Cognitive and Neural Humor Processing: The influence of structural stimulus properties and Theory of Mind

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Table of Contents

Abstract

The aim of the present dissertation is to broaden the knowledge of cognitive humor processes that are the basis of humor appreciation through a multidisciplinary approach: psychological as well as cognitive-linguistic humor theories were taken into account. The focus of interest lies mainly on the incongruity-resolution step of humor processing in relation to structural properties of humorous stimuli as well as individual differences in experience seeking, empathy and systemizing skills. Neuronal correlates—measured by means of functional Magnetic Resonance Imaging (fMRI)—as well as several behavioral measures were used: questionnaires, rating scales as well as explanations of the punch line. Three central themes were addressed: 1) cognitive and affective processes (particularly incongruity-resolution) of visual humorous material, i.e., non-verbal cartoons, 2) the influence of structural properties such as Logical Mechanisms (LMs), as well as incongruity-resolution vs. nonsense humor on neuronal correlates of humor processing, and 3) the relationship between Theory of Mind and humor—Theory of Mind as stimulus characteristic (what cognitive skills are required in order to understand the punch line correctly) and as mental ability (and closely related to empathy) that can vary within subjects.

The results revealed the following network to be involved in incongruity-resolution without pre-processing steps: ventro-medial prefrontal cortex, inferior frontal gyrus, temporo-parietal junction (TPJ) and supramarginal gyrus. The rostral cingulate zone—an area known to be involved in conflict monitoring and error processing—was activated only during the unsuccessful attempt to understand a joke in a picture that contained an irresolvable incongruity. Furthermore, several LMs, i.e., the cognitive rule how the incongruity has to be resolved, moderated neural activation patterns during humor processing. Whereas semantic cartoons required the above-mentioned neural network, more specific areas were involved for processing visual puns (higher-order visual areas) and Theory of Mind cartoons (so-called mentalizing areas). On the one hand, this shows that LMs influence humor processing, on the other hand that Theory of Mind is not always involved in humor processing, as "mentalizing" areas were not involved in visual puns and only to a lesser degree in semantic cartoons.

Moreover, incongruity-resolution humor (i.e., humorous stimuli that can always completely be resolved) evokes more brain activation than nonsense humor (i.e., the incongruity of the joke cannot be completely resolved, much residual incongruity remains), particularly in the TPJ—an area that is involved in integrating information or coherence

building. It can therefore be concluded that structural mechanisms—be it LMs or the resolvability of the incongruity (incongruity-resolution and nonsense humor)—influence neural correlates of humor processing.

Furthermore, experience seeking—a personality variable known to influence humor processing—was shown to affect neural activation patterns: higher experience-seeking scores lead to increased activation in prefrontal, posterior temporal regions and the hippocampus. This might be due to a more intense exploration of the humorous stimuli as experience seekers tend to search novel mental stimulation. Furthermore, experience seeking leads to increased brain reactivity during the processing of nonsense in contrast to incongruity-resolution humor, which is in line with behavioral studies that showed that experience seekers prefer nonsense humor.

Furthermore, empathizing and systemizing was shown to influence processing of humorous stimuli with different LMs: for example, empathizers more often give emotional/motivational and more mentalistic explanations as to why they think a cartoon is funny—particularly in Theory of Mind cartoons. As typical mentalistic explanations occur more often in Theory of Mind cartoons and are uttered more often by individuals with high scores on empathizing, it can be concluded that mentalizing is not always involved to the same degree in humor processing: it depends on stimulus as well as individual characteristics.

In conclusion, these studies show that stimulus characteristics (such as LMs or the resolvability of the incongruity) and inter-individual differences (experience seeking, empathizing, systemizing) influence cognitive as well as affective humor processing. This is the first empirical evidence that LMs influence humor processing. Furthermore, present studies show that mentalizing is not always involved in humor processing, since not all humorous stimuli evoke activation in "mentalizing" areas or provoke mentalistic explanations. This might help to better understand the underlying processes of humor appreciation but also opens more research questions that have to be addressed in the future.

Part I: Theoretical Background

1 Introduction

Humor is a multifaceted phenomenon for which numerous theories have been developed (see Ruch, 2007; Martin, 2006). In 1923 Greig already listed 88 different theories on humor; nowadays there might exist even more models that attempt to describe and explain humor-related phenomena. Humor can be considered from several perspectives such as: an outlook on life (in a more philosophical way), a coping mechanism (stressing its benevolent function), a cognitive skill, a response to a stimulus with funny potential or even as the humorous stimulus itself (jokes, cartoons, or movies, but even people or situations). Numerous components of humor are distinguished (e.g., humor creation, humor comprehension and appreciation). Furthermore, several adaptive functions have been proposed for humor that range widely and are often contradictory (Keltner & Bonanno, 1997, see Gervais & Wilson, 2005). Humor can be therefore understood as an umbrella term for all phenomena in the field of the comic (besides this terminological system, there also exists another one, see chapter 2). There is neither a conclusive definition of humor, nor an all-encompassing measurement tool.

In order to investigate the multifaceted phenomena related to humor (e.g., sense of humor or affective humor processing), various ways of "measuring" humor were developed in the research literature. Depending on the aim what should be measured numerous humor questionnaires were developed (e.g., Situational Humor Response Questionnaire, SHRQ, Martin & Lefcourt, 1984; Sense of Humor questionnaire, SHQ, Svebak, 1974; State-and-Trait-Cheerfulness Inventory, STCI, Ruch, Köhler & van Thriel, 1996; 3 Witzdimensionen Humor Test, 3 WD, Ruch, 1992; see, for an overview, Ruch, 2007b). The humor response can also be assessed by analyzing people's overt expressions, i.e. smiles and laughter which can be analyzed by means of the Facial Action Coding System (Ekman & Friesen, 1978; Ekman, Friesen & Hager, 2002). Another option is to ask people to rate humorous stimuli, for example on funniness, preference, appreciation, aversion or on other perceptual qualities (e.g., Ruch & Rath, 1993; Samson & Ruch, 2005). Recognition times, or how long it takes until the punch line is understood can be measured, as well as subjective comprehensibility. Furthermore, it is possible to ask people to describe how they understand the punch line of humorous stimuli or events. Aside from pure behavioral studies, a few studies exist that measured neural correlates during humor processing with functional Magnetic Resonance

Imaging (fMRI) as well as with Electroencephalography (EEG, e.g., Goel & Dolan, 2001; Wild et al., 2006; Bartolo, Benuzzi, Nocetti, Baraldi & Nicheli, 2006; Coulson & Kutas, 2001).

