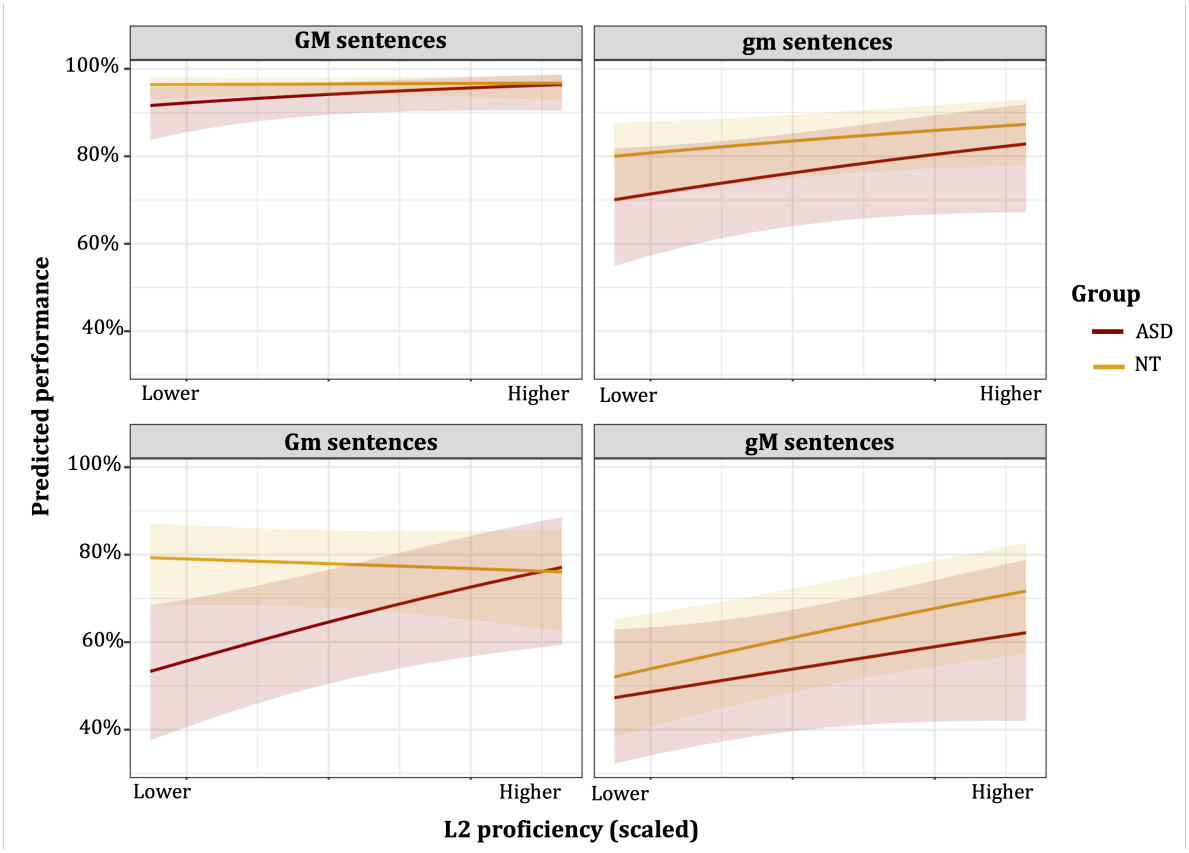
Figure 2. Predicted performance in the four sentence types in bilingual and monolingual autistic and NT children



3.2.2. *RQ2: Effect of L2 proficiency on MA requiring cognitive control (i.e., Gm sentences relative to GM sentences; comparison [a])*

The predicted probabilities of the model investigating the impact of L2 proficiency on metalinguistic performance is presented in Figure 3.

Figure 3. ***Predicted performance on each sentence type in autistic and NT children as a function of L2 proficiency***



The model revealed no significant two-way or three-way interaction implicating L2 proficiency and comparison [a] (Table 4), indicating that L2 proficiency did not differently impact autistic and NT children in Gm sentences. However, L2 proficiency positively predicted performance on the task on overall for both groups, as shown by the significant main effect of L2 proficiency (Estimate = -0.199, SE = 0.089, z = 2.236, p = .025; Table 4): Both autistic and NT children with higher L2 proficiency outperformed respective peers with lower L2 proficiency.

Table 4. Output of the GLMM model for RQ2

	Est.	Std. Err	Z value	*p*
(Intercept)	1.890	0.128	14.756	< .001
Group	-0.491	0.178	-2.755	.006
L2 proficiency	0.199	0.089	2.236	.025
Gm vs. GM [a]	-0.497	0.169	-2.938	.003
gM vs. GM [b]	-1.128	0.168	-6.707	< .001
Sentence type [omnibus]	0.032	0.207	0.153	.878
Age	0.812	0.074	10.964	< .001
Non-verbal IQ	0.170	0.078	2.187	.029
Receptive vocabulary in L1 (PPVT)	0.302	0.056	5.388	< .001
Language_English	-2.612	0.739	-3.536	< .001
Language_French	2.849	0.651	4.376	< .001
Language_German	1.852	0.676	2.740	.006
Language_Italian	-0.544	0.988	-0.551	.582
Group: L2 proficiency	0.172	0.155	1.108	.268
Group: Gm vs. GM [a]	-0.159	0.114	-1.389	.165
Group: gM vs. GM [b]	0.207	0.114	1.820	.069
Group: Sentence type [omnibus]	-0.039	0.137	-0.281	.779
L2 proficiency: Gm vs. GM [a]	-0.038	0.060	-0.634	.526
L2 proficiency : Gm vs. GM [b]	0.058	0.060	0.971	.332
L2 proficiency: Sentence type [omnibus]	-0.022	0.072	-0.302	.763
Group: L2 proficiency : Gm vs. GM [a]	0.229	0.119	1.923	.054
Group : L2 proficiency : gM vs. GM [b]	-0.292	0.119	-2.459	.014
Group: L2 proficiency : Sentence type [omnibus]	0.126	0.144	0.875	.382

NOTE. [a] : planned comparison [a] between Gm and GM sentences; [b]: planned comparison [b] between gM and GM sentences; [omnibus] corresponds to the overall effect of sentence type.

Visual inspection of performance suggests a positive association between L2 proficiency and accuracy on Gm sentences (Figure 3). To explore this trend further, we conducted exploratory trend analyses using the emmeans package (Lenth, 2023), estimating the slope of L2 proficiency within each group and sentence type. Results indicated that among autistic children, higher L2 proficiency significantly predicted better performance on Gm sentences (Estimate = 0.373, SE = 0.158, 95% CI [0.064, 0.683]), whereas no such association was found in NT children (Estimate = -0.064, SE = 0.112, 95% CI [-0.283, 0.154]). These exploratory findings align with the visual trends shown in Fig. 3 but should be intepreted cautiously, given the non-significant higher-order interaction.

3.2.3. RQ3: Effect of L2 proficiency on MA requiring analyzed knowledge (i.e., gM sentences relative to GM sentences; comparison [b])

The model for RQ3, which was identical than the model for RQ2, showed a significant 3-way interaction between *group*, *L2 proficiency*, and *sentence type gM sentences relative to GM sentences* (comparison [b]; Estimate = - 0.292, SE = 0.119, z = - 2.459, p = .014; Table 4). In NT children, the interaction between L2 proficiency and comparison [b] was significant (Estimate = 0.201, SE = 0.073, z = 2.743, p = .006; Table A in Appendix S3): on gM sentences,the effect of L2 proficient was positive, but only marginally significant (Estimate = 0.308, SE = 0.162, z = 1.894, p = .058; Table B in Appendix S3). There was no effect of *L2 proficiency* on GM sentences in NT children (p = .918; Table C in Appendix S3). In autistic children, the interaction between sentences *gM relative to GM sentences* was not significant (p = .332; Table D in Appendix S3). Yet, autistic children with higher L2 proficiency significantly outperformed peers with lower L2 proficiency on the overall task, as indicated by the significant main effect of L2 proficiency in the autistic group (Estimate = 0.331, SE = 0.144, z = 2.301, p = .021; Table D in Appendix S3).

3.2.4. Common effects to RQ1, RQ2 and RQ3

Across the models for RQ1 (monolingual vs. bilingual status) and RQ2–RQ3 (continuous L2 proficiency), a consistent pattern of effects emerged for the covariates: age, non-verbal IQ, and receptive vocabulary in the testing language were all significant positive predictors of overall task performance (see Table 3 and Table 4). Older children significantly performed better than younger children, children with higher IQ better than children with lower IQ, and children with greater language skills in the testing language, as indexed by receptive vocabulary, outperformed peers with lower language skills. Additionally, both models indicated that performance varied by testing language: participants tested in English scored significantly below the overall mean (i.e., the grand mean across all languages), whereas those tested in French and German performed significantly above the overall mean.

4. Discussion

This study investigated (1) whether reported bilingualism effects on MA requiring *cognitive control* and *analyzed knowledge* previously observed in two-dimensional GJTs were replicated in a sample of *N* = 180 neurotypical children aged 5 to 12, and (2) whether these effects extended to *N* = 90 children diagnosed with ASD. It furthermore clarified the role of L2 proficiency on metalinguistic performance in both populations.

4.1. Findings and implications

4.1.1. Effects on MA requiring cognitive control (Gm sentences): bilinguals versus monolinguals

The first research question examined the ability of NT and autistic bilingual children, regardless of their level of L2 proficiency, to judge sentences requiring *cognitive control* by comparing them to their respective monolingual peers. After controlling for age, non-verbal IQ, and language skills in the testing language, bilingual autistic children significantly outperformed their monolingual peers in MA requiring *cognitive control* (Gm sentences). This finding aligns with previous research reporting bilingual advantages in executive functioning in autism (Romero & Uddin, 2021), including cognitive flexibility (Gonzalez-Barrero & Nadig, 2019; Peristeri et al., 2021), inhibition (Li et al., 2017), and sustained attention (Sharaan et al., 2021). The current study adds new evidence to the growing body of work showing a non-detrimental – and potentially beneficial – impact of dual-language exposure on cognitive and linguistic outcomes in this population (Drysdale et al., 2015; Gilhuber et al., 2023; Lund et al., 2017). On the one hand, the findings suggest that the positive effects of bilingualism on MA, well-documented in the NT population (Adesope et al., 2010), may similarly emerge in autistic children. On the other hand, they indicate that the bilingualism-related advantages in cognitive control found in autism (Gonzalez-Barrero & Nadig, 2019; Peristeri et al., 2021) may also generalize to tasks of linguistic nature.

Importantly, bilingual children with ASD performed at a level comparable to that of bilingual NT participants. In contrast, among monolinguals, NT children significantly outperfomed monolingual autistic children in sentences requiring cognitive control, likely reflecting the well-documented executive functions difficulties often observed in autism (Craig et al., 2016; Demetriou et al., 2018). These findings suggest that bilingualism may act as a naturalistic compensatory mechanism, mitigating performance differences between autistic and NT children in tasks or items engaging cognitive control. Bilingualism may also offer more pronounced cognitive support in populations with executive function vulnerabilities, an interpretation aligning with the view that cognitive advantages of bilingualism may be most pronounced in populations experiencing executive functions difficulties (Romero & Uddin, 2021).

However, contrary to our hypotheses and previous research (Bialystok, 1986, 1988; Bialystok & Majumder, 1998), the expected positive effect of bilingualism on sentences requiring higher *cognitive control* was not replicated in neurotypical children. Instead, we found no difference between NT monolinguals and bilinguals in judging Gm sentences.

One likely explanation for this absence of effect lies in the nature of bilingual experience in our sample. Unlike participants in previous studies, who were often enrolled in bilingual immersion programs where the second language was used actively and consistently in an academic setting (Bialystok, 1986, 1988; Cromdal, 1999), the bilingual children in our study presented more varied linguistic backgrounds, and were not specifically enrolled in structured dual-language programs. Bilingual immersion environments provide continuous and structured exposure to both languages, which amplify the cognitive demands associated with managing two linguistic systems (Linck et al., 2009; Nicolay & Poncelet, 2013, 2015). Without this structured bilingual environment, the benefits of bilingualism on cognitive control in this task may be less pronounced.

Another possible explanation is that individual differences in executive functioning, such as phonological short-term memory (STM) or working memory (WM), could have influenced performance. Phonological STM refers to the ability to temporarily store verbal information, such as the words or structure of a sentence, while WM additionally involves the manipulation of that information for task-related goals (Diamond, 2013). These abilities are crucial for holding sentence content and task instructions in mind while making judgments. Although some studies suggest that bilingualism may enhance WM (e.g., Morales et al., 2013), findings are largely mixed (Calvo et al., 2016; Giovannoli et al., 2020; Lowe et al., 2021; Monnier et al., 2021), and these components were not directly assessed in the present study. Their contribution to performance on cognitively demanding metalinguistic tasks thus remains an open question.

More broadly, replicating bilingual advantages has proven difficult in bilingual research (Bak, 2016; Paap, 2022), given the multifaceted nature of bilingualism and its many interacting variables (de Bruin, 2019; Luk, 2015). Unmeasured sociolinguistic factors, such as language status, community context, amount of exposure and use, may also influence outcomes (Byers-Heinlein et al., 2019; Luk & Grundy, 2022; Masullo et al., 2023). These findings reinforce growing calls to move beyond categorical comparisons of monolingual versus bilingual children, and instead examine continuous individual differences. One such factor - L2 proficiency - may be particularly relevant in explaining performance on metalinguistic tasks. Prior research indeed suggested that individual differences in L2 proficiency matter. For instance, Cromdal et al. (1999) found that only bilingual neurotypical children with high L2 proficiency outperformed their monolingual peers in *cognitive control*, whereas those with lower proficiency did not show this advantage. When children were tested in their most proficient language, children with high L2 proficiency outperformed their peers with lower L2 proficiency on MA requiring *analyzed knowledge*, suggesting a positive, predictive impact of L2 proficiency. To date, however, the impact of L2 proficiency on grammatical judgment performance - both involving *cognitive control* or *analyzed knowledge* - has not been directly tested when operationalized as a continuum. This gap is addressed in the second and third research questions.

4.1.2. Effects of L2 proficiency on MA requiring cognitive control (Gm sentences)

There was no statistical evidence for an impact of L2 proficiency on Gm sentences in our study, neither in NT nor in autistic children. However, post-hoc trend analyses using estimated marginal means suggested that higher L2 proficiency related to better performance on *cognitive control* among autistic children. Nevertheless, this effect did not emerge in the primary model, and should therefore be interpreted with caution.

These findings suggest that other factors of the bilingual experience, not captured by L2 proficiency alone, might play an additional role in supporting the better performance of autistic bilingual children in our study (see RQ1), and of NT bilingual children in previous work (Bialystok, 1986; Bialystok & Majumder, 1998; Cromdal, 1999), as compared to respective monolingual peers. Such a result reflects the multidimensional nature of bilingualism, and aligns with recent recommendations to consider a combination of both categorical and continuous approaches to bilingualism to provide a more nuanced understanding of how individual linguistic experiences may impact cognitive and linguistic outcomes (Kremin & Byers-Heinlein, 2021). Consistent with previous claims (Bialystok & Barac, 2012), the effect of bilingualism on MA requiring cognitive control may be more sensitive to domain-general effects of bilingualism than to the absolute level of linguistic knowledge in a second language. Further research should investigate whether other factors of the bilingual experience that have been shown to influence cognitive control, such as language switching or intensity of bilingual language use (Carter et al., 2023), predict performance on MA requiring *cognitive control*.

4.1.3. Effects of L2 proficiency on MA requiring analyzed knowledge (gM sentences)

Finally, the last research question examined the direct impact of *L2 proficiency* on performance in sentences engaging additional demand on *analyzed knowledge*, namely ungrammatical sentences with appropriate meaning (i.e., gM). Second-language proficiency did not significantly impact performance on these items in either group, despite a positive trend. This finding does not fully align with previous studies using group comparisons (Bialystok, 1988; Cromdal, 1999), which notably reported advantages for 'fully' bilinguals over 'partially' bilinguals in gM performance. However, it is important to note that these earlier studies did not directly examine the role of L2 proficiency as a continuous predictor. In our study, there was not enough evidence to support the prediction that children with high L2 proficiency may develop greater level of linguistic knowledge through the mastery of a second language. While the process of organizing and comparing two linguistic systems may promote the ability to identify abstract linguistic structures, rules, and concepts efficiently (Bialystok, 1988; Galambos & Goldin-Meadow, 1990), other factors (e.g., proficiency in the testing language, richness of the linguistic experience) may also contribute to performance on MA requiring analyzed knowledge.

Importantly, autistic children with higher L2 proficiency outperformed their peers with lower L2 proficiency in the GJT on overall, suggesting that the "boost" in metalinguistic awareness previously observed in bilingual NT children (Adesope et al., 2010) may also carry over to children with ASD.

4.1.4. Additional effects

In each model, age had a significant positive influence on performance. Consistent with previous work (Bialystok, 1986; Melogno et al., 2022; Scribner & Cole, 1981), this highlights the developmental trajectory of metalinguistic competence over school years. Non-verbal IQ also significantly predicted performance across groups: Children with higher non-verbal IQ obtained significantly better metalinguistic performance than children with lower performance. This finding aligns with previous work (Wolfer et al., 2024) and underscores the cognitive effort required by this two-dimensional task. Consistent with previous research indicating strong associations between vocabulary knowledge and metalinguistic performance (Nagy, 2007; Smith & Tager-Flusberg, 1982), language skills in the testing language, as indexed by vocabulary breadth, significantly predicted performance.

Differences in performance were observed in the different language groups, namely depending on the language of testing: Children were tested in their L1, which was either English, French, German, Italian or Spanish. Precisely, English-tested participants obtained lower performance than the *grand mean* of performance (i.e., mean performance of all participants in all languages). In contrast, German-tested and French-tested participants obtained better scores. Post-hoc investigations revealed that German-tested participants were relatively older in average (109 ± 19 months; French-tested: 100 ± 23 months, English-tested: 107 ± 25 months, Italian-tested: 96 ± 31 months, Spanish-tested: 108 ± 24 months). They were also mostly neurotypical (78% of neurotypical children). These factors could explain the better performance observed. However, *age* is unlikely to explain the better performance observed in French-tested participants, as children were relatively younger on average (100 ± 23 months) than other language groups. They presented a balanced proportion of autistic individuals in their sample (53% of autistic children). This suggests that other unmeasured factors may have contributed to their stronger performance (e.g., literacy exposure). In contrast, English-tested children were not specifically younger in average (107 ± 27 months) than other language groups, yet presented a higher rate of autistic children than neurotypical children in their sample (81%), which could explain the lower performance observed. Lower performance exhibited by English-tested participants had already been reported in a preliminary investigation using this GJT (Wolfer et al., 2024). These may stem from characteristics of the stimuli affecting grammatical sensitivity in English, as compared to other languages (see Wolfer et al., 2024 for a discussion; particularly, difficulty detecting grammatical mistakes, likely due to variation in use or omission of the -s agreement marker in English).

4.2. Limitations

The present study has several limitations. First, due to the complexity of the tasks and the necessity of assessing cognitive and linguistic factors using standardized measures, only children who were capable of attending to the tasks and sustaining attention throughout the assessment were able to complete the full protocol. Efforts were made to enhance accessibility, including the digitalization of the entire protocol and the simplification of task instructions to better accommodate children with language impairments and greater autism severity (Wolfer et al., 2024). However, the sample of autistic children may not fully capture the heterogeneity of the broader autistic population. Although individuals with low IQ constitute approximately one-third of the autistic population, they are underrepresented in research and were also absent from this study (Russell et al., 2019).

Second, while the measure of L2 proficiency used in this study was relatively detailed as it separately assessed comprehension, speaking, reading, and writing skills, it nevertheless relied on parent-reported assessments, which can be less reliable than standardized objective measures (Bishop & McDonald, 2009). Additionally, some parents may have had to estimate their child's proficiency in a language they did not fluently speak themselves, potentially leading to inaccuracies in their evaluation. Yet, the use of objective measures to assess language proficiency also comes with limitations: Research has shown that language proficiency cannot be fully captured by assessing a single subdomain (e.g., receptive vocabulary alone), as children often exhibit varying levels of ability across lexical, morphosyntactic, and phonological domains (Dockrell & Marshall, 2015; Olson, 2023). These uneven linguistic profiles are even more pronounced in autistic individuals (Schaeffer et al., 2023; Silleresi, 2023), making it difficult to identify a single measure that accurately reflects overall language proficiency. Assessing all language domains objectively would require administering multiple standardized tests for each participant, significantly increasing assessment duration. Creating a composite proficiency score also presents methodological challenges, particularly when there are discrepancies between subdomain scores, potentially resulting in a measure that is difficult to interpret and less reflective of observable language abilities.

Third, this study did not investigate the impact of a third language on performance, although research on this topic is growing (Cenoz, 2003). While some studies suggest an association between third-language acquisition and metalinguistic awareness, the nature of this relationship remains unclear (D'Angelo & Sorace, 2022). Future research may explore how L3 experience interacts with language-related cognitive processes in both neurotypical and autistic populations.

5. Conclusion

This study challenges simplified assumptions about bilingualism by showing that its effects on metalinguistic awareness vary across populations, cognitive and linguistic demands under consideration. Using the widely applied two-dimensional GJT, we tested a large and linguistically (neuro-)diverse sample of 90 autistic and 180 neurotypical children. By combining categorical and continuous approaches to bilingualism, the finding offer a more nuanced understanding of how bilingual experience influences metalinguistic outcomes.

In neurotypical children, the absence of a bilingual advantage on items indexing *cognitive control* invites a more critical perspective on claims of universal cognitive benefits. In contrast, bilingual children with ASD outperformed monolingual peers in items requiring *cognitive control*, and autistic children with higher L2 proficiency performed better on the overall GJT than peers with lower L2 proficiency.

These results provide new evidence that bilingualism is not detrimental, and may in fact confer specific benefits, even in populations with cognitive and/or linguistic vulnerabilities such as children with ASD. More broadly, this work aligns with contemporary perspectives in bilingualism research that prioritize transparent, theoretically informed, and inclusive approaches (de Bruin, 2019; Kremin & Byers-Heinlein, 2021; Rothman et al., 2023; Surrain & Luk, 2019). By integrating neurodiverse populations and modeling bilingualism as both a categorical and continuous construct, this study demonstrates that bilingualism cannot be understood without attention to individual variation and developmental context. It expands the generalizability of bilingualism research and highlights the need to consider cognitive and linguistic diversity as central to understanding bilingual development.