In the present work, humor is understood both as stimuli with funny potential (like jokes or cartoons) as well as a cognitive process which leads (possibly) to a positive affective state such as exhilaration or enjoyment. Zigler, Levine and Gould (1967) stated that the humor response depends on the demand that the stimulus makes on cognitive capacities. In cognitive humor theories, several structural and formal elements were described that might alter cognitive processing which might also reveal different activation patterns in the brain. For example, the degree of incongruity and its resolution, which was described to be an essential component of humorous stimuli (e.g., Suls, 1972; McGhee, Ruch & Hehl, 1990), might moderate the humor response. Incongruity, the presence of at least two potential meanings that are incompatible with each other, is the structural feature that is considered the central characteristic of humor (e.g., Suls, 1972; Raskin, 1985; Ruch et al., 1990). Many theoretical and empirical papers were written about its effect on humor response. Cognitive-linguistic humor theories described Logical Mechanisms (LM) which are cognitive rules on how to resolve the incongruity in order to get the joke (Attardo & Raskin, 1991; Attardo, Hempelmann & DiMaio, 2002). Whenever LMs were considered theoretically, and humorous texts (be they verbal or visual) were analyzed regarding the LMs (e.g., Paolillo, 1998; Tsakona, in press), there seems to be a lack of empirical verification. Furthermore, neural correlates of cognitive processing of humorous stimuli that vary regarding their structural elements (e.g., degrees of incongruity or LMs) have not yet been investigated. Although recently two brain imaging studies on humor took personality characteristics into account (Mobbs et al., 2005; Rapp et al., 2008), experience seeking has not been investigated yet with brain imaging methods. Because experience seeking is a personality characteristic that is known to influence humor processing (e.g., Deckers & Ruch, 1992) the present study aims to investigate neural activation processing during humor appreciation depending on experience seeking scores.

In addition, several personality characteristics, as well as cognitive skills were postulated to correlate with humor processing. Theory of Mind (e.g., Premack & Woodruff, 1978) and empathy (e.g., Baron-Cohen, 2002, 2003) were described in some humor models to be essential for humor comprehension (Howe, 2002; Jung, 2003). Some studies focused on the relationship concerning mind-reading abilities and humor processing (e.g., Lefcourt, 1995;

Uekermann, Channon & Daum, 2006) however, the relation is not clear yet. Individuals known to have a deficit in empathy and mind-reading were even described to have a lack of humor (Asperger, 1944). Recent studies showed that individuals with Asperger Syndrome indeed have some deficits in humor processing (for a review, see Lyons & Fitzgerald, 2004; Samson & Hegenloh, 2008). Individuals with Asperger Syndrome are known to have low skills in empathy, whereas they have high skills in systemizing, which is the drive to analyze or construct a system (i.e., identify the rules or the laws that govern a system in order to predict how it will behave; Baron-Cohen, 2002, 2003). However, the studies that investigated humor processing in individuals with Asperger Syndrome did not create a consistent picture. The question emerged whether the differences between the studies can be explained through stimuli differences (see Samson & Hegenloh, 2008) or whether it is possible that humor processing that is related to Theory of Mind and empathy depends on structural elements of the stimuli, such as different LMs? This question becomes even more significant if taken into account that one of the LMs, i.e., obvious error, seems to be related to false belief tasks (e.g, recognizing that someone else has a false belief, e.g., Wimmer & Perner, 1983)—tasks that were often used in research literature in order to assess mind-reading skills.

In general, this dissertation focuses on the mental processes involved in "getting the joke" or perceiving an event as funny. The aim is mainly three-fold: first, the neural network involved in resolving incongruity shall be investigated without pre-processing steps such as incongruity-detection; second, the neural response shall be investigated in dependence on so-called incongruity-resolution and nonsense humor, which are known to differ regarding the resolvability of incongruity, as well as in dependence on LMs. Here, the influence of experience seeking, a personality characteristic that is known to influence humor, shall be analyzed as well; third, the influence of LMs on cognitive and affective processing shall be investigated dependent on empathizing and systemizing skills in healthy subjects. This becomes even more interesting when considering humorous stimuli whose LM is based on obvious error (e.g., it is necessary to attribute false mental states to the characters portrayed in the cartoons in order to understand the punch line), or in other words: Theory of Mind cartoons.

The present dissertation is structured as follows: Part I includes the theoretical background such as humor theories, individual differences that influence humor processing, empathy, Theory of Mind and humor, as well as an introduction into the method of fMRI. Part II—the main part of this thesis—consists of several papers: 1) a theoretical paper about cartoon research, 2) an fMRI study that addresses the incongruity-resolution process as well as the influence of LMs, 3) another analysis of the fMRI data that focuses on the difference between incongruity-resolution and nonsense humor, also in relation to experience-seeking humor and 4) two studies addressing the question of the influence of empathizing and systemizing on humor processing, and particularly on how humor is related to Theory of Mind.

2 Humor and Humor Theories

2.1 The concept of humor and humor theories

The most well-known philosophical lexicon of the German language (Ritter et al., 1974) states that *humor* is used in everyday language for all laughter related phenomena.

A rich set of phenomena relating to humor has been accumulated in different cultures, and numerous words for their description have come to use. However, there is still no agreed-upon terminology in research on humor and certainly no consensual definition (Ruch, 2007). The term *humor* has a long history and referred first to bodily fluids in the humoral medicine of the ancient Greeks: blood, phlegm, black bile, and yellow bile. The mixture of fluids known as humors (Greek: χυμός) was expressed in a person's physical appearance, physiognomy and proneness to disease. The predominance of one humor produced a given temperament. Pathologies of all kinds were explained by imbalanced humors. Through progress in medical science, this view of humors as body fluids that influence temperament and health was abandoned, although it persisted in folk tradition. Since 1565 humors were used to describe an unstable behavior or mood, positive or negative mood states, which were described as good and bad humor (Ritter et al., 1974). By the beginning of the 17th century, good humor referred to a disposition, trait, or habit (Ruch, 2004; Roeckelein, 2002).

Today, two different terminological systems exist: the first is derived from the field of aesthetics, where *humor* designates only one element of the comic, and is distinguished from wit, mock/ridicule or fun. In this tradition comic quality was distinguished from other aesthetic qualities like beauty or harmony. Humor—next to wit, fun, nonsense, sarcasm, ridicule, satire, irony, and so on—usually denotes a cognitive-affective style of dealing with adverse situations by finding them amusing. Therefore, humor in its narrow sense is based on sympathy and is by definition benevolent. Although this view of humor is reflected in the writings of Allport, Freud, and Maslow, it is not used within experimental psychology, which rediscovered humor in the 1970s (Chapman & Foot, 1977; Goldstein & McGhee, 1972) and was primarily concerned with people's reactions to jokes or cartoons. The second use of the term *humor* is an umbrella term for all funny phenomena, including the capacity to perceive, interpret, enjoy, create, and relay incongruous communication. Therefore, comic is replaced by humor as an all-embracing term. Among the current meanings of humor are a) playful recognition, enjoyment and/or creation of incongruity; b) a composed and cheerful view on adversity that allows one to see its light side and thereby sustain a good mood; c) the ability to make others smile or laugh. In this tradition, humor is treated as a neutral term that is not restricted to a positive meaning (Ruch, 2004, 2007).

Here, *humor* is used in two ways, as follows: on the one hand it refers to the stimuli that have funny potential as in the non-verbal, one panel cartoons seen in the present work. On the other hand, humor is understood as the cognitive capacity to process potentially funny incongruities, which means to comprehend and appreciate humorous stimuli. Humor processing is understood in the sense of cognitive processing of complex stimuli with a potential affective (positive) experience resulting from successful cognitive (comprehension) processes. Humor processing has therefore a clearly cognitive component (which is described in more detail in the next chapters) and a feeling component which can be described as "funniness experience", amusement, mirth, pleasure or also exhilaration (Ruch, 1993). However, the processing of humorous stimuli can also provoke feelings different from funniness or exhilaration, as was shown in several studies (e.g., Ruch & Rath, 1993; Samson & Ruch, 2005).

When describing humor processing and its related cognitive and affective components, there are several possibilities to embed them in different approaches of explaining humor, as numerous theories have been proposed to explain the perceived funniness of humor. Many different approaches exist to describe humorous phenomena or to explain humor. In 1923 Greig already listed 88 different theories of humor (see Martin, 2006). It can be assumed that today, the number has even increased. These approaches can be classified according to several criteria. However, the attempts to define categories remain always imperfect since many theories (or models) can fall into more than one category, whereas others seem inappropriate for classification (see Keith-Spiegel, 1972; Martin, 2006).

Cognitive approaches are the most important together with psychoanalytical (Freud, 1905, 1928), arousal (e.g., Berlyne, 1972) and superiority and disparagement theories (e.g., Zillmann & Cantor, 1976; Gruner, 1978; for a review of theories, see Keith-Spiegel, 1972; Martin, 2006, 2007; Ruch, 2007). Interestingly, also some of the theories that did not attempt to describe or explain humor from a cognitive perspective incorporate statements of cognitive-perceptual aspects of humor. For example, Freud's (1905, 1974) ideas about "jokework" (cognitive techniques that describe the composition of a joke, i.e., displacement, condensation, etc.) and Berlyne's (1972) "collative variables" (i.e., novelty, element of surprise, complexity, change, ambiguity, incongruity, and redundancy) both refer to cognitive components. Cognitive theories typically analyze the structural properties of humorous stimuli or the way they are processed (sometimes these are intermingled). As cognitive humor theories are most relevant here, they will be introduced in the next chapter. By focusing particularly on the underlying cognitive aspect of humor processing, the influence of other variables on humor appreciation, such as motivational aspects, mood, social context, etc., are of course not denied.

2.2 Cognitive Humor Theories

Cognitive humor theories have in common that they postulate the detection or perception of an incongruity—a disproportion, disagreement or discrepancy between elements in the joke—which forms the basis of any kind of humorous experience (Suls, 1972; Shultz, 1976; Rothbart & Pien, 1976; Pien & Rothbart, 1976; McGhee, 1979, McGhee et al., 1990) to be essential for experiencing humor. According to Shultz (1976) there is a conflict between what is expected, and what actually occurs (incongruity or punch line). In other words: humor involves bringing together two normally disparate ideas, concepts, or situations in a surprising or unexpected manner. Koestler’s (1964) term “bisociation” refers to the juxtaposition of two normally incongruous frames of reference, or the discovery of various similarities or analogies implicit in concepts normally considered to be remote from each other. Initially, Aristotle considered that incongruity is a necessary condition for humor (see, Deckers, 1993). Early proponents in the 18th century of this viewpoint include, for example, Gerard (1759) who described the objects of humor as uncommon mixtures of relations and the contrariness in things. Beathie (1776) believed that laughter arose when two or more inconsistent or unsuitable circumstances were united into one complex assemblage**,** or Priestley (1777) described the cause of laughter as the perception of contrast. Kant (1790, 1798) considered laughter to be an affection arising from the sudden transformation of a strained expectation into nothing. In the 19th century, Spencer (1860) stressed that not all incongruities cause laughter: only the descending ones, that is, if some great things are transferred to something small. In the contrary case other emotions result such as wonder—when something with an insignificant entity develops unexpectedly into something great. Schopenhauer (1788-1860) stated that laughter occurs through the sudden perception of the incongruity between a concept and the real objects. Therefore, incongruity is often described to be a necessary (but probably not sufficient) element that potentially funny stimuli have in common (for an introduction and summary see Martin, 2006; Attardo, 1994).

Whereas Nerhardt (1976)[1] postulates that the detection of incongruity is sufficient to experience humor, most cognitive humor theories postulate that this incongruity has to be resolved in order to be able to appreciate the joke (Suls, 1972, 1983; Shultz, 1976; Rothbart & Pien, 1977, see also McGhee et al., 1990 and Deckers & Buttram, 1990). Pure incongruity may also evoke puzzlement and even aversive reactions (see Forabosco, 1992). In order to resolve the incongruity, humor is described to be processed in several stages: first, an incongruity has to be detected, then, this incongruity has to be resolved (e.g., the information processing model of Suls, 1972; Attardo, 1997). Resolving the incongruity means to explain or understand the relation of (at least) two incongruous elements, for example, the relation between two opposite (and therefore incongruent) scripts[2] or in other words: to make sense of the incongruity or to integrate the two scripts.

Suls (1972) postulated that humorous stimuli are processed in a *two-stage* process, first, the incongruity has to be detected and then, it has to be resolved, similar to a problem solving process. Attardo (1997) describes three stages of humor processing (encoding—incongruity-detection—incongruity-resolution), whereas Coulson and Kutas (2001) also postulate at least three stages. They name the incongruity-resolution process "frame-shifting" (for several reasons, this model has recently been criticized, see Attardo, 2006). However, they claim that the stages in humor processing do temporally overlap as they couldn't differentiate them in investigating humor processing by means of EEG. Empirical evidence that humor is processed at least in two stages comes from Carroll, Young and Guertin (1992): They presented captioned cartoons and analyzed eye movements by means of an eye tracker and could differentiate the following two stages: 1) an exploratory stage (visual analysis of the picture and identification of characters and objects in the picture, shorter fixation duration, more fixations and longer saccades), which corresponds probably to the encoding stage (Attardo, 1997) and 2) a search-and-problem-solving-stage (slower eye movements, longer fixation times) where the eyes come under control of top-down processes. This corresponds probably to the incongruity detection as well as the incongruity-resolution stage postulated in

[1] Nerhardt (1970, for an overview, see Martin, 2006) developed the weight judgment paradigm in order to experimentally manipulate incongruity, which he defined as divergence from expectation. He showed that the extent of incongruity was directly related to mirth. Other studies came to similar results.

[2] Scripts are here understood as knowledge and attributes associated with a word, event or here, also with a visual element. Scripts are not understood here as described by Schank and Abelson (1977) and often used in psychology as groups of causal chains that represent knowledge about frequently experienced events (e.g. going to a restaurant). Schank and Abelson (1977) define a script as a stereotyped sequence of actions that defines a well-known situation and has associated with it.

the model of Suls (1972). Studies in developmental psychology also confirm that humor is processed stepwise: Children younger than five years (Shultz, 1972; Pien & Rothbart, 1976; McGhee, 1979) but also elderly people (Shammi & Stuss, 2003) have trouble executing the incongruity-resolution process and are more amused by the incongruity itself (see also McGhee, 1979; Wicki, 1992). This also shows that humor processing is dependent on executive functions which are developed after the age of five years.

One can argue that the problem-solving aspect (e.g., described in by Suls, 1972) in humor appreciation is peripheral. Indeed, Derks, Staley and Haselton (1998) rightfully raised the question whether joke comprehension is so challenging that it has a problem-solving quality. The authors suggest that perceiving humor is more of an automated expert-like behavior.