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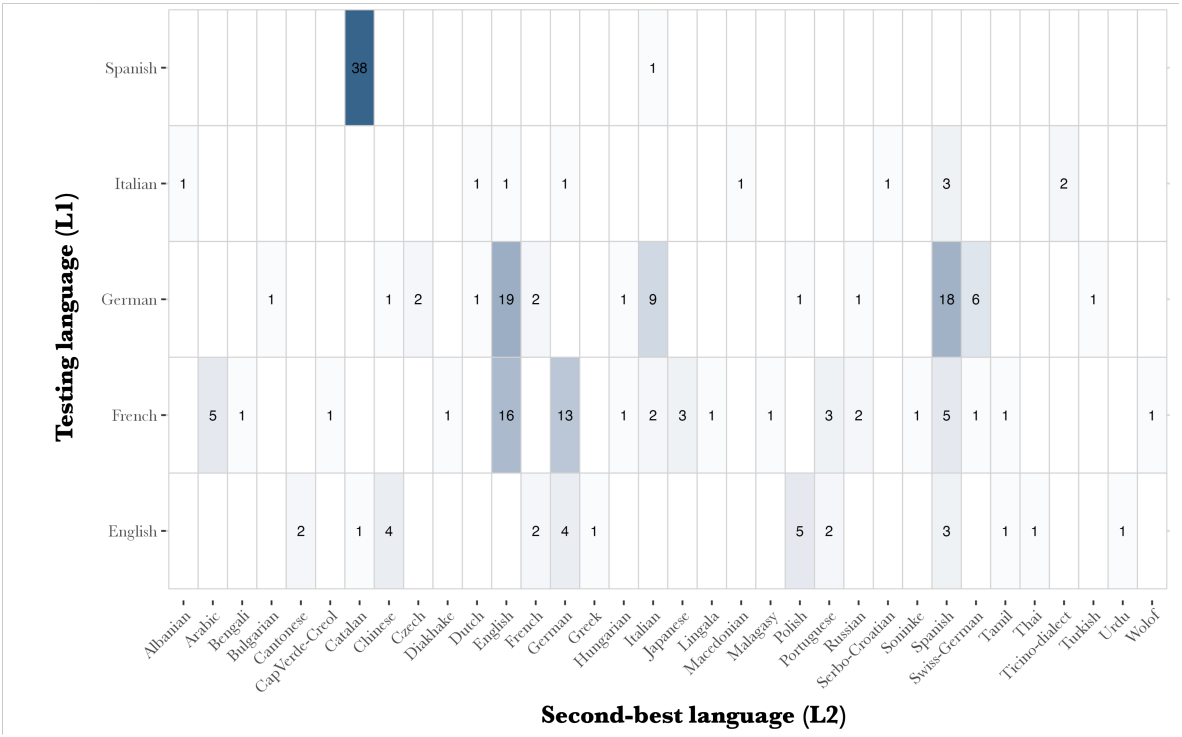
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Appendix

Appendix S1. Bilingual characteristics of the sample

- *Table A. Variety of Languages participants were exposed to.*



Numbers represent number of participants.

- *Table B. Description of bilingual-related characteristics of the sample.*

	Autistic children (N=90)			Neurotypical children (N=180)		
	L1	**L2**	**L3**	**L1**	**L2**	**L3**
Age of First Exposition Mean (SD) [range]	8.17 (18.1) 0 [0, 95]	14.2 (25.9) 0 [0, 120]	26.1 (26) 24.5 [0, 84]	5.25 (12.9) 0 [0, 60]	10.1 (22.3) 0 [0, 97]	25.8 (37.2) 1.00 [0, 126]
Place of First Exposition						
Home	73 (81.1%)	49 (54.4%)	8 (8.9%)	138 (76.7%)	87 (48.3%)	19 (10.6%)
Other	5 (5.6%)	5 (5.6%)	1 (1.1%)	9 (5.0%)	12 (6.7%)	4 (2.2%)
School	12 (13.3%)	17 (18.9%)	13 (14.4%)	33 (18.3%)	29 (16.1%)	17 (9.4%)
Relative exposure since birth (%)	72.2 (29.0) 81 [0, 100]	31.4 (24.9) 30.1 [0, 92.6]	12.3 (14.0) 6.6 [0, 45]	72.0 (27.8) 76.2 [4.19, 100]	34.8 (23.9) 35.9 [0, 95.8]	14.7 (14.7) 9.44[0, 50]
Relative use in the last year (%)	82.1 (22.2) 91 [15, 100]	21.2 (21.5) 14 [0, 83]	4.55 (10.0) 1.50 [0, 47]	78.4 (25.4) 91.0 [6, 100]	27.8 (24.3) 23 [0, 94]	8.05 (9.94) 3 [0, 40]

NOTE. In the group of autistic children, N = 71 caregivers reported the presence of a second Language (L2), and N = 22 the presence of a third Language (L3). In the group of neurotypical children, N = 128 caregivers reported the presence of a L2 and N = 40 of a L3.

Appendix S2. **Post-hoc investigations of interactions for RQ1**

Table A. Output of the GLMM for RQ1 in NT children only

	Est.	Std. Error	z value	*p*
(Intercept)	2.249	0.160	14.062	< .001
Bilingual status	-0.027	0.203	-0.135	.893
Gm vs. GM [a]	-0.372	0.190	-1.958	.050
gM vs. GM [b]	-1.357	0.187	-7.266	< .001
Sentence type [omnibus]	0.156	0.229	0.681	.496
Age	0.927	0.089	10.367	< .001
Non-verbal IQ	0.229	0.099	2.313	.021
Receptive Vocabulary in L1 (PPVT)	0.238	0.081	2.933	.003
Language_English	-2.370	0.819	-2.894	.004
Language_French	3.008	0.881	3.412	.001
Language_German	0.546	0.786	0.695	.487
Language_Italian	-1.073	1.103	-0.972	.331
Bilingual status:Gm vs. GM [a]	-0.302	0.166	-1.823	.068
Bilingual status:gM vs. GM [b]	0.549	0.163	3.359	.001
Bilingual status:Sentence type [omnibus]	-0.286	0.193	-1.481	.139

Table B. Output of the GLMM for RQ1 in autistic children only

	Est.	Std. Error	z value	*p*
(Intercept)	1.533	0.183	8.364	< .001
Bilingual status	0.663	0.264	2.509	.012
Gm vs. GM [a]	-0.725	0.172	-4.220	< .001
gM vs. GM [b]	-0.870	0.171	-5.086	< .001
Sentence type [omnibus]	-0.046	0.210	-0.220	.826
Age	0.686	0.122	5.637	< .001
Non-verbal IQ	0.077	0.118	0.654	.513
Receptive Vocabulary in L1 (PPVT)	0.400	0.078	5.150	< .001
Language_English	-4.517	1.528	-2.956	.003
Language_French	2.045	1.000	2.044	.041
Language_German	4.343	1.292	3.362	.001
Language_Italian	0.063	2.153	0.029	.977
Bilingual status:Gm vs. GM [a]	0.533	0.187	2.854	.004
Bilingual status:gM vs. GM [b]	-0.532	0.187	-2.837	.005
Bilingual status:Sentence type [omnibus]	0.299	0.228	1.312	.190

Table C. Output of the GLMM for RQ1 in autistic children only, in Gm sentences specifically

	Est.	Std. Error	z value	*p*
(Intercept)	1.250	0.414	3.015	.003
Bilingual status	1.755	0.638	2.753	.006
Age	1.409	0.322	4.384	< .001
Non-verbal IQ	0.670	0.309	2.166	.030
Receptive Vocabulary in L1 (PPVT)	0.433	0.190	2.280	.023
Language_English	-6.593	3.756	-1.755	.079
Language_French	4.067	2.413	1.685	.092
Language_German	5.160	3.136	1.645	.100
Language_Italian	0.258	4.831	0.053	.957

Table D. Output of the GLMM for RQ1 in autistic children only, in GM sentences specifically

	Est.	Std. Error	z value	*p*
(Intercept)	2.826	0.320	8.842	< .001
Bilingual status	1.195	0.491	2.435	.015
Age	0.579	0.226	2.565	.010
Non-verbal IQ	0.080	0.196	0.407	.684
Receptive Vocabulary in L1 (PPVT)	0.478	0.129	3.695	< .001
Language_English	-2.320	2.454	-0.945	.345
Language_French	4.687	1.743	2.689	.007
Language_German	2.887	2.481	1.164	.244
Language_Italian	-3.505	2.878	-1.218	.223

Table E. Output of the GLMM for RQ1 in bilingual children (ASD and NT)

	Est.	Std. Error	z value	*p*
(Intercept)	1.990	0.141	14.110	< .001
Group	-0.277	0.202	-1.373	.170
Gm vs. GM [a]	-0.485	0.172	-2.827	.005
gM vs. GM [b]	-1.095	0.171	-6.407	< .001
Sentence type [omnibus]	0.025	0.210	0.120	.904
Age	0.824	0.085	9.732	< .001
Non-verbal IQ	0.203	0.093	2.180	.029
Receptive Vocabulary in L1 (PPVT)	0.341	0.069	4.967	< .001
Language_English	-2.221	0.947	-2.346	.019
Language_French	2.329	0.749	3.111	.002
Language_German	1.894	0.799	2.371	.018
Language_Italian	-0.836	1.301	-0.642	.521
Group:Gm vs. GM [a]	0.075	0.134	0.560	.576
Group:gM vs. GM [b]	-0.108	0.134	-0.808	.419
Group:Sentence type [omnibus]	0.118	0.162	0.730	.466

Table F. Output of the GLMM for RQ1 in monolingual children (both ASD and NT)

	Est.	Std. Error	z value	*p*
(Intercept)	0.891	0.264	3.370	.001
Group	-1.231	0.352	-3.497	< .001
Gm vs. GM [a]	-0.614	0.191	-3.219	.001
gM vs. GM [b]	-1.139	0.185	-6.175	< .001
Sentence type [omnibus]	0.069	0.228	0.301	.764
Age	0.910	0.151	6.037	< .001
Non-verbal IQ	0.129	0.139	0.930	.352
Receptive Vocabulary in L1 (PPVT)	0.257	0.100	2.564	.010
Language_French	1.480	0.378	3.916	< .001
Language_German	0.973	0.357	2.724	.006
Language_Italian	0.465	0.437	1.064	.287
Group:Gm vs. GM [a]	-0.768	0.211	-3.644	< .001
Group:gM vs. GM [b]	0.983	0.210	4.677	< .001
Group:Sentence type [omnibus]	-0.428	0.252	-1.697	.090

Table G. Output of the GLMM for RQ1 in monolinguals for Gm sentences

	Est.	Std. Error	z value	*p*
(Intercept)	2.433	0.822	2.961	.003
Group	-3.126	1.039	-3.010	.003
Age	1.695	0.474	3.574	< .001
Non-verbal IQ	0.832	0.431	1.927	.054
Receptive Vocabulary in L1 (PPVT)	0.501	0.289	1.732	.083
Language_French	0.285	1.067	0.267	.789
Language_German	-1.223	1.097	-1.115	.265
Language_Italian	-1.798	1.246	-1.442	.149

To address convergence issues, the random-effect structure for this model was simplified to only include random intercepts for participants (1|participant).

Table H. Output of the GLMM for RQ1 in monolinguals for GM sentences

	Est.	Std. Error	z value	*p*
(Intercept)	2.939	0.480	6.120	< .001
Group	-0.727	0.573	-1.268	.205
Age	0.142	0.244	0.582	.560
Non-verbal IQ	0.323	0.250	1.292	.196
Receptive Vocabulary in L1 (PPVT)	-0.004	0.159	-0.025	.980
Language_French	0.276	0.600	0.459	.646
Language_German	0.563	0.669	0.842	.400
Language_Italian	-0.228	0.669	-0.341	.733

To address convergence issues, the random-effect structure for this model was simplified to only include random intercepts for participants (1|participant).

Appendix S3. **Post-hoc investigations of interactions for RQ2/RQ3**

Table A. Output of the GLMM for RQ2/RQ3, in NT children only

	Est.	Std. Error	z value	*p*
(Intercept)	2.231	0.154	14.521	< .001
L2 proficiency	0.064	0.099	0.651	.515
Gm vs. GM [a]	-0.424	0.187	-2.269	.023
gM vs. GM [b]	-1.254	0.184	-6.817	< .001
Sentence type [omnibus]	0.101	0.227	0.445	.656
Age	0.917	0.090	10.229	< .001
Non-verbal IQ	0.223	0.099	2.259	.024
Receptive Vocabulary in L1 (PPVT)	0.243	0.081	3.004	.003
Language_English	-2.227	0.834	-2.670	.008
Language_French	2.973	0.876	3.393	.001
Language_German	0.623	0.788	0.791	.429
Language_Italian	-0.873	1.109	-0.787	.431
L2 proficiency: Gm vs. GM [a]	-0.154	0.074	-2.079	.038
L2 proficiency: gM vs. GM [b]	0.201	0.073	2.743	.006
L2 proficiency: Sentence type [omnibus]	-0.098	0.089	-1.098	.272

Table B. Output of the GLMM for RQ2/RQ3, in NT children only, in gM sentences

	Est.	Std. Error	z value	*p*
(Intercept)	1.192	0.368	3.236	.001
L2 proficiency	0.308	0.162	1.894	.058
Age	1.213	0.160	7.598	< .001
Non-verbal IQ	0.075	0.168	0.444	.657
Receptive Vocabulary in L1 (PPVT)	0.378	0.138	2.731	.006
Language_English	-4.884	1.439	-3.394	.001
Language_French	4.986	1.516	3.289	.001
Language_German	1.855	1.358	1.366	.172
Language_Italian	-0.394	1.979	-0.199	.842

Table C. Output of the GLMM for RQ2/RQ3, in NT children only, in GM sentences

	Est.	Std. Error	z value	*p*
(Intercept)	3.663	0.350	10.480	< .001
L2 proficiency	-0.018	0.177	-0.103	.918
Age	0.343	0.159	2.157	.031
Non-verbal IQ	0.559	0.189	2.965	.003
Receptive Vocabulary in L1 (PPVT)	-0.043	0.146	-0.292	.770
Language_English	0.247	1.707	0.144	.885
Language_French	2.632	1.964	1.340	.180
Language_German	-3.165	1.434	-2.207	.027
Language_Italian	-2.870	1.727	-1.662	.096

Table D. Output of the GLMM for RQ2/RQ3, in autistic children only

	Est.	Std. Error	z value	*p*
(Intercept)	1.736	0.184	9.436	< .001
L2 proficiency	0.331	0.144	2.301	.021
Gm vs. GM [a]	-0.590	0.166	-3.563	< .001
gM vs. GM [b]	-1.003	0.165	-6.068	< .001
Sentence type [omnibus]	0.031	0.202	0.154	.878
Age	0.628	0.122	5.133	.000
Non-verbal IQ	0.065	0.120	0.544	.587
Receptive Vocabulary in L1 (PPVT)	0.370	0.077	4.806	< .001
Language_English	-4.705	1.516	-3.104	.002
Language_French	2.035	1.003	2.030	.042
Language_German	4.334	1.295	3.348	.001
Language_Italian	0.855	2.179	0.392	.695
L2 proficiency: Gm vs. GM [a]	0.087	0.094	0.924	.356
L2 proficiency: gM vs. GM [b]	-0.091	0.093	-0.970	.332
L2 proficiency: Sentence type [omnibus]	0.039	0.113	0.342	.733

This study provides novel evidence that bilingualism influences metalinguistic awareness in neurotypical and autistic children in distinct ways. While bilingual autistic children, as a group, demonstrated better performance on sentences engaging *cognitive control* compared to their monolingual peers, no such effect was visible in the neurotypical group. Importantly, autistic children with greater L2 proficiency exhibited better overall metalinguistic performance than peers with lower L2 proficiency. This finding reinforces the idea that dual-language exposure is not detrimental and can, in fact, be beneficial for cognitive and linguistic outcomes in autistic individuals. To my knowledge, this is the first study to demonstrate a (positive) impact of bilingualism on metalinguistic performance in autistic children, challenging misconceptions about the potential drawbacks of bilingual exposure in this population.

In the next chapter, I will focus on another higher-order skill of communication that is tightly linked with both linguistic and cognitive factors: narrative macrostructure. The next study will examine the effect of exposure to additional languages on narrative macrostructure in school-aged neurotypical and autistic children. In addition, it will explore whether Theory of Mind, working memory, and metalinguistic awareness influence macrostructure.

6 Narrative macrostructure

6.1 Bilingualism effects on narrative macrostructure in autistic and neurotypical children

The impact of exposure to additional languages and cognitive factors on narrative macrostructure in autistic and neurotypical children

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Data availability statement. The data that support the findings of this study, and code to reproduce the analyses are openly available in OSF at https://osf.io/6xmj2/ [DOI 10.17605/OSF.IO/6XMJ2]

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the author(s) used ChatGPT to assist with revision and proofreading. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.

Abstract

This study adopts a twofold approach to examine how bilingual exposure and (socio-)cognitive factors influence narrative macrostructure in children. First, it investigated the impact of *Exposure to Additional Languages* (EtAL) on the narrative macrostructure of 90 autistic and 168 neurotypical children (ages 5–12), tested in their most proficient language, either English, French, (Swiss-)German, Italian or Spanish. Macrostructure was assessed through story structure, story complexity, and the mention of Internal State Terms (IST), using a series of generalized mixed effects models controlling for age, sex, language skills, and non-verbal IQ. Among neurotypical children, greater EtAL predicted better story structure compared to peers with lower EtAL. No such effect was found in autistic children, suggesting that the potential benefits of EtAL may not extend equally across populations. Additionally, EtAL did not predict story complexity or IST-use in either group. Second, the study investigated the impact of Theory of Mind (ToM), working memory (WM), and metalinguistic awareness (MA) on macrostructure. While ToM and WM showed no significant effects, MA positively predicted story structure across groups. Findings indicate that dimensions of narrative macrostructure may benefit from exposure to multiple languages and MA, especially in neurotypical children. Results further support that bilingual exposure is not detrimental to the communicative development of autistic children. Leveraging a large, neurodiverse sample and a continuous, hypothesis-driven measure of bilingualism, this study offers generalizable insights into how bilingualism and (socio-)cognitive factors influence narrative development across neurodiverse populations.

Keywords

Narrative Macrostructure; Autism Spectrum Disorder; Bilingualism; Theory of Mind; Working Memory; Metalinguistic Awareness

Bilingualism, the use of and exposure to multiple languages regardless of proficiency (Grosjean, 1982), is known to influence various aspects of communication, language development, and cognition (Adesope et al., 2010; Bialystok, 2009; Bonuck et al., 2022). Research suggests that bilingual exposure influences linguistic outcomes, yet its specific effects on narrative macrostructure, the overall organization and structure of a story (Berman, 2009; Trabasso & Nickels, 1992), remains unclear. Exposure to additional languages (EtAL) provides access to diverse linguistic structures and storytelling conventions, potentially influencing how individuals structure and organize their narratives (i.e., narrative macrostructure) in the dominant language (Bruner, 1990; Minami, 2002). Different languages emphasize distinct ways of sequencing events, expressing causality, and expressing mental state (Bliss & McCabe, 2008; Tannen, 1980). As a result, children with greater EtAL may develop richer narratives than peers with lower EtAL, integrating elements from multiple languages. Yet, the impact of EtAL on macrostructure remains underexplored, especially in children with Autism Spectrum Disorder (ASD), who often face challenges in this realm (Baixauli et al., 2016).

Effective narrative production not only relies on rich language abilities, but also on higher-order (socio-)cognitive abilities, such as the ability to understand and attribute thoughts and emotions to others (Theory of Mind; ToM), to temporarily store and manipulate information (Working Memory; WM), and the ability to reflect on and manipulate language structures (Metalinguistic Awareness; MA). Autistic children, who often face challenges in these very domains, also experience difficulties with narrative coherence and organization. However, the relative contributions of ToM, WM, and MA to narrative macrostructure in both autistic and neurotypical (NT) children remain insufficiently understood.

The current study aimed to address these knowledge gaps by (1) examining whether EtAL impacted the narrative macrostructure of NT and autistic children, and (2) determining the respective contributions of ToM, EF and MA in narrative macrostructure. Specifically, we were interested in examining whether children with a greater exposure to languages other than their L1 (i.e., language with the highest proficiency) would present richer macrostructure skills. This continuous operationalization of bilingual exposure overcomes the limitations of monolingual *versus* bilingual group comparisons (De Houwer, 2023) and allows a more nuanced investigation of how varying levels of bilingual exposure impact narrative macrostructure in both autistic and NT children.

1. Narrative macrostructure

1.1. Narrative macrostructure: theoretical background

Oral narrative production, the ability to produce verbal "account[s] of events occurring over time" (Bruner, 1991, p. 6), are fundamental to human communication (Gagarina et al., 2016). Strongly linked to the development of literacy and associated with academic achievement (Bishop & Edmundson, 1987; Bliss et al., 1998), narratives develop from preschool throughout primary school (Berman, 2009). Narratives are typically analyzed at two distinct, yet complementary levels of competence: *microstructure*, the linguistic-related aspects of the discourse, such as morphosyntactic accuracy and lexical diversity, and (2) *macrostructure*, referring to the overarching organization, structure and coherence of the story, assumed to reflect "underlying mental narrative schema[s]" (Bohnacker, 2016, p. 21).

The richness of narrative productions can be analyzed through *story grammar models* (Stein & Glenn, 1979), a theoretical framework enabling to examine macrostructural elements systematically across studies with various populations. According to this framework, stories contain both a *setting,* on the one hand, and an *episode* structure that relates the events, on the other (Stein & Glenn, 1979; Westby, 2005). While the setting specifies the context of the story (e.g., time and place, protagonists), the *episode* consists of a sequence of different constitutive components: (1) a Goal (G) pursued by the protagonist, (2) a protagonist's Attempt (A) to reach the goal, and (3) an Outcome (O) resulting from the attempt and pertaining to the goal (Westby, 2005).

This framework underpinned the *Multilingual Assessment Instrument for Narratives* (MAIN; Gagarina et al., 2012, 2019), a tool to assess narrative skills via telling, retelling and model story in various populations. MAIN comprises four parallel stories, each with a carefully designed six-picture sequence controlled for micro- and macrostructure, as well as linguistic, cognitive and cultural appropriateness. It additionally provides standardized scoring scheme to enable systematic evaluation. Because of this theoretically based design, standardized procedure of elicitation, scoring and analyses, MAIN has been adapted in 100 languages and is widely used by researchers and clinicians in bilingual populations of various ages, cultural backgrounds and developmental profiles, such as children with Developmental Language Disorders (DLD), Down Syndrome or ASD (see Lindgren et al., 2023 for an overview; Mattiauda et al., 2024).