However, the question remains why incongruity resolution is followed by feelings of enjoyment. Ruch (2001) assumes that—in order to differentiate humor processing from problem-solving—after the incongruity-resolution process, the recipient is aware that the fit of the solution is a pseudo or "as if" fit. It has to be realized that it is only a *playful* resolution, that it is playing with nonsense, similar to meta-knowledge that a joke was processed. At a meta-level we experience that we have been fooled; our ability to make sense, to solve problems, has been misused.

The notion that incongruity-resolution is important has been criticized, since it was only investigated with jokes whereas it might be possible that in other forms of humor incongruity might be more important than its resolution (see Martin, 2006). However, it must be assumed here, that the underlying cognitive mechanisms are the same in any form of humor, be it jokes or humor that people experience in their daily lives. Furthermore, it is assumed that incongruity might not be as surprising as described in the theories (e.g., by Suls, 1972; Martin, 2006). In social interaction, but also in experimental settings, where people were instructed to rate cartoons or jokes for their funniness, an incongruity is actually expected in the presented joke material or in the joke that will be told (many details can advert that a joke will follow in social situations, e.g., facial expressions, but also the explicit question "Did you hear the one about…"). It is assumed that incongruity may not need to be unanticipated to be enjoyed (see also Martin, 2006).

Recently, a study by Herzog, Harris, Kropscott and Fuller (2006) investigated amongst others four predictor variables that should tap into different stages during humor processing: incongruity and surprise should measure earlier stages of humor processing, difficulty and resolution should measure later stages. However, all four predictor loaded on one factor, which was called by the authors as comprehension: incongruity and difficulty loaded negatively. This shows not only how difficult it is to measure indicators of cognitive processes of humor comprehension but also that surprise might not only be evoked in earlier stages of humor processing but also associated with or evoked through resolution. However, it might be possible that, as the four predictors were not rated by the same subjects, the subjects just did not differentiate between the constructs that the authors wanted to measure. Maybe they all understood something associated with incongruity, resolution, difficulty etc. that is actually comprehension. It is possible that by investigating all four ratings in the same subjects that there is indeed a differentiation of the four predictors possible. Or—this must also be said—it is just not possible to investigate surprise, incongruity, etc., directly (or subjectively) as the subjects do not have access to the processes going on during humor processing. However, this study shows how difficult it is to get good measures of indicators of cognitive humor processing.

Whether the incongruity has to be resolved *completely* or not is a current debate. Hempelmann and Attardo (2007) claim that the resolution of the incongruity is always only partial and newer attempts of describing cognitive humor processing postulate that the resolution is always partial, as the logic that enables it is *always playful*, or faulty. However, it is known that there are jokes wherein the incongruity is not resolved (or not resolved completely, i.e., nonsense jokes) in contrast to jokes where the incongruity can be resolved (almost) completely (incongruity-resolution jokes). The next chapter will address these two types of humor that differ in their resolvability of the incongruity.

2.3 Incongruity-resolution and nonsense humor

Factor analytic studies by Ruch and colleagues (Ruch, 1981, 1992, 1995, see also Ruch & Hehl, 2007) found consistently two types of humorous stimuli differing in regard to their structure, or concerning the resolvability of the incongruity. Jokes and cartoons within each of these two groups may have different content (themes, targets) but are similar with respect to their structural properties and the way they are processed. The so-called incongruity-resolution and nonsense jokes put different loads on different cognitive capacities which even influence the preference of one over the other depending on personality characteristics (e.g., Ruch, 1988; Ruch & Hehl, 2007). Incongruity-resolution humor and nonsense humor can be seen as two extremes on the continuum that describes the resolvability of the incongruity: on the one extreme of a continuum, *incongruity-resolution jokes* contain an incongruity that is (almost) completely resolvable. The common element in this type of humor is that the recipient first discovers an incongruity which is then playfully resolvable upon reinterpretation of the information available in the joke or cartoon. Figure 1A demonstrates an example of an incongruity-resolution cartoon: the incongruity lies in the circumstance that the patient does not know that the psychotherapist is exercising instead of listening carefully. The incongruity is resolved if the psychotherapeutic session is reinterpreted as so boring for the psychoanalyst that he engages in another activity. It’s also a comment on the prejudiced assumption that psychotherapists merely pretend to be empathic (according to Ruch, 1981, incongruity-resolution jokes are more open to interpretations than nonsense jokes).

On the other end of the continuum is *nonsense humor*, which also has a surprising or incongruous punch line. However, the punch line may provide no resolution at all, provide a very partial resolution (leaving an essential part of the incongruity unresolved) or actually create new absurdities or incongruities. In nonsense humor also, there is first something like a problem solving process involved, but not successful (or only partially) (McGhee et al., 1990). Figure 1B demonstrates a nonsense cartoon: two skiers are chased by a shark which seems to swim in the snow. The incongruity is only partially resolvable through the visual analogy of one visual element (the diagonal line) that designates a mountain in connection with the skiers and the sea in connection with respect to the shark. It can’t be both, so this situation is actually impossible and has more residual incongruity than the incongruity-resolution example (in which the situation is unusual, but most likely possible). Several issues, such as why there is a shark on the slope, remain unanswered (residual incongruity).

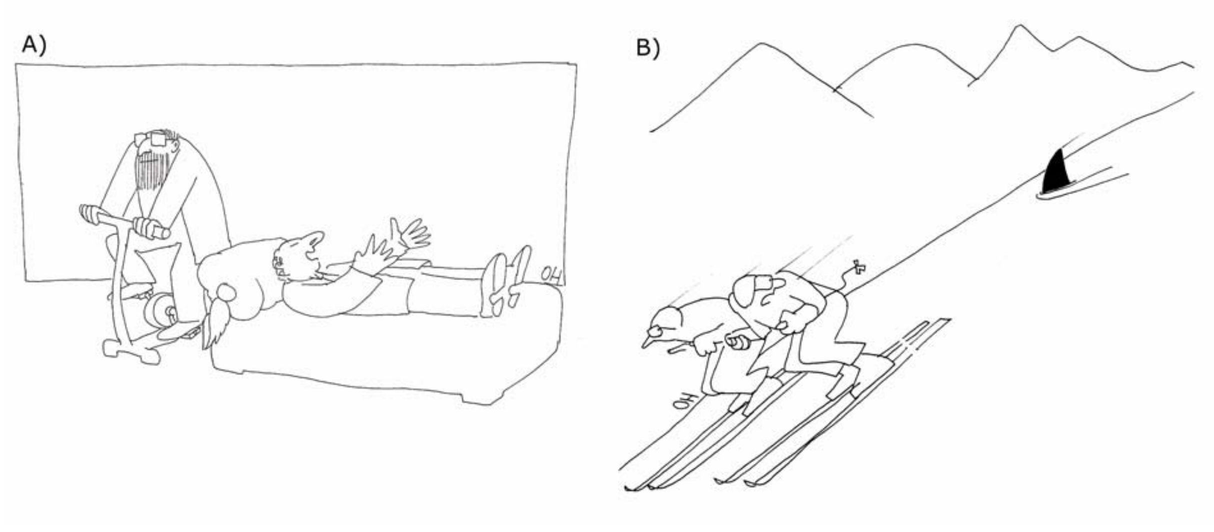

Figure 1: Stimulus examples of an incongruity-resolution cartoon (A) and of a nonsense cartoon (B). Cartoons by Oswald Huber.

McGhee et al. (1990) postulated three types of nonsense humor: 1) the punch line may provide no resolution at all, 2) provide a partial resolution (leaving an essential part of the incongruity unresolved) or 3) actually create new absurdities or incongruities.

In nonsense humor the resolving information creates the impression of making sense out of the incongruities without actually doing so (McGhee et al., 1990). These authors refer to the above-mentioned model of Rothbart and Pien (1977) who proposed to distinguish between possible and impossible incongruities and between complete and incomplete resolutions (p. 37):

1. Impossible Incongruity: elements which are unexpected and also impossible given one's current knowledge of the world, for example, cookies crying.
2. Possible Incongruity: elements that are unexpected or improbable but possible, for example, a dignified man slipping on a banana peel.
3. Complete Resolution: the initial incongruity follows completely from resolution information.
4. Incomplete Resolution: the initial incongruity follows from resolution information in some way, but is not made completely meaningful because the situation remains impossible.

Rothbart and Pien (1977) argue that possible incongruities can be resolved completely while for impossible incongruities there is always a residue of incongruity left. According to Rothbart and Pien (1977) the following riddle is an incongruity-resolution joke: "How far can a dog run into a forest?" "Only halfway. After that he'll be running out of the forest." Here is an example for a joke, where there is no complete incongruity-resolution: „Why did the elephant sit on the marshmallow?" „Because he didn't want to fall into the hot chocolate." In this joke, the answer can provide some explanation of the incongruity, but also introduces a new element of incongruity. A further example of Rothbart and Pien (1977) is the following joke: „Why did the cookie cry?" "Because its mother had been a wafer so long." There are two elements of incongruity, the fact that cookies don't cry and the initial incongruity or surprise of the answer to the riddle. The answer contains its own resolution—the phonological ambiguity of 'a wafer' (away for), but also adds the additional incongruity of a cookie having a mother.

Ruch (1999) claims that nonsense is a "higher" form of humor. It is more artistic, a very sophisticated play with our ability and tendency to make sense. The assumed superior quality of nonsense humor has guided the search for certain personality variables that were expected to predict appreciation of nonsense. The 3 Joke Dimension Test of humor appreciation (3 Witzdimension Humor Test, 3 WD, Ruch, 1992) is a performance test measuring funniness and aversiveness of incongruity-resolution humor, nonsense humor and sexual humor. The latter is the only content-related factor that emerged in their factor analytic studies (as this type of humor is not of particular interest here, see, for example, Ruch & Hehl, 2007). In the 3 WD jokes and cartoons have to be rated on two seven-point scales (e.g., 0 = not at all funny; 6 = very funny). With the 3 WD it is possible to measure the preference for incongruity-resolution and nonsense humor. Furthermore, several indices have been derived and validated (Ruch, 1992, Ruch & Hehl, 1988; Ruch et al., 1990). Scores of total funniness and total aversion (computed by adding the ratings of the three categories) served as indicators of the subject's overall positive and negative responses to humor, respectively. A structure preference index (SPI; obtained by subtracting incongruity-resolution from nonsense) allows to assess the relative preference for resolution in humor over irresolvable or residual incongruities and *vice versa*.

Incongruity-resolution and nonsense humor seem to strongly influence humor processing: many studies showed that the preference for one over the other type of humor is related to personality characteristics (e.g., Forabosco & Ruch, 1994; see below, chapter 3 and 4) and correlates with aesthetic preferences (Ruch & Hehl, 2007). However, up to now, no study attempted to investigate whether incongruity-resolution and nonsense humor show differences in neural activation patterns.

2.4 The General Theory of Verbal Humor

Because of the lack of valid psychological models on humor processing (the majority are not providing any further explanation beyond the two-or three-stage process) it is fruitful to draw upon more elaborated cognitive *linguistic* models such as the Semantic Script Theory of Humor (Raskin, 1985) and its revision, the General Theory of Verbal Humor (GTVH, Attardo & Raskin, 1991). According to Raskin (1985) two conditions are necessary and sufficient to perceive a text as funny: 1) the text is compatible, fully or in part, with two distinct scripts and 2) the two distinct scripts are opposite (i.e., the negation of each other, if only for the purpose of a given text). There are three ways in which the scripts may be in opposition to each other: actual vs. non-actual, normal vs. abnormal, or possible vs. impossible, etc. At a more concrete level, script oppositions (SOps) can be described in terms of pairs as good vs. bad, life vs. death, money vs. no money, etc. For example, Raskins' prototypical joke (“Is the doctor at home?" the patient asked in his bronchial whisper. "No," the doctor's young and pretty wife whispered in reply. "Come right in.") is compatible with the two scripts "doctor" and "lover" and the scripts are opposite on the sex vs. non-sex basis (for an elaborated interpretation see Raskin, 1985).

The GTVH defines six Knowledge Resources (KRs) that are relevant to describe humorous texts (be it verbally or visually) on several, hierarchically ordered levels: SOp, Logical Mechanism (LM), Situation (SI), Target (TA), Narrative Strategy (NS), and Language (LA) (see table 1).

Table 1: Parameters of GTVH (after Attardo & Raskin, 1991).

Parameter	**Definition**	**Instance (examples)**
Language (LA)	Verbalization of the text: word choice, placement of functional elements, etc.	- verbal humor (punning) - position of the punch line
Narrative Strategy (NS)	Narrative structure of the humorous text (genre)	- narratives - question and answer dialogues - riddles
Situation (SI)	The situational embedding of the joke: characters, activities, objects, setting, etc.	- doctors jokes - jokes about blondes
Target (TA)	Humor often aims at (social) stereotypes as 'butts'	- Austrians - Scots
Script Opposition (SOp)	Central requirement fort he generation of a humorous effect: opposition between script	- good vs. bad - possible vs. impossible
Logical Mechanism (LM)	Cognitive operation needed to achieve a (partial) resolution of the incongruity	- juxtaposition - false analogy - figure ground reversal

For cognitive processes, two KRs are of particular interest and shall be described here in more detail: Script Oppositions (SOp) and Logical Mechanisms (LM). Humorous texts consist of at least two scripts which are opposite to each other, but do partly overlap. The SOp can be described according to their degree of abstraction: actual vs. non-actual, normal vs. anormal, possible vs. impossible. The LM is the dynamic function that brings about the script overlap, which means, that it describes the relation of the two scripts. LMs can also be described as the cognitive rule, *how* an incongruity has to be resolved in order to understand the joke. Therefore, the SOp is related more to the incongruity, the LM more to the resolution of the incongruity (Attardo, 1997). Attardo et al. (2002) made a list 27 possible LMs, such as role exchange, figure ground reversal, parallelism, false analogy, cratylism, etc. That these are not only applicable to describe verbal humor was shown by Paolillo (1998) who analyzed LMs of cartoons. Also Tsakona (2006, in press) analyzed visual humor in terms of the GTVH. As the incongruity can only playfully be resolved, Hempelmann and Samson (2007) argue that also the LM is pseudological.