MAIN enables to assess three macrostructural dimensions: *story structure*, *story complexity* and the *use of internal states terms*. *Story structure* indexes the quantity aspect, reflecting the number of episodic elements such as goals, attempts, outcomes stated by the speaker, while *story complexity* reflects the quality dimension, measuring the combination of these elements to deliver well-formed episodes (i.e., with the full Goal-Attempt-Outcome sequence showing higher complexity and more developed narrative construction; Gagarina et al., 2012). Finally, the use of *IST* reflects the speaker's

"awareness of the goals and intentions of characters"(Altman et al., 2016, p. 168). *Internal state terms* refer to words describing thoughts, feelings, intentions and internal experiences of oneself and others, such as metacognitive verbs (e.g., to think, to want) or words expressing emotions (e.g., happy). On the one hand, IST provides an indication of a speaker's Theory of Mind (ToM), the ability to attribute mental states to others, and to predict their behaviors based on these beliefs (Baron-Cohen et al., 1985; Premack & Woodruff, 1978). On the other hand, they appear as relevant contributors to produce coherent and developed narratives, as a speaker must consider both the mental representation of the story's characters and the listener's state of knowledge to be rightfully informative (Altman et al., 2016; Westby, 2005). As such, narrative macrostructure involves different socio-cognitive factors, including ToM (see section 3).

1.2. Narrative macrostructure in ASD

Children diagnosed with ASD experience persistent difficulties with social communication while presenting a great heterogeneity of cognitive and linguistic profiles (American Psychiatric Association, 2022; Schaeffer et al., 2023; Silleresi, 2023). A meta-analysis conducted on studies investigating narrative skills in autistic children with an IQ in the normal range revealed major challenges in narrative macrostructure, as compared to neurotypical (NT) peers, with a large-effect size (Baixauli et al., 2016). Narrative productions of autistic children and adolescents tend to be less coherent, less well connected and structured within the *story grammar* framework than those of neurotypical peers (Baixauli et al., 2016; Diehl et al., 2006; Stirling et al., 2014). Children with ASD have been shown to produce narratives lacking key story grammar elements, and containing more irrelevant comments (Norbury et al., 2014). As effective storytelling also relies on socio-pragmatic skills, such as adapting to the context and the audience (Ketelaars et al., 2016; Norbury et al., 2014), difficulties in narrative macrostructure have been associated with their challenges with socio-pragmatic abilities (Beauchamp et al., 2023). Pertaining to IST-use, findings are rather mixed: While some studies find that autistic children produce fewer terms relative to mental and affective states than NT peers (Begeer et al., 2010; Diehl et al., 2006), other studies observe no differences in IST production between groups (Capps et al., 2000; Greco et al., 2023; Tager-Flusberg & Sullivan, 1995).

Narrative macrostructure thus varies across populations with different cognitive profiles such as autistic children, and is likewise influenced by diverse language experiences, including bilingualism.

2. Bilingualism effects

2.1. Bilingualism effects on narrative macrostructure in NT children

Investigating the impact of bilingualism on narrative macrostructure provides valuable insights into how dual language exposure affects narrative skills. Studies on the relationship between bilingualism and narrative macrostructure in NT children have yielded controversial results. A handful of studies comparing mono- and bilingual children showed that bilinguals outperform monolinguals on narrative macrostructure (e.g., Chen & Yan, 2011; Tsimpli et al., 2016 on story structure and IST). Specifically, the study by Tsimpli et al. (2016) revealed that typically developing bilingual children performed better in story structure and produced significantly more ToM-related language, namely emotion and mental state terms, in their narratives than their monolingual peers. In contrast, the work by Lindgren (2018) demonstrated that Turkish-Swedish bilinguals exhibited notably lower performance in story structure compared to their Swedish monolingual peers. Furthermore, other studies on macrostructure production found comparable performance between monolinguals and bilinguals on story structure, IST use (Boerma et al., 2016; Haman et al., 2017; Rodina, 2017 for the L2 Norwegian of Russian-Norwegian bilinguals) and story complexity (Kunnari et al., 2016) across monolingual and bilingual children.

Apart from a monolingual *versus* bilingual categorization, some other studies have sought to highlight the effect of exposure on narrative macrostructure, generally focusing on bilingual children only. They opted for different measures, including the amount of exposure, the Age of Onset of bilingualism, or the Length of Exposure, and yielded mixed results (Lindgren et al., 2023). Particularly, in terms of amount of exposure, studies usually focused purely on whether the exposure to a particular language was crucial for narrating in that language (e.g., Lindgren, 2018). Evidence on whether exposure to additional languages impacts narrative production in the L1is limited. For instance, Haman et al (2017) investigated both L1 and L2 language exposure on L1 narrative performance of Polish-English bilingual children. Results indicated that children's narrative skills in L1 were strongly associated with exposure both to the L1 and the L2. This evidence supports the idea that exposure to additional languages benefits the production of narrative macrostructure in bilinguals.

This idea is further reinforced by the fact that differences in storytelling styles exist between languages and cultures: Speakers may structure events and discourse elements in different ways depending on the languages they are exposed to (Bruner, 1990; Minami, 2002). Cultural communicative styles differ in the focus of the story (e.g., emphasis on *how* or *why* an event happened; Tannen, 1980), or on what is considered a 'good story' (chronological, goal-driven sequence versus overall thematic maintenance, indication of emotions; Bliss & McCabe, 2008; Minami, 2002; Tannen, 1980). Since narrative macrostructure is largely language-independent

(Bohnacker et al., 2022; Lindgren et al., 2023), children may benefit from these different storytelling styles and integrate them in the narrative macrostructure of their L1, thereby resulting in richer narrative macrostructure. More studies are still needed to investigate this possibility.

2.2. Bilingualism effects on narrative macrostructure in autistic children

In research focusing on the autistic population, findings are scarcer, although more consistent. A handful of studies investigating bilingualism effects on narrative macrostructure reported null effects (Baldimtsi et al., 2016; Beauchamp et al., 2023; Hoang et al., 2018; Peristeri et al., 2020). Peristeri et al. (2020) examined narrative abilities in a sample of twenty bilingual and twenty monolingual autistic boys aged 7;5 - 12;0 matched on chronological age. While bilingual children outperformed their monolingual peers in story structure complexity – a composite measure including both the presence of story grammar elements (i.e., story structure) and the complexity of goal-directed episodes (i.e., story complexity), no group difference was observed in the production of IST. These findings closely replicated those of Baldimtsi et al. (2016), which used a similar narrative elicitation task and design in a smaller, independent sample of six bilingual and six monolingual autistic children of the same age range. Hoang et al. (2018) further confirmed the lack of differences in the use of evaluative devices (including IST), in a study including five autistic bilinguals and five autistic monolinguals. In addition, groups did not differ in their measure of *story structure* either. Finally, Beauchamp et al. (2023) reported no difference in narrative story structure in 10-year-old autistic bilinguals, as compared to their aged-matched monolingual peers. In this study, relative exposure to the language of testing (in proportion) did not significantly correlate with narrative macrostructure in the autistic participants (N=134; Beauchamp et al., 2023).

These studies offer insights into the narrative abilities of autistic children from various language backgrounds. They are valuable to the autistic community, where language-related challenges are often a primary concern for caregivers (Beauchamp & MacLeod, 2017; Drysdale et al., 2015). However, the limited sample sizes (i.e., six participants in Baldimtsi et al., (2016); five in Hoang et al., (2018); twenty in Peristeri et al., (2020) in each group) raises questions about the generalizability of the findings and the possibility to detect significant effects (Schäfer & Schwarz, 2019).

Both the heterogeneity observed in the NT population (*Section 2.1*), and the apparent absence of effect in the autistic population (*Section 2.2*), may reflect the oversimplified treatment of bilingualism as a binary construct (i.e., monolingual *versus* bilingual groups). Bilingualism is inherently multidimensional, with individuals varying notably in their language exposure, proficiency levels, age and mode of acquisition, language combinations (Marian & Hayakawa, 2021; Unsworth, 2016). Grouping participants based on an arbitrary bilingual criterion (e.g., a specific percentage of exposure to a second language) may obscure the nuanced individual differences in the

bilingual experiences (De Houwer, 2023). Yet, measuring and accurately capturing bilingualism is challenging (Kašćelan et al., 2021; Marian & Hayakawa, 2021; Surrain & Luk, 2019). Providing a transparent description of the sample and justifying the selection of bilingual variables based on research hypotheses may help disentangle the specific impact of targeted bilingual dimensions on the outcome (Byers-Heinlein et al., 2019), in both neurotypical (Surrain & Luk, 2019) and autistic individuals (Hantman et al., 2023). A hypothesis-driven approach to select the bilingual variables under study may also clarify which aspects of the bilingual experience are most relevant (Hantman et al., 2023; Surrain & Luk, 2019).

3. Cognitive factors related to narrative macrostructure

Delivering rich, coherent narratives arguably involves the interplay of several socio-cognitive factors besides mere linguistic skills. Specifically, it has been hypothesized that the lower performance in narrative macrostructure exhibited by autistic children could result from reduced abilities in abilities involved in the narrative task, such as ToM and WM (Baixauli et al., 2016).

Theory of Mind plays an important role in effective storytelling by allowing individuals to convey story characters' mental states, thereby promoting detailed and cohesive narratives (Nicolopoulou & Richner, 2007; Pelletier & Astington, 2004; Trabasso & Nickels, 1992). Previous research reports positive associations between ToM abilities and narrative competence, in neurotypical children (Gamannossi & Pinto, 2014). Similarly, associations between ToM understanding and narrative competence are described for autistic individuals (Capps et al., 2000; Tager-Flusberg & Sullivan, 1995). However, inconsistent findings are reported in both populations (absence of correlation in NT children in Charman & Shmueli-Goetz, 1998; in ASD: Losh & Capps, 2003).

In addition, producing a coherent narrative requires higher-order skills such as WM. Working memory refers to the ability to temporarily hold information in mind and manipulate it in order to accomplish a task or purpose (Baddeley & Hitch, 1974). It is critical for reasoning, connecting thoughts and perceptions to create a meaningful knowledge, and it is a core aspect of executive functions, which are top-down cognitive processes implemented to achieve a goal (Diamond, 2013). Working memory is necessary for narrative construction, enabling the narrator to maintain a coherent overall structure by tracking the main events and characters, organizing them into a logical sequence, and ensuring consistency throughout the story (Veraksa et al., 2020; Whitely & Colozzo, 2013). Previous works showed positive associations between WM and narrative competence in NT children aged 5-6 (Veraksa et al., 2020; Whitely & Colozzo, 2013).

Finally, MA, the ability to reflect upon language as an object of thoughts (Tunmer & Herriman, 1984), also appears to be important for narrative macrostructure (Cortazzi & Jin, 2007; Kupersmitt et al., 2014; Russak & Zaretsky, 2021). For instance, MA may facilitate self-monitoring of speech,

enabling speakers to detect and correct linguistic inaccuracies at the phonological, lexical or morphosyntactic levels. This, in turn, supports narrative coherence and fluency, key components of macrostructure (Kormos, 2006; Levelt, 1989). It also helps refining lexical choices, to adjust and adapt to the audience and their feedback while telling the story (Cortazzi & Jin, 2007). Oral narratives elicited based on pictures require the understanding and synthesis of the events depicted into a coherent story so as to maintain the logical flow (Tunmer & Bowey, 1984). It requires understanding and inferring the temporal and causal relationships between the events for each protagonist, and organizing stories according to story schemata (Westby, 2005). Better knowledge of the story grammar elements that are present in any narratives, and awareness of the context of the story delivery, both lead to more coherent and well-formed narratives (Westby, 2005).

The assumption that autistic individuals would be impaired in narrative macrostructure because of primary difficulties in factors involved in the task is therefore plausible (Baixauli et al., 2016). Autistic children, indeed, present consistent impairments in both phonological and visual WM (Habib et al., 2019), and challenges with ToM are well established (e.g., Baron-Cohen et al., 1985; Mazza et al., 2017; Tager-Flusberg, 2007), compared to NT peers. In addition, autistic children have been reported to have difficulties with tasks engaging metalinguistic knowledge (Lewis et al., 2007), although recent work nuances this finding when language abilities are controlled for (Wolfer et al., 2024). While challenges with these skills may arguably have cascading effects on the narratives of autistic children, the empirical contribution of WM, ToM and MA on narrative macrostructure remains to be determined in children with varying exposure to languages.

4. Research questions

The study has two main objectives. It first compared narrative macrostructure - measured as *story structure*, *story complexity*, and *IST-use* - in autistic and neurotypical children across several L1s: English, French, German, Swiss German, Italian, and Spanish. Cross-linguistic comparisons are justified given that story complexity has been shown to be relatively stable across languages and less dependent on language-specific features, while story structure, although more language-sensitive, can still be compared meaningfully when language background is considered (Gagarina et al., 2019; Bohnacker, 2022). In the present study, language was included as a covariate in the statistical models to account for both its impact and potential differences across L1s. Precisely, we investigated the impact of the exposure to additional languages over the past twelve months (EtAL) on narrative macrostructure, as well as the contribution of cognitive-related skills including WM, ToM, and MA. We specifically focused on current, relative exposure to additional languages rather than categorizing bilinguals using a binary criterion (e.g., simultaneous vs sequential), so as to capture recent linguistic input and sensitivity to shifts in recent language environment, which is particularly relevant for school-aged children (Beauchamp et al., 2023; Gonzalez-Barrero & Nadig, 2018;

Unsworth, 2016). Given that language use and exposure fluctuate over time, measuring recent input provides valuable insight into how linguistic contact may influence narrative organization.

This study aimed to determine: *(1) How exposure to additional languages in the past twelve months (EtAL) affects the narrative macrostructure, measured as story structure, story complexity and IST, in the L1 of autistic and NT children?*

We predicted that, in both groups, increased EtAL would enhance macrostructure, measured as *story structure, story complexity and IST*. Prior research has shown that exposure to multiple languages can influence how individuals structure and organize narratives in their dominant language, by providing access to diverse linguistic structures, discourse styles, and storytelling conventions (Bruner, 1990; Minami, 2002). Therefore, greater EtAL was expected to enhance children's ability to organize, elaborate, and enrich their storytelling by providing linguistic and cultural richness and exposing them to multiple narrative styles and communicative conventions. This, in turn, may foster the ability to structure stories more effectively, incorporate nuanced details such as including internal state terms, resulting in richer narratives. Additionally, the exposure and managing of multiple linguistic systems may enhance children's understanding of story grammar elements, and the ability to monitor and sequence information to produce clear narratives. Alternatively, in line with prior research reporting null effects of bilingualism in the autistic population on macrostructure (e.g., Beauchamp et al., 2023; Hoang et al., 2018), the effect of EtAL may be absent in autistic children.

Since narrative macrostructure has been hypothesized to rely on ToM, WM and MA, we furthermore explored whether these factors would moderate the potential relationship between EtAL and narrative macrostructure in autistic and neurotypical children. The second research question aimed to elucidate: *(2) How do ToM, WM and MA impact narrative macrostructure measured as story structure, story complexity and IST in autistic and NT children presenting different EtAL?*

We predicted that cognitive-related skills (i.e., ToM, WM, and MA) would positively impact narrative macrostructure in both neurotypical and autistic children. Specifically, for *story structure*, we predicted that greater ToM abilities, WM and MA would lead to higher production of story grammar elements. For *story complexity*, we predicted that ToM, WM and MA would significantly contribute to the production of more complex story episodes, since this dimension, and especially the production of its inferred components (e.g., Goal), is related to higher-order cognitive skills. It requires the ability to understand and express the protagonists' emotional state, but also to hold in memory and properly combine the story components (i.e., Goal, Attempt, Outcome) to achieve higher complexity of the story. For *IST*, we predicted that children with greater ToM would produce more IST, particularly terms related to ToM (i.e., ToM-related IST). We thus expected autistic children to produce fewer ToM-related IST than their neurotypical peers (Begeer et al., 2010; Diehl et al., 2006).

Methods

Participants

A total of *N* = 258 children (39% girls, 61% boys) between 5;0 and 11;11 years old participated in this study. The group of autistic participants included *N* = 90 children (106 ± 22.7 months; 5;1 – 11;11 years old), formally diagnosed with ASD following the criteria of the DSM-5 (American Psychiatric Association, 2022), prior to the study by a certified clinician. The group of neurotypical children included *N* = 168 children (99.7 ± 23.3 months, 5;0 – 11;11) with no reported suspicion or diagnosis of ASD, nor any other developmental disorder. Caregivers completed the *Social Communication Questionnaire* (*SCQ*; Rutter et al., 2003), and NT participants had scores below 15, confirming the absence of significant social communication difficulties associated with ASD. Participants were recruited via flyers, websites, contact with clinicians, schools and autism centers. Children were tested in Europe (Switzerland, France, Germany, Spain, UK) and North America (USA, Canada).

NT children were significantly younger than autistic peers ($W = 8686$, $p = .049$), had stronger L1 language skills ($W = 3847$, $p < .001$) and came from families with higher parental education levels ($W = 4793$, $p < .001$). Nonetheless, parental education was high in both groups, with most caregivers holding post-secondary degrees. The autistic group included more boys (82%) than the NT group (49%), reflecting the well-documented sex ratio imbalance in autism(American Psychiatric Association, 2022; Zeidan et al., 2022). Following prior studies on narrative macrostructure in ASD (Hoang et al., 2018; Peristeri et al., 2020), only children with non-verbal IQ ≥ 80 were included. Autistic participants had significantly lower non-verbal IQ scores than NT peers ($W = 5503$, $p < .001$). Autistic participants had on average lower IQ than NT children ($W = 5503$, $p < .001$). Given group differences in variables known to influence narrative macrostructure - *age* (Bohnacker, 2016; Gagarina et al., 2016), non-verbal IQ (Botting, 2005), *L1 language skills* (Bohnacker, 2016; Fiani et al., 2022), and *sex* (Kauschke et al., 2016) - these were statistically controlled in statistical analyses. See Table 1 for detailed sample characteristics.

Table 1. Sample characteristics

	Autistic children N = 90	NT children N = 168	Test and *p*-value
Age (months)	106 (22.7)	99.7 (24.2)	$W = 8686$, $p = .048$
Sex assigned at birth			
Female	16 (17.8%)	85 (50.6%)	$\chi^2 (1) = 25.16$, $p < .001$
Male	74 (82.2%)	83 (49.4%)	
Parental educational level[a]	4.01 (1.09)	4.70 (0.67)	$W = 4793$, $p < .001$
General Language skills[b]	-0.68 (1.63)	0.39 (0.95)	$W = 3847$, $p < .001$
Non-verbal IQ	97.7 (12.6)	103 (11.0)	$W = 5503$, $p < .001$
SCQ score	20.1 (7.40)	4.20 (3.03)	$W = 5345$, $p < .001$
WM span	3.40 (2.23)	4.22 (1.75)	$W = 5560$, $p = .009$
ToM	12.7 (3.88)	17.8 (2.09)	$W = 1689.5$, $p < .001$
MA	0.77 (0.26)	0.84 (0.24)	$W = 5629$, $p = .005$
Testing language			
N English	11 (12.2%)	33 (19.6%)	
N French	34 (37.8%)	38 (22.6%)	
N German	16 (17.8%)	56 (33.3%)	
N Swiss German	2 (2.2%)	14 (8.3%)	
N Italian	19 (21.1%)	11 (6.5%)	
N Spanish	8 (8.9%)	16 (9.5%)	

Note. Mean (SD) are presented. SCQ : Social Communication Questionnaire (range 0 – 40).

Missing data: SCQ (ASD = 6, NT = 2); WM (ASD = 5, NT = 5); ToM (ASD = 3, NT = 2); MA (ASD = 4, NT = 1).

[a] Parental education was determined by the highest reported value between the two caregivers, corresponding to the highest level of schooling achieved, from (1) primary school to (5) university.

[b] Composite z-score for receptive vocabulary and morphosyntax.

All children were tested in their most proficient language (L1), defined via parental ratings from the Quantifying Bilingual EXperience questionnaire (*Q-BEx*; De Cat et al., 2022), either in English, French, German, Swiss German, Italian, or Spanish. This questionnaire was used to retrieve information of the participants' experience on up to three languages, such as their relative exposure and estimated proficiency in each language. For proficiency, parents indicated on a 4-point Likert scale the child's abilities in *speaking*, *understanding*, *reading* and *writing* in each language. Scores were summed by language, converted into a percentage of proficiency. The L1 corresponded to the language in which the individual demonstrated the highest proficiency. EtAL was calculated as the percentage of time children were exposed to any language other than their L1 over the past 12 months. For example, a monolingual child had an EtAL of 0; a child exposed equally to L1 and L2 had an EtAL of 50. Sample specifications pertaining to bilingual experiences are presented in Supplementary Material S1.

Procedure

Participants were tested individually in a quiet room in their most proficient language. They were accompanied by a trained experimenter and could take as many pauses as they wanted. Testing took place in several sessions and included the tasks presented in the *Materials* section below.

Materials

1. NARRATIVE ASSESSMENT

Administration. The *Multilingual Assessment Instrument for Narratives* (*MAIN*; Gagarina et al., 2012, 2019) was used to elicit oral narratives in children's most proficient language. It was selected for its suitability with multilingual populations and potential for systematic comparisons across studies. The standardized task administration procedure and scoring scheme in "telling" mode were followed, and children were allowed to choose which story they wanted to tell, either *Baby Birds* or *Baby Goats*. These two parallel stories are considered comparable in terms of story length, story grammar, plotline and number of protagonists. Each story consisted of six pictures, depicting a series of events constituting three episodes (Goal – Attempt - Outcome). Participants were invited to look at the pictures as long as they wished. They were then asked to tell the story to a stuffed toy, a naive listener blind to the story who could not see the pictures. Pictures were unfolded two by two as the participant told the story. Forty-seven percent of the sample selected the *Baby Birds* story (respectively 51% of the autistic group, 43% of the NT group), 54% told the *Baby Goats* story (49% of the autistic group, 57% in the NT group).