An interesting interdisciplinary approach to analyze humorous stimuli was done by Hempelmann and Ruch (2005): They analyzed the stimuli of the 3 WD (Ruch, 1992) regarding criteria that were derived from the GTVH. The GTVH had to be adapted in several ways in order to be applicable for their study. The two most prominent expansions are a first attempt at introducing *degrees* of incongruity and resolution. Initially, degrees of incongruity were ascribed to the oppositeness in the set of *un/real* relations into which two scripts are presented in a joke (Raskin, 1985): *im/possible*, *ab/normal* (un/expected), or *non/actual*. The im-/possible SOp has a high incongruity, whereas ab-/normal SOp is said to have medium incongruity. The SOp of non-/actual has low incongruity. The degree of resolution (*RES deg*) factor, derived from the type of the LM, aims to capture the complexity of the false logic of the joke that connects the two scripts and thus creates the effort necessary for the resolution. The test question here was “How hard is it to comprehend the relation/overlap of the two scripts?”. The possible answers range, again, in four steps from very simple to very complex with two further intermediate values: They also rated the residual incongruity (*rINC*) of the joke that remains after its partial resolution through the LM. The test question “How much incongruity remains un(re)solved; how much new incongruity has the LM introduced; how puzzled are you still at the end of the joke?” (cf., Rothbart & Pien, 1977) could again be answered in one of four degrees, from lower to higher amount of rINC.

Hempelmann and Ruch (2005) demonstrated that the linguistic and the psychological approach fit together. They showed that incongruity-resolution and nonsense differ in the following way: The degree of initial as well as rINC increase with the loading on the nonsense factor. Prototypical nonsense jokes and cartoons less often have a SOp of the actual/non-actual type but more frequently one of the possible/impossible category. There was no correlation with the degree of resolution (Hempelmann & Ruch, 2005).

2.5 Implications from the GTVH for the present studies

Attardo et al. (2002) assumed earlier on that different LMs might have different demands on cognitive processes. Without taking into account the GTVH, Goel and Dolan (2001) showed that different neural activation patterns are involved during the processing of two groups of verbal humor, that differ in their LM: they presented verbal puns (LM: cratylism) and semantic humor (several LMs without the LM cratylism).

Three groups of LMs that are relevant to the present studies shall be described in more detail here: puns, semantic jokes and "obvious error" or Theory of Mind. As this thesis focuses on the processing of visual material, the three LM groups are described here particularly related to cartoons: visual puns (PUNs) are analogous to verbal or phonological puns, as defined by Hempelmann (2004). What these cartoons have in common is that one visual element activates two scripts that are incongruent to each other (Hempelmann & Samson, 2007). In the incongruity-resolution stage these two scripts have to be integrated, in terms of the GTVH (Attardo & Raskin, 1991), a script overlap has to be created. Semantic cartoons (SEMs) are cartoons that are based on pure semantic relationships in contrast to visual resemblance (as in PUNs). In SEMs, the incongruity lies in the opposition of two scripts based on pure semantic/content-related aspects. Here, several LMs are subsumed, such as exaggeration, juxtaposition or role exchange. In order to resolve the incongruity, the viewer has to recognize the LM that describes the relation of those scripts. The third group is of particular interest, because cognitive abilities have to be activated which are closely related to Theory of Mind capacities or mind-reading (Premack & Woodruff, 1978; see also chapter 4). These Theory of Mind (TOM) cartoons are based on the LM which was originally named as "obvious error" (Attardo et al., 2002; Paolillo, 1998): "A participant in the situation fails to recognize or acknowledge something exceedingly obvious or saliently presented" (Attardo et al., 2002, p. 6). TOM cartoons are a sub-group of SEM cartoons but in TOM cartoons false mental states have to be attributed which is necessary in order to understand the joke. These cartoons are similar to false-belief tasks (Wimmer & Perner, 1983) in the sense that the viewer has to attribute mental states to the portrayed characters: The viewer has to recognize that one character does not know what the other character thinks or intends to do.

Up to now, no empirical studies exist on different LMs and their effect on humor appreciation or even neural processes.

3 Interindividual differences in humor processing: Experience seeking

The question if individual differences have an influence on the appreciation of humorous stimuli has already been subject to discussion. Here, the question is whether personality characteristics do exist that influence humor processing dependent on structural differences of the humorous stimuli. The preference of one type of humor over the other (e.g., incongruity-resolution humor over nonsense humor) was shown in numerous articles to correlate with personality characteristics such as openness, conservativism, tolerance of ambiguity, but also sensation seeking (e.g., Ruch, 1988; Hehl & Ruch, 1985; Forabosco & Ruch, 1994; Ruch & Hehl, 2007). Sensation seeking is a trait defined by the seeking of varied, novel, complex, and intense sensations and experiences, and the willingness to take physical, social, legal and financial risks for the sake of such experience (see Zuckerman, 1994). Sensation seeking can be measured via self-report questionnaires, such as the Sensation Seeking Scale (Zuckerman, Eysenck, & Eysenck, 1978). One subscale is of particular interest in relation to humor: *Experience seeking,* which involves seeking of novel sensations and experiences through the mind and senses, as in arousing music, even psychedelic drugs, art, and travel, and through social nonconformity (e.g., artists, hippies, homosexuals, see Zuckerman, 1994). Experience seekers were shown to prefer nonsense humor over incongruity-resolution humor (e.g., Ruch, 1988; Forabosco & Ruch, 1994). Deckers and Ruch (1992) found experience seeking to be correlated with the Situational Humor Response Questionnaire (SHRQ, Martin & Lefcourt, 1984). Thus, individuals who smile and laugh in a wide variety of situations tend to seek thrills and adventure and avoid boredom in their lives. Furthermore, these results might suggest that high sensation (experience) seekers search for more situations that make them laugh and might even explore humorous stimuli more intensely. Also Lourey and McLachlan (2002) demonstrated that high sensation seekers reported perceiving a variety of situations as being funnier (measured with the SHRQ) and displaying a more overt expression to humor. They concluded that perceiving events as being funny offered the sensation seeker a novel source of stimulation and that displaying an overt expression (smiling, laughter) of humor offered sensation seekers another mode of experiencing intensive stimulation. In summary, experience seeking seems to relate to experiencing and appreciating humor, and nonsense humor is preferred over incongruity-resolution humor. As sensation seeking is currently explained with the use of a model influenced by genetic, biological and physiological factors (see for a review, Zuckerman, 2006), it is likely that people with varying degrees of experience seeking show differences in their neural response during humor processing.

Therefore the experience seeking subscale of the Sensation Seeking Scale (SSS-V, Zuckerman et al., 1978) is of particular interest in the fMRI study.

4 Empathy, Theory of Mind and Humor

4.1 Theoretical considerations about empathy, Theory of Mind and Humor

Another characteristic where individuals differ and which potentially might influence humor capacity might be empathy or Theory of Mind. Empathy is the capacity to recognize or understand another's state of mind or emotions, or in other words, the ability to “put oneself into another's shoes”. Various definitions of empathy exist, however, they agree mainly on three primary components: a) an affective response to another person, which often, but not always, entails sharing that person’s emotional state, b) a cognitive capacity to take the perspective of the other person, and c) emotion regulation (see Decety & Jackson, 2006). Whereas some researchers emphasize rather involuntary components of empathy, for instance, Hoffman (1981), who sees empathy as a largely involuntary vicarious response to affective cues from another person, others, such as Batson et al. (1997) emphasize people’s intentional role-taking ability, which is based on mainly cognitive processes. Depending on how empathy is triggered, bottom-up processing (e.g., the automatic tendency to mimic the expressions of others) or top down-processing (e.g., the capacity to put oneself in someone else’s position) are more relevant. Empathy has therefore more emotional (e.g., feeling with) and more cognitive (e.g., understanding other mental states or emotions of others) components.

The cognitive component of empathy is sometimes described as perspective taking, mentalizing or Theory of Mind (e.g., Premack & Woodruff, 1978; Baron-Cohen, 2006). Theory of Mind describes the ability to represent other people’s mental states, such as beliefs, desires, emotions and goals in order to predict their actions (Baron-Cohen et al. 1985; Premack & Woodruff, 1978). The highest form of Theory of Mind is to understand *false* mental states of others and Theory of Mind abilities are often investigated with so-called Theory of Mind tasks such as the Sally-Ann task which cannot be correctly solved before the age of four to five years in normally developed children (Wimmer & Perner, 1983). Understanding a character’s mental state is called a first-order belief, whereas understanding what one character believes about another character’s beliefs is a so-called second-order belief. Second-order beliefs, which are fundamental to deception and sarcasm, are more complex (e.g., Brownell & Stringfellow, 2000; Stone, Baron-Cohen & Knight, 1998). Some mental disorders were related to a lack of empathy and Theory of Mind, such as the Asperger Syndrome (see also chapter 5).

Several methods were developed in order to measure empathy or it's components. The Empathizing Quotient (EQ) developed by Baron-Cohen and Wheelwright (2004), shall be described here in more detail. According to Baron-Cohen and colleagues, empathizing is apart from systemizing one of two cognitive styles (e.g., 2003, 2004): Empathizing is defined as the drive to identify emotions and thoughts in others and to respond to these with an appropriate emotion. The EQ measures emotional (feeling an appropriate emotion triggered by another's emotion), cognitive (understanding and/or predicting feelings, thoughts, etc. of others, i.e., Theory of Mind) and a mixed component of empathy. The original version of the EQ consists of 40 items with additional 20 filler items. Short versions of the EQ were developed in English (Lawrence et al., 2004; Wakabayashi et al., 2006). Samson and Huber (2008) developed a short German version of the EQ which consists of 13 items.

Humor processing is influenced by the development of metalinguistic skills, such as verbal IQ and the integration of information across narratives (i.e., drawing inferences), as well as social competence (see Emerich, Creaghead, Grether, Murray & Crasha, 2003) and personality characteristics (e.g., Ruch, 1992; Ruch & Hehl, 2007). Humor processing might also be influenced by empathy or its more cognitive components, Theory of Mind or mentalizing. Several empirical studies addressed this question (see next chapter) and two recent humor models postulate that mind-reading is always part of humor processing (Howe, 2002; Jung, 2003). Howe (2002) stated that the essential element of humor is the observation and understanding of thought processes in the mind of the subject of a joke.

Where could empathy and Theory of Mind play a role in humor processing? In a social setting, in order to understand a joke, it is crucial that the listener realizes that a remark was meant to be funny. To realize that the intention is to produce humor (as well as sarcasm or irony), someone has to adopt (at least partially) the perspective of another person. But also to understand a joke itself, it is useful to understand the perspectives of portrayed characters in a joke; especially if the joke plays with false beliefs of others. Otherwise, it is also conceivable that the more emotional components of empathy might play a role in humor processing. Put-down or hostile humor might sometimes be disliked because someone feels sympathy with the targets of a joke. That is, they have an aversion to these jokes because they are too aggressive.

The next chapter summarizes the existing literature about the relationship between empathy, Theory of mind and humor.

4.2 Empirical studies on empathy, Theory of Mind and Humor

Some models of humor claim explicitly that Theory of Mind abilities are necessary to process humor (Howe, 2002; Jung, 2003). However, several studies investigating this question have come to mixed results. Some studies support the so-called mind-reading hypothesis by Howe (2002). For instance, Roberts and Johnson investigated already in 1957 the relation between humor and empathy. 12 cartoons were presented to 28 psychiatric patients. They showed that those who showed more empathy on several instruments appreciated the cartoons most. However, this study is methodically weak for several reasons. More recently, Uekermann et al. (2006) showed that in normal aging the decrease in the ability to comprehend humor is related to the decrease in the ability to answer mentalistic questions. In another study, Uekermann, Channon, Winkel, Schlehbusch and Daum (2007) showed that alcoholic patients have reduced humor processing skills and also show mentalizing deficits. Bartolo et al. (2006) compared funny to un-funny cartoons and found by using fMRI areas in the brain that are associated with mentalizing. They concluded that incongruity-resolution might occur through a process of intention attribution. Yip and Martin (2006) correlated several humor tests (i.e., Humor Styles Questionnaire, HSQ, Martin, Puhlik-Doris, Larsen, Grey & Weir, 2003; State-Trait-Cheerfulness-Inventory, STCI, Ruch, Köhler & van Thriel, 1996) with the Mayer-Salovey-Caruso Emotional Intelligence Test (MSCEIT, Mayer, Solovey & Caruso, 2002) and the Interpersonal Competence questionnaire (ICQ, Buhrmester, Fuhrmann, Wittenberg & Reis, 1988). Emotional perception (a subscale of the MSCEIT facets) correlated negatively with aggressive and self-defeating humor (HSQ), whereas another subscale, emotional management, correlated positively to self-enhancing humor (HSQ) and cheerfulness (STHI) and negatively to bad mood (STHI). All the ISQ scales correlated positively with cheerfulness and negatively with bad mood. Some of them were also positively correlated with more positive humor styles (affiliative and self-enhancing) and negatively to aggressive and self-defeating humor. It seems that humor is related in complex ways with social skills and emotional intelligence.

However, other studies showed a weaker or no relation between humor and Theory of Mind or empathy: Farrant et al. (2005) investigated patients with frontal lobe epilepsy and showed that humor appreciation can be impaired even if Theory of Mind abilities are preserved. Another study by Gessner and Kashdan (2006) demonstrated that empathy (measured by the means of the Interpersonal-Reactivity-Index [IRI], Davis 1983) had no influence on humor processing: neither on friendly humor (wit), nor on hostile humor (witticism) (measured with the WOW humor scale, Gessner & Kashdan, 2006). However, perspective taking (the more cognitive subscale of the IRI) was positively correlated to wit and negatively related to witticism (Gessner & Kashdan, 2006). Forsyth, Altermatt and Forsyth (1997) claim that it is important to include cognitive-information processing abilities in studies of humor as they show that verbal creativity, figural creativity and *emotional empathy* correlated with some of the 5 humor types they were investigating: verbal creativity correlated with play-on-words jokes, figural creativity correlated with academic/social issues cartoons and emotional empathy (measured with the emotional empathy scale, Mehrabian & Epstein, 1972) correlated negatively with negative ethnic stereotype jokes. Added laughter amplified this negative correlation. Though, as they found no correlation with emotional empathy scores and negative stereotyping based on gender or on professional background (e.g. policeman, lawyer or student of politics), they could only partially support the mind-reading hypothesis.