Coding and Scoring. Productions were transcribed verbatim by native speakers of each language, namely the first author and trained research assistants blinded to the groups and study hypotheses. The MAIN scoring grid (Gagarina et al., 2019) was then followed to compute macrostructure scores: First, to assess *story structure (*i.e., the quantity measure), each stated element of the story grammar was awarded 1 point (i.e., story setting specification in time or place; IST statement to initiate an event or describe the final situation of an episode; (G) Goal, (A) Attempt or (O) Outcome mention). The maximum score possible was 17. Second, *story complexity* (i.e., the quality measure) was evaluated by determining the level of complexity in each of the three episodes. A score of 0 was given if no G, A or O was expressed in an episode. A score of 1 would be given if either A, O or AO was produced, a score of 2 would be given if either G, GA or GO was expressed. Finally, a score of 3 was given if a full GAO episode was verbalized. The maximum score for story complexity was 9 (max = 3 for each episode). Third, the production of *IST* was identified. Following Peristeri et al. (2020), IST were further classified into two separate categories: terms associated with ToM (i.e, called "ToM-related ISTs"), such as terms conveying emotions, intentions, desires (e.g., "sad", "think", "want"), and

terms considered unrelated to ToM, such as perceptual, physiological or linguistic terms (i.e., "ToM-unrelated ISTs", like "see", "smell", "say"). Each occurrence, even repetitions, was awarded 1 point.

Inter-rater reliability. 26.79% of the transcriptions and coding were independently transcribed and coded a second time by native speakers of the respective languages. Coders were trained research assistants, blind to the study hypotheses and groups. Any discrepancy between the transcriptions and scores were discussed and resolved by mutual agreement to reach 100% similarity.

2. NON-VERBAL IQ

The short, online version of the *Raven's Progressive Matrices* (Raven's-2; Raven et al., 2018) was used to assess non-verbal reasoning. Participants chose one option among five that best matched the geometric pattern containing a missing piece displayed on the screen. The resulting standardized non-verbal IQ score (100 ± 15) was computed.

3. LANGUAGE SKILLS

Participants completed a digital version of the *Test for Reception of Grammar* (TROG; Bishop, 2003) to assess their receptive morphosyntactic abilities in the testing language, and the digital version of the *Peabody Picture Vocabulary Test* (PPVT-4; Dunn & Dunn, 2007) evaluated their receptive vocabulary breadth (see Supplementary Material S2 for the references of the different language versions). Participants listened to pre-recorded words (for the PPVT) and sentences with increasing morphosyntactic complexity (for the TROG) and selected the corresponding image from four options on screen. Z-scores, compared to the manuals' reference norms of each language, were calculated separately for the TROG and the PPVT. The average of the two z-scores was used in the analyses to create a composite score reflecting both lexical and morphosyntactic proficiency, following the approach of Engberg-Pedersen (2018) and Yau et al. (2016). Because no Swiss German version of the PPVT and TROG exists, the 16 participants (14 NT children, 2 autistic children) who told the story in Swiss German completed the German version of these tasks, as the two languages are closely related (Scherrer, 2012).

4. THEORY OF MIND

Caregivers completed the *Theory of Mind Inventory 2* (ToMI-2; Hutchins et al., 2012) rating 60 statements on a 0–20 scale to assess children's everyday ToM abilities. For this study, we focused on 16 items relevant to narrative production: the six assessing mental state understanding (e.g., *"My child understands the word 'want'."*) and the ten items targeting emotion recognition ("*My child recognizes when others are sad."*). The average of these items (range: 0–20) was used as the ToM score, reflecting socio-cognitive skills likely involved in the MAIN storytelling task.

5. WORKING MEMORY

To assess WM, the *Frogs Matrices Task* (FMT) adapted by Morales et al. (2013) was administered. Children had to recall the reverse order of positions of 2 to 6 frogs presented sequentially. The memory span was determined by the longest sequence of frogs that the participant could accurately recall in at least one of the two trials (i.e., ranging between 0 and 6).

6. METALINGUISTIC AWARENESS

Metalinguistic awareness was assessed using a non-verbal, digital Grammatical Judgment Task (GJT) minimizing cognitive and linguistic demands (Wolfer et al., 2024). Participants judged the grammaticality of 16 semantically appropriate sentences (8 grammatically correct, 8 incorrect) by selecting either a candy or a sock to feed a cartoon monster. To account for response bias (e.g., tendency to judge all sentences as correct), an MA-score was calculated using the following formula from Linebarger et al. (1983): MA-score = 0.5 + (y – x) (1 + y – x) / 4y (1 x), where x = false alarm rate, and y = hit rate. Scores range from 0 (poor discrimination) to 1 (perfect), with 0.5 indicating chance performance.

Statistical plan

To investigate the impact of *EtAL* on narrative macrostructure (RQ1), and the influence of WM, ToM, and MA on performance (RQ2), generalized linear models were fitted separately for each macrostructure dimension (i.e., *story structure*, *story complexity*, *IST-use*). Both RQ1 and RQ2 were examined with the same model for each dimension. All models included *age*, *group*, and *EtAL* (and their interactions), along with covariates (*language skills*, *non-verbal IQ*, and *sex*). Socio-cognitive variables were added stepwise, and model selection was based on AIC. Full information is presented in Supplementary Material S3.

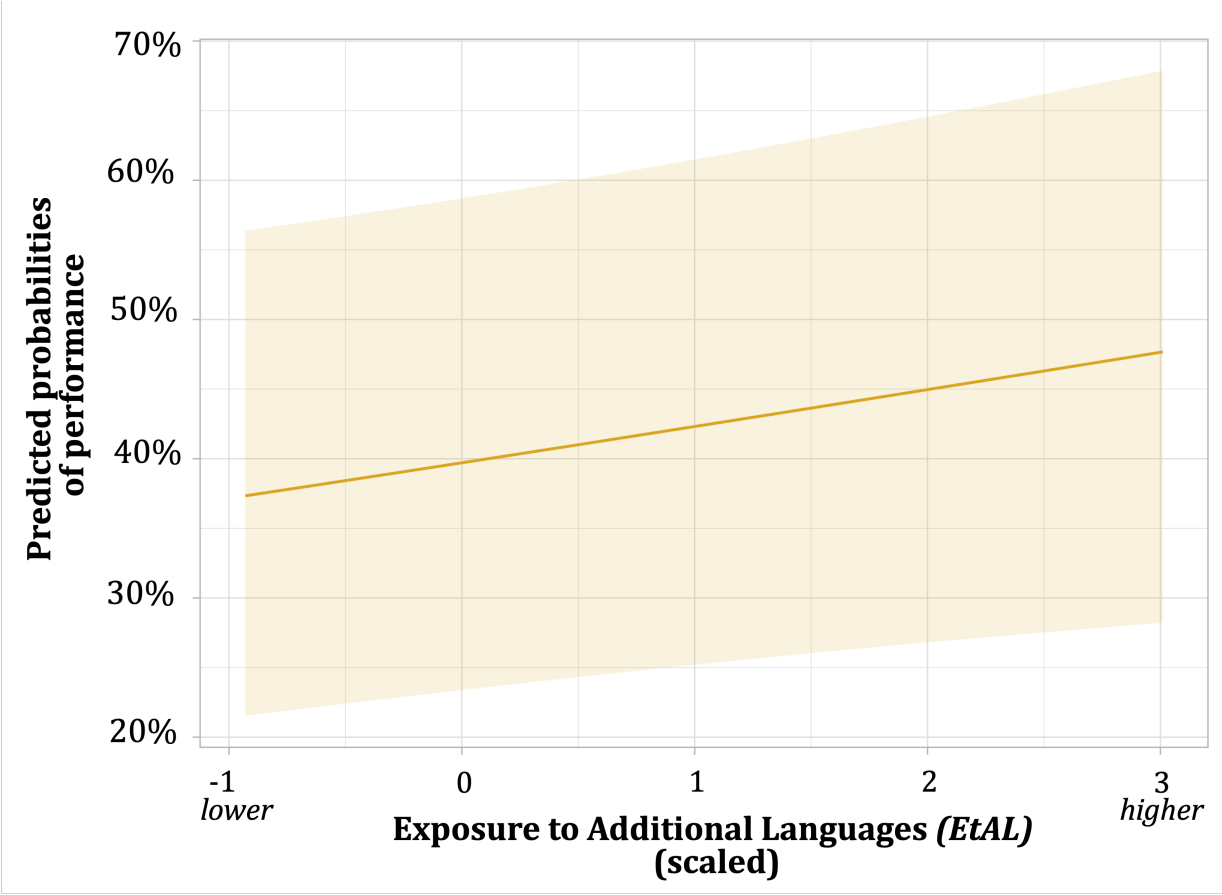
Results

STORY STRUCTURE. On a possible maximum score of 17, the group of autistic children obtained a mean score of 5.42 ± 2.48 SD, ranging from 0 to 12 (median value: 5). The group of NT children obtained a mean score of 6.72 ± 2.16 SD, ranging from 1 to 13 (median value: 6.5).

The best model for STORY STRUCTURE was the model with the maximal structure (Supplementary Material S3, Table S4A): it revealed a significant interaction between *group* and *EtAL* (β = -0.20, SE = 0.10, z = -1.96, p = .049). Simple effects analyses were further conducted to locate the source of the interaction. In NT children, EtAL positively impacted performance (β = 0.11, SE = 0.06, z = 1.97, p = .048; Table S4B): NT children with greater EtAL obtained significantly better scores on story structure, than children with lower EtAL (Figure 1). This effect, however, was not detected in autistic children (β = -0.06, SE = 0.09, z = -0.71, p = .47; Table S4C), suggesting a different impact of EtAL in the two groups.

Performance improved with age (β = 0.19, SE = 0.06, z = 2.85, p = .004; Table S4A), and girls outperformed boys (β = 0.34, SE = 0.10, z = 3.47, p < .001). Metalinguistic awareness also significantly predicted story structure (β = 0.11, SE = 0.06, z = 1.98, p = .047), while ToM and WM did not yield significant effects (all ps > .05).

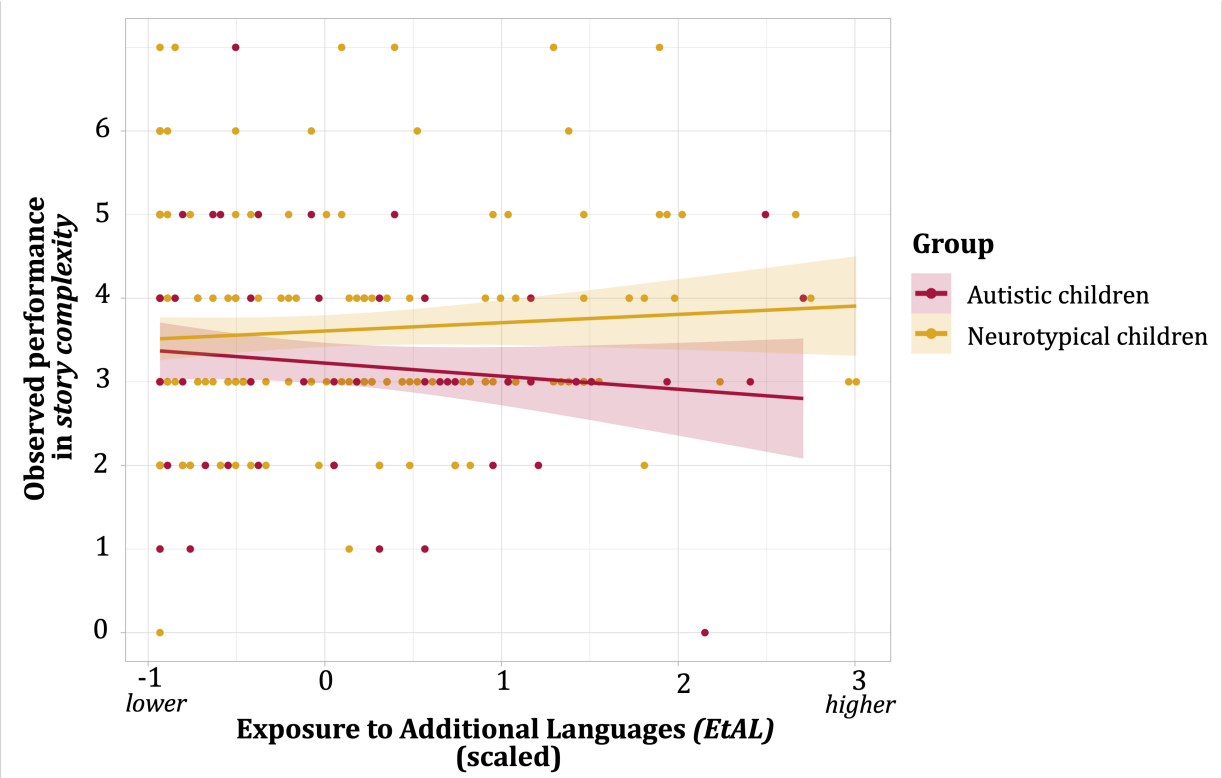
Figure 1. ***Predicted performance as a function of EtAL in the group of NT children***



STORY COMPLEXITY. Autistic children obtained a mean score of 3.11 ± 1.28, ranging from 0 to 7 (median value: 3). Neurotypical children exhibited a mean score of 3.68 ± 1.22 SD, ranging from 1 to 7 (median value: 4).

The best model for STORY COMPLEXITY was, again, the model with maximal structure (Supplementary Material S3, Table S5). It showed no significant main effects of *EtAL* (p > .05). Furthermore, the three-way interaction between *EtAL*, *age*, and *group* was also non-significant (β = 0.197, *SE* = 0.189, t = 1.043, p = .298), indicating no differential impact of EtAL on story complexity across groups or age. Similarly, the other cognitive and linguistic predictors did not reach significance (all ps > .05). Figure 2 illustrates performance on story complexity as a function of EtAL in both groups.

Figure 2. ***Observed scores for story complexity as a function of EtAL in autistic and NT children***

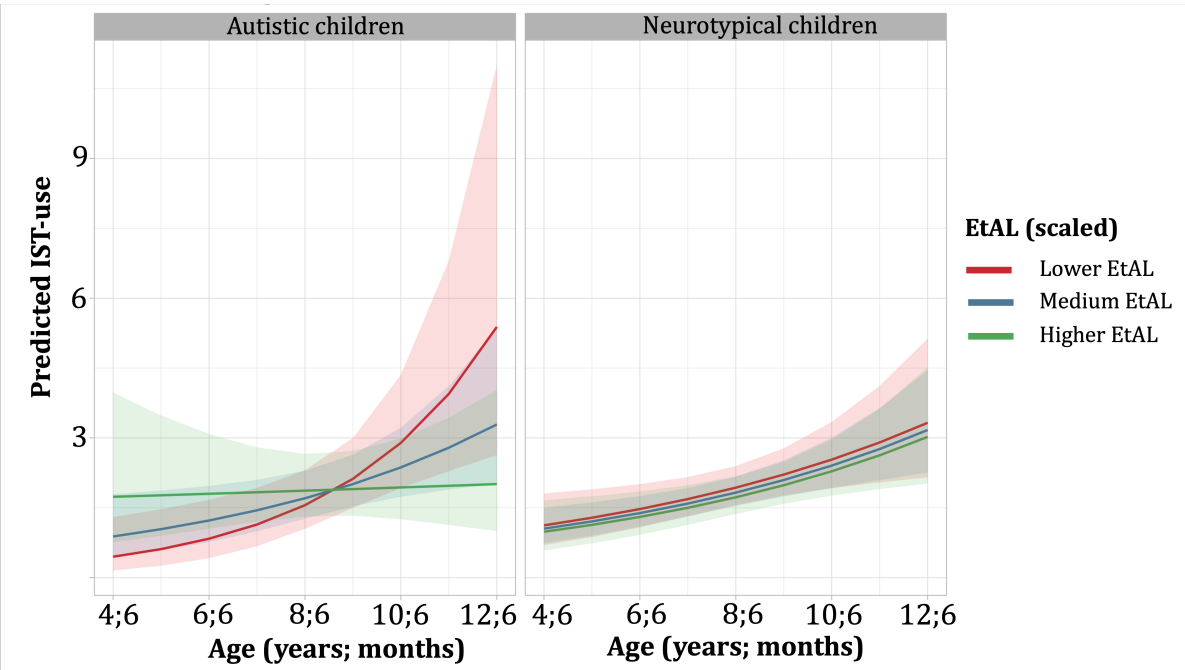


IST-USE. The group of autistic children produced an average of 2.34 ± 2.02 IST (1.16 ± 1.28 ToM-unrelated IST; 1.19 ± 1.48 ToM-related IST). Most of them produced 2 words; scores ranged from 0 to 7 IST produced. The group of NT children produced an average of 3.0 ± 2.13 IST (1.70 ± 1.53 ToM-unrelated IST; 1.30 ± 1.30 ToM-related IST). Scored ranged from 0 to 11, and most of the neurotypical children produced 3 IST.

The best model for IST-USE was also the model with maximal structure (Supplementary Material S3, Table S6A). It revealed a significant three-way interaction between *EtAL*, *age* and *group* (β = 0.38, SE = 0.19, z = 1.98, p = .048). Post-hoc investigations revealed that *age* and *EtAL* did significantly impact the production of IST in the autistic group (β = -0.31, SE = 0.11, z = -2.76, p = .006, Table S6B), but not in the neurotypical group (β = 0.08, SE = 0.05, z = 1.47, p = .14, Table S6C). As shown in Figure 3, autistic children displayed a differential impact of EtAL depending on age: At younger ages, those with lower EtAL tended to produce fewer ISTs than peers with greater EtAL. However, this pattern reversed at older ages, where children with lower EtAL showed a steeper increase in IST production. Nevertheless, the high variability in predicted performance suggests caution in interpreting this trend, particularly for older children, where confidence intervals widen considerably. Moreover, overall IST production remained relatively low across participants, suggesting that, despite the observed interaction, the practical impact of EtAL on IST production in autistic children may be limited. In contrast, in NT children (Figure 3, right panel), the relationship

between age and IST production remained stable across different levels of EtAL, indicating no meaningful interaction between these factors in this group.

Figure 3. ***Predicted IST-use as a function of age and EtAL in autistic and NT children***



EtAL significantly interacted with condition (β = 0.23, SE = 0.10, z = 2.33, *p* = .02): For both groups, ToM-related IST production decreased with greater EtAL (β = -0.20, SE = 0.08, z = - 2.57, p = .01; Table S6D), while ToM-unrelated ISTs showed a non-significant increase (β = 0.02, SE = 0.06, p = .71; Table S6E).

The interaction between *age* and *condition* was significant (β = 0.36, SE = 0.10, z = 3.72, *p* < .001; Table S6A). These variables further interacted with *condition* (β = 0.38, SE = 0.22, z = 0.88, *p* = .0048). Specifically, among autistic children, older age was associated with fewer ToM-related ISTs (Table S5F) and more ToM-unrelated ISTs, though these trends did not reach significance. No age-related differences were observed in NT children (Table S6C).

Girls produced significantly more ISTs than boys (β = 0.45, SE = 0.09, z = 4.93, *p* < .001). Although ToM, WM, and MA improved model fit, none significantly predicted IST use (all *p*s < .5).

Discussion

This study examined the impact of the *Exposure to additional languages* (*EtAL)* on the narrative macrostructure in L1 of autistic and age-matched NT children between age 5 and 12. Accounting for age, sex, language skills, and non-verbal IQ, NT children benefitted from greater EtAL on their story structure. Specifically, neurotypical children with greater EtAL produced more elaborate narratives than their peers with lower EtAL, as reflected by the inclusion of more story structure elements (e.g., mention of the setting, a goal, attempt or outcome in an episode). This finding is consistent with the prediction that increased EtAL would support narrative macrostructure by fostering the inclusion of more relevant *story grammar* elements in children's L1 narratives. For instance, multilingual exposure may provide access to more diverse storytelling conventions and communicative practices, promoting a richer understanding of how narratives are organized and presented across contexts (Bruner, 1990; Minami, 2002). This aligns with previous research reporting higher scores on story structure in L1 for children with greater exposure to L1 and L2, than children with lower exposure to these languages (Haman et al., 2017). It also suggests that neurotypical children may take advantage of their exposure to additional languages to enrich their storytelling skills in their L1.

In contrast, no effect of EtAL on story structure was detected in autistic children, suggesting a different impact of EtAL between autistic and NT children. The lack of difference in story structure between autistic children with varying EtAL aligns with previous research monolingual/bilingual groups comparisons (Beauchamp et al., 2023; Hoang et al., 2018). One possible explanation for this difference is that autistic children process and generalize linguistic information differently than their NT peers: Difficulties with pragmatic inferencing and extracting implicit meaning from linguistic input (Bodner et al., 2015; Loukusa et al., 2007) could limit their ability to identify and apply relevant storytelling elements across languages. Additionally, challenges in generalizing acquired knowledge may further constrain their ability to transfer storytelling skills from their additional languages to L1, preventing the macrostructural advantages observed in neurotypical children (Carruthers et al., 2020; de Marchena et al., 2015). Importantly, the finding of no detrimental effect of EtAL on the storytelling abilities of autistic children supports accumulating evidence that autistic children with dual-language exposure may achieve similar language and communicative outcomes than their monolingually-raised peers (Beauchamp et al., 2020; Hambly & Fombonne, 2012; Peristeri et al., 2020).

As for *story complexity,* no effect of EtAL was found in any of the groups. While this finding may appear at odds with studies reporting a bilingual advantage in *story (structure) complexity* (e.g., Baldimtsi et al., 2016; Peristeri et al., 2020), several methodological differences are important to consider. These studies used a composite measure termed *story structure complexity*, which combined both the presence of story structure elements and episodic elaboration. In contrast, the

present study assessed these components separately. Moreover, previous studies relied on categorical group comparisons (bilingual vs. monolingual), which may obscure individual variability in language experience (De Houwer, 2023). By treating exposure to additional languages as a continuous variable, the present approach offers a nuanced perspective on how a specific aspect of the bilingual experience may influence linguistic outcomes.

The absence of impact of EtAL on *story complexity* aligns with previous findings suggesting the relative language-independence of the skill to combine elements in narratives. This higher-level of narrative organization is cognitively more demanding than story structure. It is possible that the cognitive and linguistic benefits of additional language exposure take longer to manifest in complex storytelling abilities. Since story complexity involves global coherence, integration of multiple elements, and hierarchical structuring, it may require sustained and long-term bilingual experience to observe developmental differences. In contrast, story structure may be more immediately influenced by language exposure, particularly through frequent engagement with diverse linguistic input. Future research should investigate whether cumulative bilingual exposure, rather than current language exposure, serves as a stronger predictor of narrative complexity. In summary, if a storyteller is able to understand the content of picture stimuli and convey the core meaning of a narrative episode, this ability reflects cognitive maturation rather than language proficiency *per se* (Gagarina et al., 2016). The present findings contribute additional evidence in support of a multidimensional model of narrative organization, highlighting the relative independence of this skill from EtAL.

EtAL impacted the production of IST in different ways. First, in autistic children, but not in neurotypical children, EtAL interacted with age in predicting IST: At a younger age, autistic children with greater EtAL produced more ISTs than those with lower EtAL. However, this trend reversed at older ages, where children with lower EtAL showed greater IST-use. Yet, due to the high variability and the continuous nature of the predictors, further examination of these tendencies was not possible. This finding suggests that the role of EtAL in IST-use (1) differs between autistic and neurotypical children, and (2) may change over time in autism. Second, findings revealed that as EtAL increased, the production of ToM-related ISTs decreased. This was unexpected, as bilingualism is typically associated with enhanced ToM abilities (e.g., Adesope et al., 2010; Kovács, 2009). One possible explanation is that the use of ISTs, particularly those related to ToM, relies heavily on lexical knowledge, situating them more within the domain of microstructure than macrostructure. Therefore, greater exposure to additional languages may not facilitate IST use unless it is accompanied by sufficient vocabulary development in the language of testing. Alternatively, it is possible that a longer duration of multilingual exposure, rather than current EtAL is necessary for effects on ToM-related ISTs to emerge.

At the same time, the interaction between EtAL and age in autistic children, and the additional interaction between *age*, *group*, and *condition* (ToM-related, ToM-unrelated ISTs) suggests that these patterns may also reflect underlying socio-cognitive and communicative difficulties associated with autism, rather than a direct effect of bilingual exposure. While NT children showed a general increase in both ToM-related and ToM-unrelated ISTs with age, autistic children tended to produce fewer ToM-related ISTs but more ToM-unrelated ISTs as they grew older. This pattern may reflect difficulties in integrating mental-state reasoning into narratives, aligning with broader challenges in social cognition and communication in autism (American Psychiatric Association, 2022; Boucher, 2012).

Furthermore, there was a significant positive effect of age on *story structure*, aligning with previous studies (Bohnacker, 2016; Bohnacker et al., 2022). Girls significantly exhibited better story structure and produced more ISTs than boys, consistent with the literature (Kauschke et al., 2016).

The second objective was to investigate the impact of cognitive narrative-related factors (ToM, WM and MA) on macrostructure. While these factors significantly improved model fit for all three macrostructure dimensions evaluated (*story structure*, *story complexity*, *IST-use*), only MA emerged as a significant independent positive predictor of story structure. This suggests that greater ability to reflect on and organize linguistic content at a higher level (Bialystok, 2001; Karmiloff-Smith, 1986) enhances macrostructure performance, particularly in terms of story structure. Interestingly, while ToM and WM did not independently predict any of the three macrostructure outcomes, their inclusion in the model nonetheless reduced unexplained variance, improving overall model precision and suggesting potential indirect contributions to narrative production. This may reflect the fact that macrostructural narrative skills typically reach a developmental plateau around age 6–7 (Berman & Slobin, 1994; Gagarina et al., 2019), and many children in our sample may have already achieved this level of narrative organization. Moreover, both WM and ToM show the most rapid development in early childhood (up to around age 6–7), with more gradual refinement continuing through middle childhood (Gathercole et al., 2004; Wellman, 2014). Previous research has shown that WM contributes to narrative abilities in younger children, but its role may diminish as narrative skills become more established (Friend & Bates, 2014; Scionti et al., 2023; Veraksa et al., 2020). It is therefore plausible that in this age range, limited developmental variability in these domains reduced their predictive power. The effect of EtAL persisted even after accounting for ToM and WM, suggesting additional mechanisms at play. Future research is warranted to confirm these possibilities.

Limitations

Due to the nature of the MAIN task, only children with verbal abilities and sufficient attentional cognitive resources could participate in this study. As a result, autistic children with intellectual and/or language impairment were not represented, reflecting a common methodological selection bias (Russell et al., 2019). Additionally, this study focused on the impact of bilingual exposure on macrostructure but did not examine other dimensions of bilingual experience (e.g., age of acquisition of the language, richness of the input received in a language, linguistic distance between language pairs, etc.), despite their potential influence on narrative macrostructure (Lindgren et al., 2023).

Conclusion

This study investigated how EtAL in the past 12 months impacted the narrative macrostructure of school-aged autistic and NT children. Participants told a story elicited from pictures in their most proficient language. Findings revealed that NT children with greater EtAL presented richer narratives in terms of *story structure* than peers with lower EtAL. This suggests that children with exposure to multiple languages may draw from this exposure to enrich their storytelling skills. This effect, however, was not present in autistic children, where EtAL did not affect macrostructure. Consequently, while children with ASD may not benefit from EtAL to the same extent as their NT peers, bilingual exposure was not detrimental to their narrative macrostructure abilities. From a societal perspective, these findings provide evidence against the (mis-)belief that bilingualism hinders language development in autistic children.

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Supplementary material

Table S1. Description of the bilingual variables of the participants

	Autistic children N = 90	**Neurotypical children N= 168**
Exposure to Additional Languages (EtAL)		
Mean (SD)	22.0 (22.9)	21.7 (23.6)
Median [Min, Max]	12.5 [0, 85.0]	12.5 [0, 92.0]
Current exposure to L1 (%)		
Mean (SD)	78.0 (22.9)	78.3 (23.7)
Median [Min, Max]	87.0 [15.0, 100]	87.5 [8.00, 100]
Current exposure to L2 (%)		
Mean (SD)	25.3 (20.1)	27.1 (22.2)
Median [Min, Max]	23.0 [0, 80.0]	23.5 [0, 92.0]
Current exposure to L3(%)		
Mean (SD)	10.2 (12.4)	9.63 (9.05)
Median [Min, Max]	5.00 [0, 45.0]	6.00 [0, 32.0]
Parent rated proficiency in L1 (%)		
Mean (SD)	78.2 (19.4)	91.3 (12.7)
Median [Min, Max]	83.3 [33.3, 100]	100 [33.3, 100]
Parent rated proficiency in L2 (%)		
Mean (SD)	52.7 (27.2)	61.2 (27.0)
Median [Min, Max]	50.0 [0, 100]	66.7 [0, 100]
Parent rated proficiency in L3 (%)		
Mean (SD)	44.8 (24.4)	40.1 (22.7)
Median [Min, Max]	41.7 [0, 83.3]	50.0 [0, 83.3]
Age of First Exposure to L1 (months)		
Mean (SD)	8.93 (19.2)	4.63 (12.2)
Median [Min, Max]	0 [0, 95.0]	0 [0, 60.0]
Age of First Exposure to L2 (months)		
Mean (SD)	18.4 (29.6)	13.4 (25.9)
Median [Min, Max]	0 [0, 130]	0 [0, 97.0]
Age of First Exposure to L3 (months)		
Mean (SD)	27.4 (31.3)	22.9 (34.4)
Median [Min, Max]	36.0 [0, 104]	1.00 [0, 126]

Supplementary material S2. Language adaptations of the PPVT and TROG

To assess receptive morphosyntax in the children's L1, the respective versions of the *Test for Reception of Grammar* (TROG) have been proposed:

- **In English:** Bishop, D. V. (2003). *Test for Reception of Grammar, version 2. London: Pearson assessment.* Addison-Wesley Professional.
- **In French**: Lecocq, P. (1996). L'É.CO.S.SE: Une épreuve de compréhension syntaxico-sémantique. Presses universitaires du Septentrion.
- **In German**: Fox-Boyer, A. V. (2006). TROG-D: Test zur Überprüfung des Grammatikverständnisses. Schulz-Kirchner Verlag GmbH.
- **In Italian**: Suraniti, S., Neri, V., & Ferri, R. (2009). TROG-2: Contributo alla validazione italiana (Giunti O.S.).
- **In Spanish**: Mendoza, E., Carballo, G., Muñoz, J., & Fresneda, M. D. (2005). Test de comprensión de estructuras gramaticales (CEG). TEA.

To assess receptive vocabulary in the children's L1, the respective versions of the *Peabody Picture Vocabulary Test* (PPVT-4) have been proposed:

- **In English**: Dunn, L. M., & Dunn, D. M. (2007). PPVT-4: Peabody picture vocabulary test. Pearson Assessments.
- **In French**: Dunn, L. M., Dunn, L. M., & Thériault-Whalen, C. M. (1993). Echelle de vocabulaire en images Peabody: EVIP. PSYCAN.
- **In German**: Lenhard, A., Lenhard, W., Segerer, R., & Suggate, S. (2015). Peabody picture vocabulary test-4. Deutsche Fassung. (Pearson Assessment).
- **In Italian**: Stella, G., Pizzoli, C., & Tressoldi, P. (2000). Il Peabody Test—Test di vocabolario ricettivo. Omega Edizione, Torino.
- **In Spanish**: Dunn, L. M., Dunn, L. M., & Arribas Aguila, D. (2006). PPVT-III Peabody test de vocabulario en imágenes. TEA Ediciones.

Supplementary material S3. Full specifications of the statistical models

To investigate the impact of *Exposure to Additional Languages* (EtAL) on narrative macrostructure (RQ1), and the influence of WM, ToM, and MA on performance (RQ2), analyses were conducted in R (version 2024.04.2+764; R Core Team, 2020) for each macrostructure dimension separately (i.e., story structure, story complexity, IST-use). Both RQ1 and RQ2 were examined with the same model for each dimension.

A base model was fitted for each dimension, including a 3-way interaction (between *group* [sum coded: ASD, NT], *age* [scaled], and *EtAL* [scaled] for story structure and story complexity), or 4-way interaction for IST-use. Covariates were added in each model to account for their impact on performance (i.e., *language skills*, *non-verbal IQ* [scaled], and *sex* [sum coded: female; male]).

For each model, prior checks on the variance inflation factor (VIF) indicated no concerning levels of multicollinearity among the predictors (VIF <3). Covariates *ToM*, *WM*, and *MA* (all scaled) were added stepwise. The model with the lowest Akaike Information Criterion (AIC) was considered to provide the best balance between model fit and complexity and was selected as the final model.

STORY STRUCTURE. Binomial GLMMs were fitted the *lme4* package (Bates et al., 2015) to model the presence/absence [1/0] of each of the 17 story elements independently. Random intercepts were included for *participants* and *items* to account for individual and item-level variability.

Formula: performance story structure ~ EtAL * Group * Age
+ language skills + Non-verbal IQ + Sex + ToMI + WM + MA
+ (1|participant) + (1|item)

STORY COMPLEXITY. GLMs followed the same structure as story structure.

Formula: performance story structure ~ EtAL * Group * Age
+ language skills + Non-verbal IQ + Sex + ToMI + WM + MA
+ (1|participant) + (1|item)

IST-USE: Negative binomial GLMMs (*glmmTMB* package; Brooks et al., 2017) included a 4-way interaction (*EtAL*, *age*, *group*, *condition* [sum coded: +0.5 ToM-unrelated IST, -0.5 ToM-related IST]). Random intercepts for *participants* were included.

Formula: performance IST-use ~ EtAL * Age * Group * Condition
+ Language skills + Non-verbal IQ + Sex + ToMI + WM + MA
+ (1 | participant)

Tables S4. Output of the GLMM for *story structure*

- Table S4A. Final model for story structure

	Performance			
	β	Std. Err	Z value	*p value*
(Intercept)	-0.716	0.362	-1.979	0.048
Group	-0.098	0.139	-0.700	0.484
EtAL	0.003	0.051	0.064	0.949
Age	0.191	0.067	2.850	0.004
Language skills	0.059	0.052	1.142	0.253
Non-verbal IQ	0.022	0.050	0.431	0.666
Sex assigned at birth	0.340	0.098	3.474	0.001
ToMI-score	0.091	0.066	1.381	0.167
WM	0.065	0.064	1.012	0.311
MA-score	0.116	0.059	1.983	0.047
Group : EtAL	-0.200	0.102	-1.966	0.049
Group : Age	-0.041	0.102	-0.401	0.688
EtAL : Age	0.027	0.056	0.477	0.634
Group : EtAL : Age	-0.060	0.113	-0.534	0.594

- Table S4B. Simple effects investigation in the group of neurotypical children

	Performance			
	β	Std. Err	Z value	*p value*
(Intercept)	-0.611	0.393	-1.554	0.120
EtAL	0.110	0.056	1.971	0.049
Age	0.279	0.072	3.854	< .001
Language skills	0.045	0.062	0.722	0.470
Non-verbal IQ	0.045	0.059	0.765	0.444
Sex assigned at birth	0.298	0.105	2.828	0.005
ToMI-score	0.048	0.107	0.455	0.649
WM	0.003	0.080	0.036	0.971
MA-score	0.077	0.068	1.140	0.254
EtAL: Age	0.051	0.052	0.977	0.329

- Table S4C. Simple effects investigation in the group of autistic children

	Performance			
	β	Std. Err	Z value	*p value*
(Intercept)	-0.599	0.353	-1.699	0.089
EtAL	-0.065	0.092	-0.709	0.478
Age	0.065	0.124	0.527	0.598
Language skills	0.057	0.096	0.592	0.554
Non-verbal IQ	-0.011	0.092	-0.114	0.909
Sex assigned at birth	0.599	0.242	2.478	0.013
ToMI-score	0.116	0.090	1.287	0.198
WM	0.127	0.110	1.153	0.249
MA-score	0.214	0.117	1.819	0.069
EtAL: Age	0.012	0.110	0.105	0.917

Table S5. Output of the GLM for story complexity

	Performance			
	β	Std. Err	t value	*p value*
(Intercept)	3.468	0.093	37.477	<.001
Group	-0.233	0.244	-0.956	0.340
EtAL	-0.017	0.088	-0.191	0.849
Age	0.101	0.118	0.856	0.393
Language skills	0.077	0.092	0.836	0.404
Non-verbal IQ	-0.074	0.089	-0.828	0.408
Sex assigned at birth	0.084	0.174	0.479	0.632
ToMI-score	0.017	0.115	0.150	0.881
WM	0.108	0.112	0.968	0.334
Group : EtAL	0.080	0.100	0.797	0.426
Group : Age	-0.199	0.176	-1.133	0.258
EtAL:Age	0.009	0.177	0.049	0.961
Group : EtAL: Age	0.045	0.097	0.466	0.642

Tables S6. Output of the GLMM for IST-use

- Table S6A. Final model for IST-use

	Performance			
	β	Std. Err	Z value	*p value*
(Intercept)	0.288	0.056	5.174	< .001
EtAL	-0.096	0.053	-1.809	0.070
Age	0.123	0.069	1.799	0.072
Group	0.088	0.142	0.619	0.536
Condition (ToM-related/ToM-unrelated ISTs)	0.104	0.094	1.111	0.266
Language skills	-0.032	0.050	-0.645	0.519
Non-verbal IQ	0.062	0.048	1.276	0.202
Sex assigned at birth	0.453	0.092	4.925	< .001
ToMI	0.124	0.066	1.880	0.060
WM	0.004	0.064	0.065	0.948
MA-score	0.063	0.059	1.064	0.287
EtAL : Age	-0.115	0.059	-1.953	0.051
EtAL : Group	0.026	0.106	0.240	0.810
Age : Group	-0.137	0.105	-1.306	0.191
EtAL : Condition	0.228	0.098	2.334	0.020
Age : Condition	0.358	0.096	3.723	< .001
Group : Condition	-0.314	0.188	-1.673	0.094
EtAL : Age : Group	-0.396	0.118	-3.349	0.001
EtAL: Age : Condition	-0.061	0.109	-0.556	0.578
EtAL : Group : Condition	0.248	0.195	1.270	0.204
Age : Group : Condition	0.380	0.192	1.978	0.048
EtAL : Age : Group : Condition	0.193	0.218	0.884	0.376

- Table S6B. IST-use model in autistic children only

	Performance			
	β	Std. Err	Z value	*p value*
(Intercept)	0.430	0.136	3.167	0.002
EtAL	-0.059	0.092	-0.645	0.519
Age	-0.005	0.126	-0.037	0.970
Condition	-0.055	0.164	-0.337	0.736
Language skills	0.005	0.091	0.059	0.953
Non-verbal IQ	0.046	0.089	0.518	0.604
Sex assigned at birth	0.694	0.198	3.498	< .001
ToMI	0.124	0.086	1.444	0.149
WM	-0.002	0.109	-0.018	0.986
MA	0.145	0.114	1.278	0.201
EtAL : Age	-0.307	0.111	-2.762	0.006
EtAL :Condition	0.344	0.168	2.049	0.040
Age : Condition	0.559	0.172	3.240	0.001
EtAL : Age: Condition	0.056	0.202	0.276	0.782

- Table S6C. IST-use model in neurotypical children only

	Performance			
	β	Std. Err	Z value	*p value*
(Intercept)	0.269	0.082	3.289	0.001
EtAL	-0.106	0.059	-1.787	0.074
Age	0.212	0.071	2.990	0.003
Condition	0.261	0.097	2.696	0.007
Language skills	-0.057	0.060	-0.953	0.341
Non-verbal IQ	0.075	0.058	1.298	0.194
Sex assigned at birth	0.394	0.103	3.832	< .001
ToMI	0.132	0.109	1.217	0.224
WM	-0.008	0.081	-0.100	0.920
MA	0.028	0.069	0.404	0.686
EtAL : Age	0.078	0.053	1.469	0.142
EtAL :Condition	0.103	0.105	0.980	0.327
Age : Condition	0.167	0.095	1.757	0.079
EtAL : Age: Condition	-0.155	0.095	-1.627	0.104

- Table S6D. Model for ToM-related ISTs in all children

	Performance			
	β	Std. Err	Z value	*p value*
(Intercept)	0.152	0.087	1.749	0.080
EtAL	-0.209	0.081	-2.568	0.010
Age	-0.014	0.102	-0.132	0.895
Group	0.162	0.210	0.775	0.439
Language skills	-0.065	0.077	-0.844	0.399
Non-verbal IQ	0.108	0.074	1.460	0.144
Sex assigned at birth	0.388	0.142	2.733	0.006
ToMI	0.108	0.098	1.109	0.267
WM	-0.063	0.095	-0.664	0.507
MA	0.083	0.086	0.962	0.336
EtAL: Age	-0.083	0.090	-0.924	0.356
EtAL : Group	-0.082	0.163	-0.504	0.614
Age : Group	-0.315	0.153	-2.053	0.040
EtAL : Age: Group	-0.492	0.180	-2.728	0.006

- Table S6E. Model for ToM-unrelated ISTs in all children

	Performance			
	β	Std. Err	Z value	*p value*
(Intercept)	0.369	0.076	4.838	< .001
EtAL	0.025	0.067	0.373	0.709
Age	0.265	0.089	2.989	0.003
Group	0.000	0.185	0.000	1.000
Language skills	-0.004	0.063	-0.058	0.954
Non-verbal IQ	0.015	0.061	0.244	0.807
Sex assigned at birth	0.511	0.115	4.450	< .001
ToMI	0.134	0.085	1.569	0.117
WM	0.072	0.085	0.854	0.393
MA	0.043	0.079	0.539	0.590
EtAL: Age	-0.145	0.074	-1.964	0.050
EtAL : Group	0.152	0.133	1.143	0.253
Age : Group	0.048	0.139	0.344	0.731
EtAL : Age: Group	-0.282	0.147	-1.915	0.056

- Table S6F. Model for ToM-related ISTs in autistic children only

	Performance			
	β	Std. Err	Z value	*p value*
(Intercept)	0.222	0.227	0.975	0.330
EtAL	-0.227	0.149	-1.523	0.128
Age	-0.191	0.195	-0.977	0.329
Language skills	0.085	0.145	0.584	0.559
Non-verbal IQ	0.077	0.138	0.558	0.577
Sex assigned at birth	0.400	0.335	1.192	0.233
ToMI	0.097	0.136	0.711	0.477
WM	-0.027	0.165	-0.162	0.872
MA	0.007	0.168	0.043	0.966
EtAL: Age	-0.320	0.179	-1.785	0.0743

- Table S6G. Model for ToM-unrelated ISTs in autistic children only

	Performance			
	β	Std. Err	Z value	*p value*
(Intercept)	0.458	0.161	2.837	0.005
EtAL	0.132	0.111	1.193	0.233
Age	0.206	0.164	1.253	0.210
Language skills	-0.070	0.113	-0.623	0.534
Non-verbal IQ	-0.015	0.116	-0.130	0.897
Sex assigned at birth	0.964	0.227	4.252	< .001
ToMI	0.123	0.109	1.126	0.260
WM	0.032	0.142	0.228	0.819
MA	0.352	0.178	1.975	0.048
EtAL: Age	-0.248	0.136	-1.830	0.067

This study examined the impact of *exposure to additional languages* (EtAL) on narrative macrostructure in autistic and neurotypical children. Findings revealed that neurotypical children with greater *exposure to additional languages* achieved higher scores in story structure compared to their peers with lower EtAL. However, this effect was not observed in autistic children, who performed similarly regardless of their exposure. Importantly, EtAL did not influence story complexity, or the use of Internal State Terms (whether related to Theory of Mind or not) in either group. Additionally, although Theory of Mind and working memory showed positive trends, their effects on macrostructure were not statistically significant. Notably, metalinguistic awareness significantly predicted story structure, but not other dimensions of narrative macrostructure. Future research is needed to confirm these patterns, and disentangle the specific contributions of bilingualism and these (socio-) cognitive skills to narrative macrostructure.

In the next and final chapter of this dissertation, I will summarize and critically examine the key findings of the experimental studies conducted in this thesis, which investigated the effects of bilingualism on co-speech gestures, metalinguistic awareness and narrative macrostructure in autistic and neurotypical children aged 5 to 12. I will then discuss the limitations of this work, considering both methodological and theoretical constraints, before outlining future research directions to further advance our understanding of how bilingualism influences the communicative skills of autistic and neurotypical children.

7 General discussion

7.1 Autism, bilingualism & communicative skills

Throughout this thesis, I have explored how different aspects of the bilingual experience influence communicative skills in children with ASD and TD. Three communicative abilities were examined: (1) gesture comprehension, as an example of non-verbal communication crucial for semantic integration and spoken message understanding; (2) metalinguistic awareness, a higher-order ability supporting flexible interactions; and (3) narrative macrostructure, reflecting the ability to produce coherent and well-structured discourse, essential for effective information transmission.

Each of these communicative skills is particularly interesting in its own right, as each interacts with language and cognition in distinct ways (see **Section 1.2**, **Section 1.3** and **Section 1.4**). Therefore, the influence of linguistic and cognitive skills has been carefully considered and accounted for at every stage of the studies, including task design, groups comparability and/or statistical approach, and interpretation of findings.

7.1.1 Synthesis of findings

7.1.1.1 Co-speech gestures

In the first experimental contribution, we aimed to better understand whether autistic children experienced difficulties in integrating gestures with speech compared to their neurotypical peers, who were matched on age, socio-economic status, non-verbal IQ, and language skills (**Section 4.1**). The task required participants to first comprehend speech, then interpret a gesture presented separately, and finally integrate both sources of information to select the correct picture. While both groups demonstrated generally good performance, a small but statistically significant difference was observed, with neurotypical children outperforming their autistic peers in overall comprehension. The difference in performance was found to be unrelated to impairments in working memory or language skills.

This finding aligns with previous research suggesting that individuals with autism face greater challenges in integrating information from multiple modalities, such as speech and gesture (Hubbard et al., 2012; Silverman et al., 2010) compared to neurotypical peers. However, the observed difference in our study was relatively minor, and did not indicate a substantial 'deficit' that would significantly impact everyday communication. The sequential presentation of speech followed by gesture likely facilitated processing, by allowing autistic individuals to analyze each stream of information independently, thereby reducing the challenges associated with simultaneous multimodal integration. Indeed, processing information presented simultaneously typically requires the identification, separation, and synthesis of concurrent modalities, which may contribute to sensory overload, particularly for individuals on the spectrum. Indeed, they often experience differences in sensory processing (American Psychiatric Association, 2022; Bogdashina, 2003). It is therefore plausible that the observed difficulties would have been more pronounced if speech and gesture had been presented simultaneously.

Additionally, as discussed in **Section 4.1**, the intake of gestural information may be less efficient in autistic children, than in neurotypical children, due to a lower intrinsic motivation toward stimuli with greater social value, such as gestures (Chevallier et al., 2012). This observation is particularly relevant in light of recent theoretical frameworks and empirical findings in bilingualism research, which explore the impact of multilingualism on pragmatic abilities. Indeed, studies suggest that exposure to multiple languages may enhance children's sensitivity to non-verbal communication cues, including eye gaze and pointing gestures (van Wonderen et al., 2023; Wermelinger et al., 2024; Yow & Markman, 2011). This provides further justification for investigating whether bilingualism may mitigate the difficulties associated with gestures in our participants with ASD.

Different theoretical hypotheses, which are not mutually exclusive, have been proposed to explain why multilingual exposure might foster greater sensitivity to the communicative context and partners (see Van Wonderen et al., 2023 for an overview). One hypothesis suggests that multilingual children must monitor *who* speaks and understands *which* language to prevent communication breakdowns. The need to track language preferences and adapt flexibly may make bilinguals more attentive to their conversation partners than monolinguals. This heightened awareness extends to non-verbal cues, such as gestures, which can help disambiguate speech, or carry culturally specific emphasis. This first hypothesis aligns with the *COME perspective* (COMmunicative-Experience; Wermelinger et al., 2024), which is particularly relevant in bilingual contexts where communication can be more prone to misunderstandings, ambiguity, or breakdowns due to linguistic approximations and cultural differences. According to this perspective, children's communicative behaviors are shaped by their exposure to interactions that vary in clarity and effectiveness. Some exchanges allow for smooth and immediate understanding (i.e., 'efficient' communicative situations), while others involve challenges that require adaptive responses, such as seeking clarification, rephrasing statements, or using alternative communicative cues (i.e., 'non-effective' communicative situations). The COME perspective suggests that frequent exposure to less effective communicative situations encourages children to expand their communicative strategies and apply them

flexibly. One such strategy involves closely monitoring the conversational context to anticipate and prevent potential misunderstandings, which in turn enhances their attention to non-verbal communication cues. Another hypothesis posits that multilingual children may rely more on contextual and communicative cues as a way to compensate for potential limitations in their vocabulary or morphosyntactic skills (Verhagen et al., 2017; Wermelinger et al., 2020). Since multilingual children often have a comparatively smaller vocabulary – when assessed in a single language – than their monolingual peers (Hoff, 2021; Thordardottir, 2011), they may need to rely more heavily on contextual information and non-verbal communication when interpreting others' speech.

These hypotheses, derived from previous research conducted in neurotypical children, open a promising avenue for investigating whether multilingual exposure influences the comprehension of gestures, with and without speech, in autistic individuals. Specifically, bilingual exposure could potentially alleviate the difficulties observed in gesture comprehension. Before addressing this question in autistic children (**Section 4.3**), I first sought to determine whether the previously documented effects of bilingualism on the comprehension of non-verbal cues, so far evidenced in eye gaze and pointing gestures, extend to other communicative cues, such as iconic and conventional gestures. A recent meta-analysis of 29 studies examined the impact of multilingualism on the sensitivity to non-verbal information, including pointing gesture (van Wonderen et al., 2023). Findings were equivocal: While no overall effect of bilingualism was found, the authors noted that effect size analyses provided some indication that multilingual children may rely more on non-verbal cues during communication compared to their monolingual peers. The authors also indicated that this effect may be present only for more subtle cues (e.g., eye gaze), rather than for more salient ones (e.g., ostensive gestures). One possible explanation for these inconsistent findings is the binary classification of bilingualism adopted in much of the literature: Studies have often contrasted monolingual and bilingual participants, overlooking the diversity of bilingual experiences (see de Bruin, 2019; De Houwer, 2023 for discussions; see **Section 3.1.2.1**). Additionally, these studies did not include specific hypotheses regarding *which aspects* of bilingual exposure might influence gesture comprehension, as recommended for a better understanding of bilingualism's effects (Antoniou et al., 2023).

Hence, the second experimental contribution of this work examined whether multilingualism – operationalized as the relative balance of exposure to multiple languages since birth – impacted the comprehension of pointing, iconic and conventional gestures in neurotypical school-aged children (**Section 4.2**). Although no hypothesis was formulated in the previous literature about which *specific aspect* of the bilingual experience may have driven the reported effects on the comprehension of (pointing) gestures, our selection of the bilingual variable was guided by the literature suggesting that multilingual exposure may foster communicative effectiveness (Fan et al., 2015; Yow & Markman, 2015, 2016). According to this body of work, it is the exposure to diverse linguistic environments and people speaking different languages, rather than proficiency in the different languages, that would facilitate effective interpersonal communication and promote sensitivity to extralinguistic cues in the communicative situation. In this second study, we included 200

neurotypical children. Ages ranged from 3 to 12 years old, and children had varying *balance of multilingual exposure*. This time, gestures were either proposed alone or were accompanied with speech, to investigate gesture comprehension in different communicative modalities. Specifically, we investigated comprehension in four communicative modalities: (1) gestures appeared alone, without speech. This modality enabled the assessment of the impact of multilingual exposure on the comprehension of gestures, as it is usually conducted in the literature (Adornetti et al., 2019; Perrault et al., 2019). Secondly, gestures appeared (2) with a reinforcing label: Both verbal and gestural information were redundant (e.g., gesturing DRIVE and saying "driving"). Third, gestures appeared (3) with a label that supplemented speech; both speech and gestures had to be processed, and combined to select the correct answer (e.g., gesturing DRIVE and saying "lady" to select the picture of a lady who is driving). Finally, in baseline items (4), no gestures were presented, but the label was spoken by the actor on screen (e.g., saying "driving", without gesture). Because neurotypical children attained ceiling performance around 8 years, statistical analyses were only conducted on younger participants, aged 3 to 8 (N = 105 children). Findings revealed that children with greater *balance of multilingual exposure* understood significantly more iconic gestures presented without speech, than their peers with lower balance of multilingual exposure. This finding aligns with the hypothesis that bilingual exposure enhances sensitivity to non-verbal cues. Iconic gesture comprehension, in particular, requires close attention to the interactional context, as these gestures visually represent elements of the surrounding environment. Furthermore, children with greater multilingual exposure may encounter communicative breakdowns or tip-of-the-tongue phenomena more frequently. Such experiences could foster a heightened reliance on gestures as compensatory strategies, reinforcing their attentional focus on non-verbal cues that substitute speech.

The third experimental contribution of this thesis aimed to determine whether the effect of balance of multilingual exposure on gesture comprehension documented in neurotypical children was also present in autistic individuals (**Section 4.3**). To ensure comparability with previous research on neurotypical children, this study employed the same experimental design, tasks, and statistical approach. The only modification concerned the assessment of language skills: A *composite score* was calculated for each participant, incorporating standardized measures of receptive vocabulary and receptive morphosyntax. This enabled us to have a measure of language skills for autistic participants, who more often than neurotypical children did not complete both vocabulary and morphosyntax tests (see **Section 7.2.5**), thereby resulting in a greater proportion of missing data on these scores. A total of 86 autistic individuals, aged 4 to 12 years, were included in the study. No effect of multilingual exposure was observed in this sample: Children performed relatively well on the task, irrespective of their multilingual exposure. Additionally, there was no difference in performance for the different types of gestures. To date, this study represents the first investigation into the effects of multilingual exposure on gesture *comprehension* in autistic children. These findings are consistent with prior research on gesture *production* in children on the spectrum, which has reported no detrimental effects of bilingualism (Valicenti-McDermott et al., 2013; Zhou et al., 2019).

Taken together, these investigations suggest that the effects of multilingual exposure may differ between neurotypical and autistic children. While neurotypical children appear to derive communicative benefits from dual-language exposure (i.e., here in gesture comprehension), the impact on autistic children seems to be less pronounced. I elaborate further on this point in **Section 7.1.2**.

7.1.1.2 Metalinguistic awareness

Shifting focus to metalinguistic awareness, another relatively understudied area in autism research, the fourth experimental contribution aimed to determine whether autistic individuals differed from neurotypical peers in their ability to judge sentences on their grammar, particularly in cases where meaning was misleading **(Section 5.1**). Specifically, a Grammaticality Judgment Task engaging *metamorphosyntactic* and *metasemantic* knowledge was designed: Sentences could be grammatically correct, or contain a grammatical mistake that had to be detected. In addition, half of the sentences had appropriate meaning, while the other half had an anomalous meaning. This anomalous meaning had to be ignored, as participants were asked to judge sentences based on their grammar only. We hypothesized that autistic children would perform like neurotypical peers on sentences with appropriate meaning, where they had to judge the grammaticality of the sentence without distracting meaning (i.e., where the anomalous meaning had to be ignored). Indeed, the task did not include linguistic structures that autistic children are reported to struggle with (i.e., sentences were short, with simple syntactic structure). In contrast, we predicted that children with ASD would obtain lower performance than neurotypical peers on sentences with anomalous meaning, due to their reported difficulties in processing sentences with odd meaning (Kalandadze et al., 2018; Morsanyi et al., 2020). The performance of $N = 38$ autistic participants was compared to that of $N = 90$ neurotypical children, all aged between 6 and 12 years. Hypotheses were partially verified: Accounting for age, non-verbal IQ and language skills, no difference between autistic and neurotypical children was detected. Findings indicated that autistic children were able to mobilize metalinguistic resources effectively, and could produce accurate grammaticality judgments even when meaning was misleading. The study also highlighted the crucial role of age and non-verbal IQ, which positively impacted performance.

The dual nature of the GJT has often been used in bilingualism research to examine both cognitive and linguistic aspects of metalinguistic performance (Bialystok, 1986, 1988; Bialystok & Majumder, 1998; Bialystok & Ryan, 1985; Cromdal, 1999). Researchers have compared performance of bilingual versus monolingual groups of neurotypical children on sentences reported to place additional demand on *analyzed knowledge* (i.e., sentences with appropriate meaning, but containing a grammatical mistake; called gM sentences), or on *cognitive control* (i.e., sentences that are grammatically correct, but have anomalous meaning that must be ignored; Gm sentences). Bilingual children have been shown to outperform monolinguals in the different dimensions under specific circumstances: Bilingual children, outperform monolingual peers on *cognitive control*. However, only children with greater L2 proficiency would outperform monolinguals on *analyzed knowledge* (Bialystok, 1988, 2001b;

Bialystok & Barac, 2012; Bialystok & Majumder, 1998; Cromdal, 1999). However, these patterns have not been confirmed using a direct and continuous measure of L2 proficiency, making it difficult to determine whether proficiency is the primary factor influencing performance. Additionally, the literature is quite heterogenous with respect to the languages used for testing. In some studies, children completed the task in their stronger language (Bialystok & Majumder, 1998), in their weaker language (Cromdal, 1999) or in both languages (Bialystok, 1988). This variability further complicates the ability to draw clear conclusions about the specific role of proficiency in GJT performance. Given the cognitive and linguistic demands of the GJT, studying its performance in autistic children provides a valuable opportunity to explore their metalinguistic abilities further. Examining GJT performance *within a bilingual framework* offers insights into whether bilingualism influences metalinguistic awareness in autistic children differently than in neurotypical children.

In the fifth experimental contribution of this thesis (**Section 5.2**), I aimed to address the limitations of previous research by more clearly defining and directly testing the bilingual variables hypothesized to drive an effect on *analyzed knowledge* and *cognitive control* in neurotypical children. I also investigated whether the effects were present in autistic children, providing a pioneering perspective on the impact of bilingualism on metalinguistic awareness in this population.

A total of $N = 180$ children with TD, and $N = 90$ children with ASD participated in this study. Children were aged between 5 and 12 years and were tested in their most proficient language. After accounting for their age, non-verbal IQ, and morphosyntactic skills, no universal bilingual benefit was observed. Neurotypical bilingual and monolingual children performed comparably on sentences requiring additional demand on *cognitive control*, suggesting that proficiency in the testing language is a crucial factor to consider. By contrast, autistic bilingual children significantly outperformed their monolingual peers on such sentences, indicating that bilingualism may support executive aspects of metalinguistic awareness in this population. Children with ASD exhibit greater variability in language proficiency than their neurotypical peers, including in their dominant language, which they may not fully master (Rapin & Dunn, 2003; Schaeffer et al., 2023; Tager-Flusberg et al., 2005). In this context, our findings provide important evidence that bilingualism is not detrimental for autistic children's language development, and may instead confer benefits on tasks involving cognitive control. This result extends and adds new evidence to previous research showing a positive impact of bilingualism on cognitive skills, such as executive functions (see Leung & Molnar, 2023 for a recent review), and paves the way for future research on effects of multilingualism on metalinguistic awareness.

Turning to the impact of L2 proficiency, no effect was found in either group on *analyzed knowledge* or *cognitive control*, suggesting that other factors, not captured by L2 proficiency alone, may play a role in shaping metalinguistic performance. However, autistic children with higher L2 proficiency performed better overall on the GJT than peers with lower proficiency, a positive finding that emphasizes the value of supporting both languages in this population.

Overall, these results show that bilingual experience does not hinder development in autism and may even provide advantages for metalinguistic skills. They further reinforce the importance of encouraging bilingual environments for autistic children (Beauchamp & MacLeod, 2017), and contribute to a growing body of work advocating for inclusive approaches to bilingualism that take developmental diversity into account (e.g., Prévost & Tuller, 2022).

7.1.1.3 Narrative macrostructure

The last experimental contribution focused on another communicative domain sharing tight links with socio-cognitive and cognitive skills: Narrative macrostructure. Research on narrative macrostructure is another area that has long been dominated by the binary comparison between bilingual and monolingual children. Only recently have studies begun to directly investigate specific aspects of bilingual experience that may influence these skills, such as *age of bilingualism onset* or *length of exposure to a second language* (see Lindgren et al., 2023 for an overview). However, the theoretical foundations regarding *which* aspects of bilingualism specifically impact these abilities remain unclear. Clarifying these mechanisms could help reconcile conflicting findings in the literature and determine which aspects of the bilingual experience are most influential (Antoniou et al., 2023; Kremin & Byers-Heinlein, 2021).

In this sixth experimental study (**Section 6**), we examined the impact of relative exposure to other languages, beyond the individual's dominant language (L1). The underlying hypothesis was that individuals with greater *exposure to additional languages* (EtAL) would be more frequently exposed to different storytelling and communication styles than those primarily interacting in a single language. Because cross-linguistic transfers occur in narrative macrostructure (Bohnacker et al., 2022; Lindgren et al., 2023), these storytelling elements would then be incorporated into the macrostructure of their first language, leading to a richer and more elaborate narrative macrostructure in L1. We tested this hypothesis on 168 neurotypical and 90 autistic children aged 5 to 12 years. The *Multilingual Assessment Instrument for Narratives* (MAIN; Gagarina et al., 2012, 2019) was used to elicit narratives, and three macrostructural dimensions were investigated: (1) *story structure*, reflecting the overall organization of the narrative, including the presence of key story elements (e.g., setting, initiating event, Goal, Attempt, Outcome); (2) *story complexity*, capturing the level of elaboration and completeness of narratives episodes, such as whether the protagonist's Goals, Attempts, and Outcomes are explicitly specified for each episode; and (3) the production of *Internal State Term* (IST-use). ISTs were further categorized into ToM-related ISTs, which include metacognitive verbs and terms conveying emotions or desires (e.g., "happy", "think", "want"), and ToM-unrelated ISTs, which refer to perceptual, linguistic or physiological states (e.g., "see", "shout", "smell"). Given that the extent to which Theory of Mind (ToM), Working Memory (WM), and Metalinguistic Awareness (MA) contribute to narrative macrostructure remains unclear in the literature, we also examined the role of these (socio-)cognitive factors in performance. Findings indicated that neurotypical children with greater exposure to additional languages delivered more elaborate narratives than

their peers with lower EtAL. Indeed, they outperformed their peers with lower EtAL on *story structure*. This suggests that neurotypical children may benefit from dual-language exposure to enrich their narratives. However, no such effect was observed in autistic children, whose performance did not vary as a function of their EtAL. One explanation is that constructing a coherent narrative is a highly social-cognitive act – it requires understanding what information listeners need and organizing events in a shared, meaningful way (Berman, 1988; Bliss et al., 1998). Autistic children often produce less coherent, less well-structured narratives than their neurotypical peers (Baixauli et al., 2016), possibly due to pragmatic challenges such as difficulty gauging listeners' knowledge and focusing on details over the big picture (Happé & Frith, 2006). Even if exposed to multiple languages, these core narrative deficits may persist because autistic children struggle to generalize discourse patterns from one context to another (Carruthers et al., 2020; de Marchena et al., 2015). Neurotypical children, on the other hand, may benefit from hearing stories told in different languages; this exposure could help them abstract *language-independent* story schemas (Tsimpli et al., 2016). Bilingual exposure might "teach" a neurotypical child that, regardless of language, a good story has a clear beginning, middle, and end, a structure they can then apply to improve their own storytelling. Autistic children do not show the same gain, and may not spontaneously infer the global "template" of a story from diverse inputs (Bodner et al., 2015; Loukusa & Moilanen, 2009), possibly focusing on rote details instead of overarching structure (Happé & Frith, 2006).

The results of this sixth study aligns with previous research indicating no detrimental effect of bilingualism on the narrative macrostructure of autistic children (Beauchamp et al., 2023; Hoang et al., 2018; Peristeri et al., 2020). Furthermore, findings suggest that autistic individuals may not always derive the same benefits from bilingualism as their neurotypical peers, a point that we explore in more detail in the following section (**Section 7.1.2**).

7.1.2 Implications

Two key messages seem to emerge from these experimental contributions:

(1) Bilingualism appears to have different effects on neurotypical and autistic children.

(2) Bilingualism seems non-detrimental to the communicative skills investigated in neurotypical children, and, crucially, in autistic children.

I will explore these conclusions in more depth in the following sections.

7.1.2.1 A differential impact of bilingualism in autistic and neurotypical children

Our studies on bilingualism (**Sections 4.2**, **4.3**, **5.2** and **6**) indicate that, regardless of how it is operationalized, the *bilingualism variable* systematically influenced communicative abilities differently in autistic children compared to neurotypical children.

More specifically, multilingual exposure did not affect gesture comprehension and metalinguistic skills in the same way for autistic and neurotypical children. Multilingual exposure, measured as the balance of exposure to multiple languages from birth, positively influenced the comprehension of iconic gestures in neurotypical children (**Section 4.2**), but had no effect on gesture comprehension in autistic children (**Section 4.3).** Similarly, neurotypical children with greater multilingual exposure, measured as relative exposure to languages other than their L1, demonstrated stronger narrative macrostructural abilities than neurotypical children with lower multilingual exposure (**Section 6**). Yet, this effect was not observed in autistic children.

This differential effect of bilingualism on communicative abilities was not limited to multilingual exposure, but also extended to language proficiency, specifically in L2. Indeed, L2 proficiency differentially affected metalinguistic abilities in neurotypical and autistic children (e.g., L2 proficiency impacted *analyzed knowledge* in neurotypical children, but not in children with ASD; Proficiency in L1 and L2 predicted overall metalinguistic performance in autistic, but not in NT children; **Section 5.2**).

Together, these findings suggest that autistic children may not derive the same communicative 'benefits' from bilingual experience as neurotypical children. This raises the question: *Why* might autistic children not capitalize on bilingual exposure to the same extent than neurotypical peers?

One potential explanation lies in the *socio-pragmatic difficulties* characteristic of autism, which may impact how linguistic and non-linguistic information is processed from the environment. Socio-pragmatic skills involve the ability to use and interpret language in social contexts, including understanding and following conversational rules, interpreting non-verbal cues, adapting communication based on the interlocutor, and understanding the social meaning behind language (Leech, 1983). Children with ASD often present challenges with joint attention, eye gaze, perspective-taking, and adapting to social contexts (Ateş & Küntay, 2018; Tomasello, 1999). These are critical mechanisms for identifying, interpreting and applying linguistic cues in multilingual settings. If a child has difficulty attending to socially relevant cues, or adjusting their language use based on different interlocutors, they may struggle to integrate input from multiple languages into their communicative repertoire. In other words, the social cues that typically foster communicative competence (e.g., tracking the language spoken, being sensitive to the context surrounding speech, detecting cultural nuances in verbal and non-verbal communication) may not be as readily accessible or useful for autistic children. As a result, their ability to integrate input across languages, and apply it effectively in communicative contexts may be diminished.

Another explanation, closely related to the socio-pragmatic difficulties, is the social motivation theory of autism (Chevallier et al., 2012). This theory posits that autistic individuals have a reduced intrinsic motivation to engage in social interactions, characterized by diminished social orienting, social reward responsiveness and social maintenance behaviors (Chevallier et al., 2012). Since bilingualism often offers dynamic, interaction-rich environments (Fan et al., 2015; Wermelinger et al., 2024), reduced social

motivation may limit the extent to which autistic children engage with diverse linguistic input. Consequently, they may have fewer opportunities to extract linguistic regularities and benefit less from bilingual exposure to the same extent as neurotypical children.

Thus, while bilingualism is generally associated with enhanced communicative abilities in neurotypical children, its benefits may not generalize in the same way to autistic children. This difference may stem from *socio-pragmatic challenges* that modify how verbal and non-verbal information from multiple language exposure is integrated and applied in communicative contexts. In addition, reduced social motivation could lead to less interest in bilingual interactions, and fewer opportunities to benefit from bilingual input.

Yet, it is important to acknowledge that there may be variability within the autistic population in *how* individuals take advantage of multilingual experience. Autism is characterized by significant heterogeneity in both linguistic and cognitive profiles (**Section 2.1.2**), and our experimental contributions revealed notable inter-individual variability in the outcome variables within the autistic group (**Section 4.3**, **Section 5.2**, **Section 6**). While our findings suggest that, at the group level, autistic children may not benefit from bilingualism to the same extent as neurotypical children – be it exposure, or on the proficiency dimension – this does not imply an *absence* of information's intake. In fact, there was often a positive trend for bilingualism-related effects, though these did not always reach statistical significance. This suggests that autistic children may indeed benefit from bilingualism, but the extent of this benefit may vary between individuals. Future research should explore *which* factors within autism might influence the ability to capitalize on bilingual experience, with greater attention to individual differences that could determine *who* benefits most from *which* aspect of bilingualism.

7.1.2.2 A non-detrimental impact of bilingualism in autistic and neurotypical children

One of the most promising findings emerging from these experimental contributions is the absence of any adverse effect – and, in some cases, the presence of a positive effect – of bilingualism on the communicative skills of autistic children. Regardless of whether the positive impact of bilingualism has been observed in autistic children (e.g., in metalinguistic skills, as discussed in **Section 5.2**) or not (e.g., in gesture comprehension in **Section 4.3**, or narrative macrostructure in **Section 6**), no detrimental effects have been identified. This indicates that autistic children exposed to multiple languages demonstrate communicative abilities comparable (if not enhanced) to those of their monolingual peers.

These findings align with the results of previous studies on the impact of bilingualism on various *linguistic* (e.g., Beauchamp et al., 2020; Drysdale et al., 2015; Hambly & Fombonne, 2012; Petersen et al., 2012; Skrimpa et al., 2021), *communicative* (e.g., Beauchamp et al., 2023; Hoang et al., 2018; Iarocci et al., 2017; Reetzke et al., 2015; Siyambalapitiya et al., 2021), and *cognitive* abilities (e.g., Andreou et al., 2020; Gonzalez-Barrero & Nadig, 2019; Iarocci et al., 2017; Montgomery et al., 2021; Peristeri, Baldimtsi,

et al., 2021; Peristeri et al., 2020; Peristeri, Vogelzang, et al., 2021; Ratto et al., 2021; Sharaan et al., 2021, 2022) in autistic children. These results are supported by recent reviews and meta-analyses (e.g., Gilhuber et al., 2023; Lund et al., 2017; Prévost & Tuller, 2022; Romero & Uddin, 2021).

They challenge misconceptions about a negative impact of bilingualism in the development of autistic children, and contribute to dispel concerns that bilingual exposure may exacerbate communication difficulties (see **Section 3.2.1)**. Although it may be challenging for clinicians to stay up to date with evolving recommendations for caregivers (Davis et al., 2024), it is essential that clinical guidance reflects current research demonstrating no detrimental effects of bilingualism. Evidence-based recommendations highlight the importance of supporting autistic children in developing and using all their languages, as this fosters family cohesion, preserved cultural identity, and promotes overall well-being (Beauchamp & MacLeod, 2017; Howard et al., 2021; Jegatheesan, 2011; Yu, 2013).

7.2 STRENGTHS AND LIMITATIONS

The current work presents several limitations – most of which can be seen as both challenges and assets, as I outline below.

7.2.1 A wide age range

First, the age range in the ABCCD project and in this thesis primarily encompassed primary school children, and included individuals as young as 3 years old up to 12 years old. This period is particularly well-suited for observing communicative skills, as language, communication, and cognitive abilities develop and mature significantly during these years (**Sections 1.1.2**, **1.2.2**, **1.3.2**, **1.4.3**). Given this development, accounting for age-related effects is essential but also methodologically challenging. The age range was chosen due to the diverse array of abilities investigated: Gesture comprehension emerges relatively early in development (**Section 1.2.2**), while metalinguistic awareness and narrative macrostructure are higher-order skills that develop later (**Sections 1.3.2** and **1.4.2**), typically from age 5 onwards. Examining these skills across primary school provides valuable insights into their developmental trajectories.

The age range was also relevant as the sample included children with autism, who often exhibit greater variability in the attainment of linguistic and cognitive skills (**Section 2.1.2**), as well as delays in the acquisition of language (e.g., Eigsti et al., 2011; Eigsti & Bennetto, 2009) and gestures (e.g., Ramos-Cabo et al., 2019). In the different experimental contributions, age was systematically considered as a covariate in the analyses, either as a main effect or in interaction with the target outcomes, to account for its influence on performance. While this approach helps to control for age-related variability, it does not fully capture the complexity of developmental changes over time. More advanced statistical techniques, such as Generalized Additive Models (GAMs; Wood, 2017), could have provided additional insights by allowing for a more nuanced exploration of age effects on task performance.

7.2.2 A WEIRD sample

Second, the present sample consists of children from WEIRD (Western, Educated, Industrialized, Rich, and Democratic) populations (Henrich et al., 2010). Data were primarily collected in Switzerland, France, Germany, Spain, the United States, the United Kingdom, and Canada (i.e., Montreal). Socioeconomic status, as indexed by the highest level of parental education, was notably high for both autistic and neurotypical children (i.e., on average 4 out of 5, corresponding to non-academic higher education). This may be explained by the voluntary nature of participation in a scientific study, which requires both time and commitment from families. This is particularly relevant given that families often, though not systematically, hosted experimenters at home. For the initial completion of

questionnaires, which were also required for study inclusion (e.g., general information, bilingualism assessment), substantial efforts were made to support families, including offering individual assistance, providing materials in five languages, and simplifying the formulation of instructions and questions. Nevertheless, completing these questionnaires still required significant *linguistic* (i.e., comprehension of questions), and *logistical* (i.e., time investment) resources.

As a result, the findings of this study should be interpreted within the context of families with a relatively high average socioeconomic and cultural background. Given the well-established impact of socioeconomic and cultural factors on children's language and cognitive development (Noble et al., 2007; Peristeri et al., 2022; Rakesh et al., 2024), these results may not be fully generalizable to *all* bilingual populations and children. Indeed, bilingualism is widespread and spans all socioeconomic strata; socio-linguistic considerations differ considerably across bilinguals, including those from immigrant backgrounds (Chondrogianni & Daskalaki, 2023; Song, 2019), heritage language learners (Montrul, 2010), and individuals in regions where bilingualism is an integral part of cultural and administrative identity (e.g., Switzerland, Canada; Studler, 2017). Linguistic experiences are shaped by a range of contextual factors, including social, cultural, educational, and socioeconomic influences, which can affect the ecological validity of findings and contribute to oversimplified interpretations of bilingualism's cognitive and linguistic outcomes (Luk & Grundy, 2022).

Furthermore, the phenomenon of diglossia between *Standard German* (*Standarddeutsch*, *Schriftdeutsch* ["written German"], or *Hochdeutsch* ["High German"] – with *hoch* ["high"] referring to its geographical sense) and *Swiss German* was not examined in depth. Parents were instructed to treat *Standard German* and *Swiss German* as two distinct languages. Indeed, although these languages share numerous lexical, syntactic, and morphological characteristics (Scherrer, 2012), mutual intelligibility between the two can be limited (Scherrer, 2012). Importantly, bidialectalism has been shown to influence cognitive outcomes, for instance in relation to executive function (Oschwald et al., 2018; Poarch et al., 2019). Given the difficulty of deciding on a standardized form of Swiss German due to regional dialectal variations across Switzerland (Christen, 1998; Scherrer, 2012), and considering that Swiss German is not commonly a written language (except in informal exchanges), the experimental protocol did not include a Swiss German adaptation.

Consequently, Swiss German-speaking children were assessed in *Standard German*, which they typically master at a level comparable to or slightly lower than *Swiss German*; they are exposed, notably, to *Standard German* through media and schooling. Hence, bidialectalism is nearly universal among German-speaking Swiss individuals. Since lexical and morphosyntactic differences exist (Christen, 1998; Scherrer, 2012), standardized assessment tools in *Standard German* may not have been fully optimal. For instance, linguistic variations may have led to 'errors' (e.g., in the PPVT, children were asked to designate the word "*Möhre"* [carrot], whereas the vernacular *Swiss German* term is "*Rüebli"*). However, this difficulty was likely more pronounced among younger children who had not yet started formal schooling, as they are predominantly exposed to informal home environments where *Swiss German* is preferred. For production tasks (e.g., the MAIN assessment), children

were invited to narrate the story in the language of their choice, allowing them to use *Swiss German* if they felt more comfortable doing so.

7.2.3 A protocol in five language versions

This project represents a significant step forward by testing children within a systematic and comparable protocol, using experimental tasks adapted into five languages. This effort is particularly valuable as it fosters collaboration between research teams, allows for the inclusion of children from more diverse linguistic and bilingual backgrounds, and extends data collection to multiple locations worldwide – recommendations that have been emphasized in research to enhance our understanding of bilingualism (Marian & Hayakawa, 2021; Prévost & Tuller, 2022). While noteworthy, this approach is not without challenges. The sample included children with highly varied bilingual experiences across several dimensions: Differences exist between participants in the *age* of second language acquisition (e.g., from birth vs. upon school entry), *mode* of acquisition (e.g., explicit instruction at school vs. exposure at home from a parent), language *exposure* (varied contexts such as school, home, or the broader community), language *use*, and *proficiency* levels. This heterogeneity complicates the investigation of bilingualism's impact on the outcome variables, an issue that I further discuss in **Section 7.2.4**.

Furthermore, adapting the materials into five languages introduces specific methodological challenges. When using standardized tests, it is not always possible to find equivalent or comparable assessments across languages in terms of item selection, scoring scheme, and age range coverage. In our case, for instance, to enable a systematic comparison of participants' receptive vocabulary levels, we opted for the *Peabody Picture Vocabulary Test* (PPVT; Dunn & Dunn, 2007), which covered a broad age range and was available in all of our target languages. However, this choice was suboptimal for the French version, as the most recent edition was largely outdated (*Echelle de Vocabulaire en Images Peabody, EVIP; Dunn et al., 1993)*. Additionally, administering tests in multiple languages incurs significant costs, and is only feasible for languages for which adapted materials are available. Translating and adapting newly created test materials into multiple languages is inherently challenging. Ensuring conceptual, linguistic, and psychometric equivalence across languages requires extensive validation (de Vijver & Hambleton, 1996; Hambleton, et al., 2004; Hambleton & Patsula, 1998; Hernández et al., 2020), which was beyond the scope of the current work. While efforts were made to provide high-quality translations and adaptations, the psychometric properties of the tasks were not systematically assessed. Therefore, the *reliability* (i.e., consistency of a test in measuring what it intends to measure across different occasions, raters, or test forms; Cronbach, 1951) and *validity* (i.e., degree to which a test accurately measures the intended construct; Messick, 1995) of the instruments cannot be confirmed, a known limitation in multilingual research (de Vijver & Hambleton, 1996; Hambleton, et al., 2004).

Moreover, while the materials were carefully translated and tested with adult native speakers of the respective languages, *cultural variations* were not extensively explored in the

material development or data analysis. Specifically, the impact of language pairs to which children were exposed was not examined in detail, apart from the complementary analyses in **Section 5.2**. Instead, bilingualism was primarily considered in terms of its global, domain-general advantages, rather than its specific effects at the level of individual languages. Future research may explore the extent to which the linguistic proximity of the languages to which children are exposed influences the development of their communicative skills. Research has shown that linguistic proximity affects cognitive and communicative processing, with more structurally similar languages facilitating cross-linguistic transfer, while greater typological distance may demand distinct cognitive resources for managing dual language systems (Jarvis & Pavlenko, 2008; Schwieter & Festman, 2023; Westergaard et al., 2017).

7.2.4 A closer look at *specific* bilingual variables

Throughout the experimental contributions, I sought to comply with the recommendations in bilingualism research to avoid the limitation of previous research (**Section 3.1.2.2**) to ensure transparent, reliable, reproducible research findings.

Precisely, bilingualism variables throughout the studies were hypothesis-driven and theoretically justified (Luk, 2022). Researchers indeed emphasize that clear theories are required to resolve inconsistent findings, and shed light on the mechanisms at play in the outcomes observed (de Bruin et al., 2021). Beyond the question of *whether* a bilingual 'advantage' is found over monolinguals in specific subdomains of language, communication and cognition, investigating *how* and *why* specific aspects of language experiences are determinant is arguably more informative in providing clear answers (Marian & Hayakawa, 2021; van Wonderen et al., 2023). To avoid binary classifications comparing monolinguals to bilinguals in our experimental contributions, we aimed to move away from the *monolingual bias* and monolingually-centered perspective that remains prevalent in psycholinguistic and neuroscience research (De Houwer, 2023; Leivada et al., 2023; Rothman et al., 2023). Instead, we employed *continuous* bilingual variables, assessing them as regressors in interaction with other predictors of individual differences. This methodological choice aligns with an approach that conceptualizes bilingualism as a dynamic and multidimensional construct, influenced by the variability in (bilingual) language experiences (DeLuca et al., 2019; Rothman et al., 2023). In addition, bilingual variables were thoroughly assessed and described (de Bruin, 2019; Luk, 2015; Marian & Hayakawa, 2021), using the collaboratively developed, and increasingly adopted Q-BEx questionnaire (De Cat et al., 2022). This tool facilitates cross-study comparisons, and enhances the characterization of the sample (Marian & Hayakawa, 2021).

Although adopting these recommendations advances both research practices and knowledge, it presents new challenges. First, achieving 'homogeneous' groups of bilingual participants across all variables contributing to the complexity of bilingualism remains a complex enterprise, and is even deemed "*impossible*" (Baker, 2011; Leivada et al., 2023). To date, no '*bilingualism quotient*' comprehensively accounts for all the determining dimensions of bilingualism, and translates them into a standardized score for straightforward

participant comparison based on their 'degree of bilingualism' (Marian & Hayakawa, 2021). Furthermore, bilingual experience variables are often interrelated and correlated (e.g., language exposure, use, and proficiency), making it difficult to disentangle whether a specific bilingual variable *independently* drives the observed effects (De Cat & Unsworth, 2023).

Conducting studies across multiple locations strengthens the generalizability of findings on a global scale, but it also introduces variability due to sociolinguistic, geopolitical and cultural differences specific to each context (**Section 7.2.3**). Researchers have thus emphasized the importance of accounting for and explicitly describing these contextual factors in bilingualism research (De Houwer, 2023; Luk, 2015; Luk & Grundy, 2022; Surrain & Luk, 2019). Although I recognize the relevance of these factors, the multi-site nature of the study made it difficult to systematically specify and analyze them for each region where testing took place. I acknowledge that this represents a limitation of the current work.

7.2.5 An inclusive testing protocol?

Finally, in a collective effort within the ABCCD project, we endeavored to design a testing protocol that was accessible and considerate of the challenges faced by autistic children, particularly concerning linguistic, cognitive, and clinical aspects. To this end, all materials were digitized and presented in an engaging, playful manner on touch-screen tablets, acknowledging the interest and effectiveness of these tools among children with ASD (Alzrayer et al., 2014; Carneiro et al., 2024; Pliska et al., 2023). Instructions and stimuli were simplified both linguistically and cognitively, where feasible (see **Sections 4.1**, **4.3**, **5.1** and **5.2**) to avoid assessment biases, and to ensure that children with language or intellectual impairments were not disadvantaged. We also ensured precise assessment of language skills using standardized tests, required mostly non-verbal response options (when possible), and evaluated IQ *non-verbally* with a tool which is suited for the autistic population (Silleresi, 2023).

Although no specific exclusion criteria were established for study participation, only participants who were able to sit at a table, cooperate with tablet-based activities, maintain attention for a sufficient duration, and respond voluntarily were included. Despite dividing the protocol into multiple sessions, the length and cognitive demands of the tasks required resources that children with significant behavioral issues, major attention disorders, or substantial intellectual impairment might not possess. Consequently, these children were not part of our sample, reflecting a notable sampling and methodological bias in autism research (Russell et al., 2019).

Despite our efforts, we can note a higher incidence of *missing data* among autistic children compared to neurotypical children. Not all tasks of the protocol could be administered to every child; some responses were unreliable (e.g., random answers) or incomplete, complicating data analysis and interpretation. Larger sample sizes are therefore required to confirm the effects observed – also because performance is more

heterogeneous in autistic than in neurotypical children. At the same time, recruiting and data collection are (generally) more complex with autistic children than with neurotypical children. Moreover, in the current case, missing data are *inherently* informative, as their absence may reflect systematic patterns related to the underlying unobserved values (i.e., *Missing data Not At Random*; MNAR). This characteristic makes it challenging to disregard such data and, conversely, requires the use of appropriate statistical methods to address them without introducing bias (Little & Rubin, 2019; Sterne et al., 2009).

7.3 FUTURE DIRECTIONS

A promising avenue for future research is the implementation of longitudinal studies tracking bilingual communicative development in both neurotypical and autistic children. While bilingual language acquisition in typically developing children generally follows a similar timeline to monolinguals (De Houwer, 2002; Muszyńska et al., 2025), much less is known about long-term trajectories in autistic children. Recent evidence suggests that bilingual exposure does not impede language growth in autism; for instance, a 12-month longitudinal study compared 60 monolingual to 60 bilingual young autistic children (Siyambalapitiya et al., 2021). Children were considered bilinguals if they were exposed at home to another language than the societal language. There was no difference in social communication outcomes over time (Siyambalapitiya et al., 2021). Similarly, an exploratory multi-year study reported that children with ASD raised in bilingual homes exhibited equivalent rates of growth in social and communicative skills while in early intervention, whether they were raised in bilingual or monolingual homes (Zhou et al., 2019). Findings additionally suggested some 'advantages' to growing up in a bilingual home environment, as bilingually exposed children made greater gains in their use of gestures (Zhou et al., 2019). Building upon these findings, extending longitudinal research across developmental stages and systematically assessing bilingual variables over time will be crucial steps for capturing nuanced trajectories in communicative skills in both neurotypical and autistic children. Given the dynamic nature of bilingualism, with factors like language proficiency, exposure, and use fluctuating over time, a longitudinal approach would allow for a more comprehensive understanding of how these variables interact with communicative development. Providing robust longitudinal evidence will also be invaluable for clinicians and educators, enabling them to refine evidence-based guidance for families. To achieve this, multi-site, collaborative research projects are necessary for collecting generalizable data across diverse linguistic and cultural contexts, as well as for addressing the heterogeneity found in autism (Prévost & Tuller, 2022). The longitudinal component of the ABCCD project will provide insight into the impact of specific bilingual variables on the communicative and cognitive development of autistic and neurotypical children, complementing the cross-sectional investigations.

Another research perspective pertains to gesture use, alongside gesture comprehension, in (bilingual) autistic children. Previous research indicates that children and adolescents with ASD exhibit reduced and qualitatively atypical gesture production across various gesture types and communicative contexts (Camaioni et al., 2003; Mundy et al., 1986, 1990; Ramos-Cabo et al., 2019; **Sections 2.2.2** and **4.3**). Differences may also extend to the synchronization of gestures with speech. For instance, while autistic adolescents did not differ from neurotypical peers in gesture frequency during a narrative task, they demonstrated significantly longer delays between gestures and related speech (de Marchena & Eigsti, 2010). This finding provides evidence of impaired integration of gestural and speech modalities in autism, further supported by studies on gesture and speech comprehension (Hubbard et al., 2012; Silverman et al., 2010; **Section 4.3**).

An important avenue for future research is to examine whether difficulties in gesture-speech integration during *production* also manifest in *comprehension* within the same individuals. If both modalities are affected, this would suggest a shared underlying mechanism influencing multimodal integration in autism, potentially related to temporal processing or sensorimotor coordination. Conversely, if some autistic individuals exhibit intact gesture comprehension but impaired production (or vice versa), this could indicate that these abilities rely on distinct cognitive or motor pathways. Investigating these within-individual variations could lead to more targeted intervention, addressing specific impairments in either the execution or perception of gesture-speech integration rather than assuming a uniform deficit.

Moreover, investigating gesture production in bilingual autistic children could provide valuable insights into how bilingualism influences gesture use. Some studies suggest that bilingual children gesture more frequently than their monolingual peers, possibly as a communicative strategy to facilitate speech production (Nicoladis, 2007). Given that autistic individuals tend to produce fewer gestures than their neurotypical peers (Ramos-Cabo et al., 2019; **Sections 2.2.2** and **4.3**), it would be particularly interesting to examine whether bilingual autistic children gesture more than their monolingual autistic peers. A retrospective study by Valicenti-McDermott et al. (2013) suggested this possibility, raising the question of whether bilingual exposure could mitigate some gesture production differences commonly observed in autism.

Furthermore, assessing the impact of specific bilingual experience variables would be crucial in identifying the factors driving any potential increase in gesture use. Investigating these dynamics could refine our understanding of *how* bilingualism interacts with multimodal communication in autism, offering new perspectives on language development and nonverbal communication strategies in the growing population of bilingual autistic individuals.

CONCLUSION

This thesis contributes to the growing body of research on bilingualism, autism, and communicative development, by examining how different aspects of the bilingual experience influence gesture comprehension, metalinguistic awareness, and narrative macrostructure. These three communicative domains are generally affected in autism, while conversely enhanced in neurotypical children with dual-language exposure. By considering both neurotypical and autistic children, this work provides new insights into the interplay between bilingualism, language, and communication, while accounting for the role of cognitive skills in these processes.

One of the strengths of this research is its broad scope and application to children across primary school. The use of digitalized tasks made assessments more accessible and engaging, particularly for autistic participants. Additionally, by integrating five languages and multiple international testing sites, this study strengthened collaboration between research teams, enabling a more inclusive and globally informed exploration of bilingualism. While challenges remain in fully capturing the complexity of bilingual experiences, this thesis sought to move beyond simple monolingual-bilingual comparisons by incorporating continuous, carefully selected bilingual variables alongside detailed assessments of language and cognitive skills.

In neurotypical children, various advantages of bilingualism were found, notably in gesture comprehension, metalinguistic awareness, and narrative macrostructure. In autistic children, while benefits were observed in metalinguistic awareness, no consistent effects were detected in gesture comprehension or narrative macrostructure. These findings indicate that bilingualism does not affect communicative abilities in autistic and neurotypical children in the same way, suggesting that the mechanisms through which bilingualism interacts with communication may differ across these populations. The benefits of bilingualism appear to arise more frequently in neurotypical children than in autistic children. Importantly, however, this research found no evidence that bilingualism negatively impacts the communicative skills of autistic children. These findings challenge lingering concerns about bilingual exposure complicating language development in autism, and reinforce the idea that bilingual autistic children should be supported in using all their languages.

Beyond these results, this thesis provides preliminary directions for future research. The differential impact of bilingualism in autism *vs*. neurotypical development highlights the need for further investigation into communicative abilities including gesture comprehension, metalinguistic awareness, and narrative macrostructure. Future research

is warranted to better understand how these domains intersect with socio-pragmatic skills and cognitive abilities, providing more insights into the mechanisms supporting (bilingual) language processing and development. Additionally, longitudinal studies will be essential for understanding how bilingual experiences influence communicative trajectories over time. Given the complexity of bilingualism and autism, collaborative, multi-site research such as the ABCCD project will play a key role in refining our understanding of these interactions, and ensuring that findings are representative of diverse populations.

In sum, this research advances our understanding of bilingualism in children with and without autism while recognizing the need for further inquiry. By showing that bilingualism may, in some cases, be beneficial and is in no instance detrimental, this work has implications for both research and practice. I hope that these findings will contribute to a more nuanced understanding of bilingualism, including in autism, and inform future studies, as well as clinical and educational guidance for bilingual autistic children and their families.

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APPENDIX

Appendix A. Accepted version of Wolfer and Durrleman (2023)

The following article is the accepted version of the published article cited as:
Wolfer, P., & Durrleman, S. (2023). Book review: Silvia Silleresi, Developmental Profiles in Autism Spectrum Disorder: Theoretical and Methodological Implications. *First Language*, *43*(6), 671 675. https://doi.org/10.1177/01427237231207521

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Reflections on Developmental Profiles in Autism

Silleresi, S. *Developmental Profiles in Autism Spectrum Disorder: Theoretical and Methodological Implications*. John Benjamins: Amsterdam, The Netherlands, 2023, 287 pp

Reviewed by Pauline Wolfer and Stephanie Durrleman, University of Fribourg (Switzerland)[1]

The volume under review, authored by Silleresi (2023), is concerned with the heterogeneity of both monolingual and bilingual children with Autism Spectrum Disorder (ASD). Alongside the recognized dyad of core autistic symptoms (American Psychiatric Association, 2013), the author observes that autistic children show diversified linguistic and intellectual abilities that have been categorized into the following four subgroups by the International Classification of Diseases ICD-11 (World Health Organization, 2018): (1) autism with both language and intellectual abilities within the norm (called ASD-LN without intellectual impairment), (2) autism with both impaired language and intellectual abilities (ASD-LI with intellectual impairment), (3) autism with spared language skills but with intellectual impairment (ASD-LN with intellectual impairment) and finally (4) autism with impaired language skills but intellectual abilities within the norm (ASD-LI without intellectual impairment). The overarching goals of this work are to determine whether these profiles are detectable with reliable tools for children growing up with one or two languages, and to explore the potential of interactive technologies for evaluating and addressing language difficulties in this population.

After an introductory chapter recalling key concepts related to autism, the author proposes a detailed review of studies investigating structural language (i.e., phonological and morphosyntactic) skills in autistic children of varying linguistic and intellectual abilities. This rich overview highlights crucial research gaps, such as the under-investigation of bilingual children with ASD, and offers interesting and pivotal research perspectives, such as the need to study children with intellectual impairment for a more realistic depiction of the whole autistic spectrum. The scoping review on structural language also reveals the variability of the tasks used and their inherent biases, explaining the heterogeneity of results. As the myriad of results reported does not always allow for firm conclusions to be drawn, the author seeks to rigorously identify the most suitable tools to efficiently measure linguistic (Chapters 2 and 3), intellectual (Chapter 4) and autistic (Chapter 5) traits in children. On the one hand, the critical perspective offered of the studies to date will be of much use to readers looking to gain insight into current investigations of language in ASD, and the attention to study design in this work to pursue these investigations ensures more replicability with respect to previous studies. On the other hand, a clearer justification of the author's criteria to select a sentence repetition task for structural language

[1]We warmly thank our colleagues Franziska Baumeister and Sarah Oudet, as well as editors Emily Stanford and Chloe Marshall for their careful reading of this review. Thanks also to the Swiss National Science Foundation for their support via the grant no. PR00P1_193104/1.

assessment in ASD would have been welcome, especially since this population displays a prevalence of echolalia (Van Santen et al., 2013) and repeating sentences does not guarantee that they are understood (Frizelle et al., 2017).

Throughout the book, the fact that bilingualism is an object of study in its own right should be acknowledged as a clear strength, considering the growing number of autistic individuals exposed to more than one language, for whom evidence-based recommendations are needed (Beauchamp & MacLeod, 2017), particularly for (bilingual) autistic children *with* intellectual impairment who are often absent from studies (Russell et al., 2019). In light of this, the experimental part of this project (Chapter 6) investigating language and IQ throughout the entire spectrum is highly commendable. The findings continue to underscore that being exposed to more than one language is not detrimental (Gilhuber et al., 2023), even when an intellectual impairment is present, which is a compelling argument to support bilingual policies for this understudied population. Still, considering the growing body of work reporting the multidimensional and heterogeneous nature of bilingualism (e.g., Luk & Bialystok, 2013), and emphasizing the importance of its characterization (e.g.,Marian & Hayakawa, 2021), it would have been desirable that the inclusion criteria for the bilingual group be explicitly articulated and subgroups of participants with different bilingual experiences be explored (Hantman et al., 2023).

Another innovative aspect of this work is the cluster analysis, which enables the identification of the four profiles described in the IDC-11 classification. If the meticulous description of these clusters is already an outstanding achievement, a qualitative exploration of the errors beyond the quantitative analysis would have served to inform the current debate on whether formal language impairment attested in ASD resembles that reported for DLD (Schaeffer et al., 2023). Also, regarding the cluster analysis, it is intriguing that certain profiles do not emerge, for instance autistic children with language impairment and high non-verbal intellectual skills (ASD-LI with *high* NVIQ). In our view, that this subgroup is largely missing from the present work would have been a logical point of departure for considering approaches predicting this dearth (Hinzen et al., 2020). Another group that is not identified is one without language impairment with *very* low non-verbal skills (ASD-LN with *very* low NVIQ), which begs the question whether this reflects the non-existence of such individuals or rather, as we ponder here, researchers' inability to detect them due to selection bias (Russell et al., 2019) and methodological limitations (Flynn et al., 2017; Woodall et al., 2010). This latter "discrepant" profile is shown to emerge once non-verbal skills are merely 'low' (as opposed to *very* low) in the well-known "Savant Christopher" (Smith & Tsimpli, 1995), a polyglot autistic adult displaying "normal" linguistic skills alongside low intellectual abilities. Nevertheless, the author at times classifies Christopher's IQ as "severely low" (p.80) estimated on his (40 to 60) standard scores on the *Draw a Man Test* (Goodenough, 1926). No mention is made in these instances of his scores of 75 and 76 obtained respectively at ages 14 and 32 on the Raven's Progressive Matrices (Morgan et al., 2002), although this tool had been claimed to be the most reliable one for non-verbal IQ measurement (Chapter 4). Moreover, considering Christopher's difficulties with

complex grammatical structures (e.g., topicalization and dislocation) even in his first language (Smith & Tsimpli, 1995), the very classification of his profile in the ASD-LN category seems debatable. Although "discrepant" profiles are scarcer and this scarcity must be theoretically accounted for, Silleresi's careful work nevertheless reveals that they are attested to a certain extent and, as such, provides further empirical support for the theoretical view of language modularity. This revelation also contributes to heightening societal awareness of the possible language-cognition dissociation, increasing chances for appropriate clinical response.

Finally, a new avenue of research via interactive technologies to train structural language skills in autistic children is presented. The author's consideration of the numerous advantages underlined here for these tools (e.g., systematicity, portability, adaptability) and specifically for this population (e.g., motivating, engaging), convincingly argues in favor of further developing and adopting these promising methods in clinical and research settings. This is particularly crucial for autistic children with intellectual impairment and even non-verbal participants for whom traditional assessment and training generally entails considerable hurdles. However, the decision in the author's own studies, to opt for a sentence repetition task to assess these skills, yet not to train them, warrants justification.

In sum, despite a few points inviting further explanation highlighted above, Silleresi's volume is an important state of the art on formal language and IQ in children with autism, growing up with one or two languages and from all levels of symptom severity, which moreover indicates insightful future perspectives in this field. This clear and accessible book[2] will be of interest to both budding and experienced researchers as well as clinicians seeking to attain a deeper understanding of the potential profiles attested, or to gain insights into optimal assessment and remediation techniques, for both bilinguals and monolinguals with ASD.

[2] A few typos leading to confusion should be corrected in a second edition of the manuscript. For instance, when presenting the "fourth" profile of children with *no* language impairment (but *with* intellectual impairment, p.8), the group is erroneously qualified as having both language and intellectual impairment (due to omission of the negation), and when presenting the groups with intellectual impairment (in Figure 2, p.41) the groups on the right are mistakenly classified as not displaying intellectual impairment.

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Research experience

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09/2021 – 09/2025

PhD in Medical Science
"The impact of bilingualism on the communicative skills of autistic and neurotypical children"

- Contributed to a longitudinal study examining the impact of bilingualism on cognitive and communicative abilities in autistic and neurotypical children (450 participants)
- Designed and developed a digital assessment protocol (*serious-game*), integrating >15 gamified tasks in five languages, incorporating both standardized tools (e.g., non-verbal IQ measures) and newly developed tasks (stimuli creation, task content, aesthetics, and piloting)
- Collaborated to secure IRB approvals and ensured compliance with ethical research standards
- Collaborated internationally with researchers (task development, scientific discussions), programmers, and illustrators
- Coordinated participant recruitment and data collection, including training and supervising collaborators involved in the study
- Managed data preprocessing, cleaning, and preparation to ensure data quality and readiness for analysis
- Performed statistical analyses in R, including Generalized Mixed Effects Models and mediation analyses

Education

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Marseille, France
08/2019 – 08/2021

Master's degree in Neuroscience:
Integrative, Cognitive and Behavioral Neuroscience
Master Thesis: *"Functional connectivity changes in the left IFG after anomia rehabilitation in the drug-resistant temporal lobe epilepsy",* sEEG data analysis
Epileptology Unit, La Timone Hospital

Haute Ecole de la Ville de Liège
Belgium
2012 - 2015

Bachelor in Speech and Language Therapy
Grade Grande Distinction (83%), rank 3/292
Final thesis project (18/20): "2 + 3 = 5! Memory retrieval or procedural solving in mental arithmetics? Applying the *Operand Recognition Paradigm* to subjects with Parkinson's Disease and a control group."

France (Alsace)
2011 – 2012
2011

First year of medical studies *(Strasbourg)*
Scientific Baccalauréat *(Landser)* Grade *Très Bien* (17.2/20) ; European section

Professional experience

Speech and language therapist, independent practice
Blotzheim, France
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- Assessment of language and cognitive abilities using normed, standardized tests and tools, analysis and interpretation
- Establishment of rehabilitation program: literature review, planning of the structure and nature of the therapeutic intervention. Therapeutic sessions, training, generation of reports, discussion with clients and caregivers
- Collaboration with fellow health professionals, cross-disciplinary discussions. Practice management, including patient database development, administrative duties, accounting

Other research and clinical skills

- Data analysis in R and Python
- ADOS-2 certification, MAKATON training
- Task implementation in Gorilla Experiments
- fMRI data preprocessing with SPM12

Languages

French	Native speaker
German	Fluent (*C1 Goethe Institut)*
English	Fluent

Scientific contributions

Publications

Wolfer, P., Baumeister, F., Cohen, D., Dimitrova,N., Solaimani, E., & Durrleman S. (2025). Co-speech gesture comprehension in autistic children. *Journal of Child Language.* https://doi.org/10.1017/S0305000925000157

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Solaimani, E., Baumeister, F., Bentea, A., Chondrogianni, V., Delage, H., **Wolfer, P.**, & Durrleman, S. (2025). Bilingualism, working memory, and relative clause comprehension in children. *Linguistic Approaches to Bilingualism*. https://doi.org/10.1075/lab.24037.sol

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Conference presentations and posters

2025

Zuban, Y., Baumeister, F., **Wolfer, P.**, and Durrleman, S., (2025, October). Comprehension of passive voice in German and French-speaking children with Autism Spectrum Disorder (ASD): no negative effects of bilingualism [Conference session]. Konstanz Linguistics Conference (KLC) 2025, Konstanz, Germany

Tsoukala, A., Vender, M., Tagliani, M., Vila Borrellas, E., Baumeister, F., **Wolfer, P.**, and Durrleman, S., (2025, June). Pronoun Production in Autism: Effects of Bilingualism and Theory of Mind. [Conference session]. ICPLA Conference, International Clinical Phonetics and Linguistics Association, Patras, Greece

Vila Borellas, E., Baumeister F., **Wolfer, P.**, E., Solaimani, E., Eigsti, I.-E., and Durrleman, S. (2025, June 12). Bilingualism and Multilingualism in Autism: Effects on Executive Functions and Gesture Comprehension. [Conference session]. The 4th Conference on Biolinguistics and Language Acquisition (online)

Schouwenaars, A., Hendriks, P., Baumeister, F., Solaimani, E., Vila Borrellas, E., **Wolfer, P.**, and Durrleman, S, (2025, June). Pronoun interpretation in bilingual children with Autism Spectrum Disorder. [conference session]. Language Abilities in Children with Autism (LACA) online meeting, organized by the University of Amsterdam, The Netherlands.

Wolfer, P., Baumeister, F., Vila Borrellas, E., Solaimani, E., and Durrleman, S., (2025, June 9-13). Multilingual effects on gesture comprehension in autistic children. [Symposium presentation]. *Capturing Diversity in Bilinguals' Development*, 15th International Symposium on Bilingualism, San Sebastian, Spain.

Baumeister, F., **Wolfer, P.**, Vila Borrellas, E., Solaimani, E., Eigsti, I.-E., and Durrleman, S. (2025, June 9-13). Increased balance in language use predicts greater interference inhibition in neurotypical and autistic children. [Symposium presentation]. *Capturing Diversity in Bilinguals' Development*, 15th International Symposium on Bilingualism, San Sebastian, Spain.

Silleresi, S., Baumeister, F., **Wolfer, P.**, and Durrleman, S. (2025, June 9-13). Influence of linguistic and cognitive factors on complement clause comprehension in multilingual and monolingual children. [Conference session]. 15th International Symposium on Bilingualism, San Sebastian, Spain.

Abd El-Raziq, M., Baumeister, F., **Wolfer, P.**, Chondrogianni, V., Solaimani, E., and Durrleman, S. (2025, June 9-13). The Impact of working memory on comprehension accuracy in subject and object relative clauses: A comparison between monolingual and bilingual children with Autism Spectrum Disorder (ASD). [Conference session]. 15th International Symposium on Bilingualism, San Sebastian, Spain.

Baumeister, F., **Wolfer, P.**, Vila Borrellas, E., Solaimani, E., Durrleman, S. (2025, May 21-23). Effects of diverse bilingual experiences on executive functioning in neurotypical and autistic children. [Poster presentation]. Multilingualism and minority languages in a global context, Davos, Switzerland.

Baumeister, F., **Wolfer, P.**, Vila Borrellas, E., Solaimani, E., Eigsti, I.-M., Durrleman, S. (2025, May 1-3). Second language proficiency and exposure richness predict executive functioning in autistic and neurotypical children. [Poster presentation]. Society for Research in Child Development SRCD 2025 Biennial Meeting. Minneapolis, Minnesota, USA

Vila Borellas, E., Baumeister F., **Wolfer, P.**, Durrleman, S. (2025, April 30). L'impacte del bilingüisme en les funcions executives i la comprensió gestual en el Trastorn de l'Espectre Autista. [Conference session]. University of Barcelona, Spain

Wolfer, P., Baumeister, F., Vila Borrellas, E., Solaimani, E., and Durrleman, S., (2025, March 24-25). The impact of multilingual exposure on gesture comprehension in children with ASD. [Conference session]. Bilingualism Matters Symposium 2025. Edinburgh, Scotland.

Solaimani, E., Baumeister, F., **Wolfer, P.**, Durrleman, S. (2025, March 24-25). Bilingualism, working memory, and comprehension of French which-questions in ASD: A winning combination. [Conference session]. Bilingualism Matters Symposium 2025. Edinburgh, Scotland.

Schouwenaars, A., Hendriks, P., Baumeister, F., Solaimani, E., Vila Borrellas, E., **Wolfer, P.**, Durrleman, S, (2025, March 24-25). Is there a bilingual advantage for pronoun interpretation in children with Autism Spectrum Disorder? [Poster presentation]. Bilingualism Matters Symposium 2025. Edinburgh, Scotland.

Baumeister, F., **Wolfer, P.**, and Durrleman, S., (2025, March 6-8). Mehrsprachigkeit und ihre Auswirkungen auf exekutive Funktionen bei Kindern mit und ohne Autismus-Spektrum-Störung. [Poster presentation]. Scientific Conference Autism Spectrum (WTAS), Heidelberg, Germany.

Baumeister, F., **Wolfer, P.**, Vila Borrellas, E., Solaimani, E., Eigsti, I.-E., and Durrleman, S., (2025, January 9-15). Second language proficiency impacts switching and visual working memory in neurotypical and autistic children. [Conference session]. Budapest CEU conference on cognitive development, Central European University Budapest, Hungary.

2024

Wolfer, P., Baumeister, F., Rudelli, N., Dimitrova, N, LeGrand, K. J., Corrigan, G., Naigles, L. R., & Durrleman, S. (2024, March 14-16). Co-speech gesture comprehension in school-aged autistic children. [Poster presentation]. Meetings on Language in Autism, Durham, NC, United States.

Wolfer, P., Baumeister, F., Rudelli, N., LeGrand, K. J., Corrigan, G., Naigles, L. R., & Durrleman, S. (2024, March 14-16). Grammatical judgment in school-aged autistic children: A window into metalinguistic awareness [Conference session]. Meetings on Language in Autism, Durham, NC, United States.

Wolfer, P., Baumeister, F., Rudelli, N., LeGrand, K. J., Corrigan, G., Naigles, L. R., & Durrleman, S. (2024, May 15-18). Metalinguistic awareness in school-aged autistic children: insights from a Grammatical Judgment Task. [Poster presentation]. International Society for Autism Research Annual Meeting (INSAR), Melbourne, Australia.

Wolfer, P., Baumeister, F., Rudelli, N., Dimitrova, N, LeGrand, K. J., Corrigan, G., Naigles, L. R., & Durrleman, S. (2024, May 15-18). Gesture replacing verbal information: Do autistic children recognize them? [Poster presentation]. International Society for Autism Research Annual Meeting (INSAR), Melbourne, Australia.

Wolfer, P., Baumeister & Durrleman, S. (2024, May 12-14). Multilingual effects on co-speech gesture comprehension in school-aged children. [Conference session]. Conference on Multilingualism, Aix-en-Provence, France.

Wolfer, P., Baumeister, F., & Durrleman, S. (2024, September 16-19). The benefits of multilingualism on co-speech gestures comprehension in school-aged children. [Symposium presentation]. *Beyond words: how do multilingual children develop their communicative skills?*, 53rd DGPs Congress/15th ÖGP Conference, Vienna, Austria.

Baumeister, F., **Wolfer, P.**, Vila Borrellas, E., Solaimani, E., Eigsti, I.-E., and Durrleman, S., (2024, October 2). Effects of bilingualism on executive functioning in neurotypical and autistic children. [Poster presentation]. Day of Cognition, University of Fribourg, Switzerland.

Baumeister, F., **Wolfer, P.**, and Durrleman, S., (2024, July 15-19). Impact of cumulative linguistic exposure on Theory of Mind in children with and without autism. [Oral presentation]. IASCL 2024: XVIth International Congress for the Study of Child Language, University of Prague, Czech Republic.

2023

Wolfer, P., Baumeister, F., & Durrleman, S. (2023, March 15). Which aspects of bilingualism contribute to semantic and phonemic fluencies? Insight from young adults [Poster presentation]. Research Day, Faculty of Science and Medicine, University of Fribourg, Fribourg, Switzerland.

Wolfer, P., Baumeister, F., & Durrleman, S. (2023, November 17). Multilingual effects on Metalinguistic awareness skills in school-aged children? [Conference session]. X-Prag.ch2023, Fribourg, Switzerland.

Baumeister, F., **Wolfer, P.**, and Durrleman, S., (2023, October 4-6). On the impact of exposure to different languages within contexts on behaviorally and questionnaire based assessed Theory of Mind in children aged 3 to 6 years. [Oral Presentation]. Crossing the Borders Conference, University of Potsdam, Germany.

Baumeister, F., **Wolfer, P.**, and Durrleman, S., (2023, September 4-6). Does the degree of exposure to different languages within and across contexts impact "Social Cognition"?. [Poster Presentation]. Q-BEx Workshop, University of Reading, UK.

Baumeister, F., **Wolfer, P.**, and Durrleman, S., (2023, April 27). How might bilingualism enhance Theory of Mind?. [Oral Presentation]. Workshop on perspective-taking, University of Cambridge, UK.

2022

Wolfer, P., Baumeister, F., & Durrleman, S. (2022, May 5). Effet du bilinguisme sur le développement de la communication des enfants avec et sans Trouble du Spectre de l'Autisme [Conference session]. CUSO PhD Day, Fribourg, Switzerland.

Wolfer, P., Baumeister, F., & Durrleman, S. (2022, September 13). Bilingualism effects on verbal and non-verbal communicative skills in children with autism spectrum disorder [Conference session]. 7th Barcelona Summer School on Bilingualism and Multilingualism, Barcelona, Spain.

Baumeister, F., **Wolfer, P.**, and Durrleman, S., (2022, September 13). Impact of bilingualism on the (social) cognitive development of children with Autism Spectrum Disorder [Conference session]. 7th Barcelona Summer School on Bilingualism and Multilingualism, Barcelona, Spain.

2021

Wolfer, P., Baumeister, F., & Durrleman, S. (2021, October 6). Autism and Bilingualism [Conference session]. Day of Cognition, Fribourg, Switzerland.

Outreach

Wolfer, P., Baumeister, F., & Durrleman, S. (2024, November 14). Langage et Autisme. [Conference session]. Lion's Club Saint-Louis invitation, Blotzheim, France.