As some studies showed that different humorous stimuli correlate to a different degree with mentalizing abilities, the assumption is raised that the stimulus characteristics substantially influence the outcome of a study investigating the relation between humor and Theory of Mind and empathy. Gallagher et al. (2000) investigated by using fMRI brain activation evoked through different cartoon conditions. In one condition, it was necessary to ascribe mental states to the persons depicted in the cartoons. The understanding of the humor in these jokes required the attribution of ignorance, false belief or deception to one of its characters and therefore, an analysis of their mental state. In the other condition—called physical cartoons—it was not necessary to attribute mental states in order to get the joke; these jokes were physical (“slapstick”) or behavioral in nature and subsequently did not require Theory of Mind capabilities for their correct interpretation.

Corcoran, Cahill and Frith (1997) found only Theory of Mind cartoons associated with so-called mentalizing areas in the brain. In another study, cartoons with and without Theory of Mind were presented to patients with schizophrenia. Schizophrenic patients found the mental state jokes significantly more difficult to understand, whereas for control subjects there was no difference between the two conditions. Marjoram et al. (2006) showed individuals with schizophrenia perform significantly worse than control subjects in Theory of Mind and non-Theory of Mind cartoon conditions, this difference being most marked in the Theory of Mind condition.

Sarfati, Hardy-Bayle and Widlocher (1997) also showed individuals with schizophrenia to be worse in Theory of Mind tasks than healthy subjects. They used a strictly pictorial task of 3 panel cartoon sequences depicting a character producing an action and the participants had to choose the fourth and final picture from a choice of three images. Successful image choice depended on the understanding of the character's intent behind the action. Individuals with schizophrenia (especially with thought and speech disorganisation) made more failures than healthy control subjects.

From this literary overview it cannot be concluded as how to Theory of Mind, Empathy and humor depend on each other. Some studies lead to the assumption that mentalizing abilities are not necessary for all jokes or cartoons (e.g., Gallagher et al., 2000; Marjoram et al., 2005) whereas other studies postulate that Theory of mind (intention attribution, mentalizing) is necessary to process humor (e.g., Uekermann et al., 2006, 2007). For example, Bartolo et al. (2006) compared funny and un-funny cartoons, found areas in the brain that are associated with mentalizing and concluded that incongruity-resolution might occur through a process of intention attribution without including a humorous control condition that does not require mentalizing.

As Theory of Mind is a critical variable in the present thesis, a mental disorder shall be presented here that is known to be associated with limited mind-reading skills: individuals with Asperger Syndrome. Although the present thesis does not investigate individuals with Asperger Syndrome, the complex topic of humor processing in relation to Theory of Mind requires a quick glance on humor processing in individuals with Asperger Syndrome—see next chapter.

5 Asperger Syndrome and Humor

Individuals with Asperger Syndrome (AS) are described to have limited Theory of Mind abilities. As the Theory of Mind is of particular interest for the present thesis, this mental disorder and the existing studies on AS in relation to humor shall be presented here.

5.1 Autism and Asperger Syndrome

Autism is a severe brain development disorder which goes along with impairment in social interaction and communication and causes restricted and repetitive behavior. The AS is one of the milder forms of autism that belong to the autism spectrum disorders (ASD). Autism and AS are both recognized neuro-developmental disorders that are defined primarily in behavioral terms. Both are distinct categories within Pervasive Developmental Disorders as defined by the DSM-IV criteria (APA, 1994). According to this current conceptualization AS differs from autism in terms of language and cognitive functioning, which are not associated with early delay, whereas, like in autism, a severe impairment in social functioning and range of interests remains. AS and also high functioning autism (HFA) belong to the autism spectrum disorders characterized by difficulties in social interaction and by restricted, stereotyped interests and activities.

Three main competing psychological theories to explain deficits in individuals with AS exist which might be relevant for humor processing: first, a *lack of Theory of Mind* has been suggested by many researchers to be the core deficit in autism (Baron-Cohen, Leslie & Frith, 1985; Baron-Cohen, 1988; Happé, 1993; Tager-Flusberg, 1993), focusing on social and communicative deficits. Happé (1993, 1994) reported a strong correlation between the ability to explain non-literal messages (e.g., lies, jokes, pretence, irony and sarcasm) and Theory of Mind abilities. Understanding the intention of others to joke but also to understand false mental states as a potential source of humor might be two examples of where mentalizing is relevant in order to “get the joke”. Theory of Mind can be seen as the cognitive component of empathy (see chapter 4). Recent findings showed while individuals with AS are impaired in cognitive empathy, they do not differ from control subjects in emotional empathy (Dziobek et al., 2008). Baron-Cohen and colleagues (Baron-Cohen, Richler, Bisarya, Gurunathan & Wheelwright, 2003) showed that individuals with AS have significantly lower empathizing skills than healthy controls. Empathizing was measured with the Empathizing Quotient (EQ) by Baron-Cohen and Wheelwright (2004). The EQ measures emotional as well as cognitive components of empathy (see chapter 4).

Second, the *Executive Function hypothesis* (Pennington & Ozonoff, 1996; Hughes, Russell & Robbins, 1994) with its emphasis on a primary cognitive impairment in a variety of mental processes was linked to deficits in Autism and AS. Executive function is an umbrella term for mental operations which enable an individual to disengage from the immediate context in order to guide behavior by reference to mental models of future goals (Hughes et al., 1994). For example, the ability to hold information in mind (working memory) might be crucial for humor comprehension.

Third, the *weak central coherence model of autism* (Frith, 1989; Frith & Happé, 1994; Happé, 1999) which also addresses cognitive abnormalities in information processing and—apart from providing behavioral explanations—also accounts for the unusual patterns of cognitive strengths found in autism. Individuals with autism and AS also have specific difficulties with the integration of diverse information at different levels which impairs their ability to construct higher-level meaning in context, i.e., 'central coherence' (e.g., Frith, 1989). Weak central coherence might explain the reduced ability of individuals with AS to understand the global meaning of a joke. Weak central coherence refers to a bias attending to parts rather than wholes, reflected in piecemeal processing that is relatively context-independent. Individuals with HFA and AS are said to sometimes have specific strengths in more detail and local oriented processing skills (see, for example, Bölte, Holtmann, Poustka, Scheurich & Schmidt, 2007; Bölte, Hubl, Dierks, Holtmann & Poustka, 2008; Müller & Nussbeck, 2008).

5.2 Autism, Asperger Syndrome and Humor

It has been generally accepted that individuals with autism and AS do not understand humor (Asperger, 1944; Wing, 1996). They are not able to laugh at themselves, they are "…rarely relaxed and carefree and never achieve that particular wisdom and deep intuitive human understanding that underlie genuine humor" (Asperger, 1944; Frith 1991, p. 82). In contrast, some anecdotal and parental reports of humor appreciation in individuals with HFA/AS were documented that show that slapstick comedy and simple jokes can be enjoyed by autistic people (Ricks & Wing, 1975) and that mildly autistic adults have a good but not very subtle sense of humor (Everard, 1976). Werth, Perkins and Boucher (2001) described—in contrast—a female with HFA who produces puns, jokes, neologisms and word plays to an unusual amount (which is not typical for autism). The predominant forms of humor were in this case word play and neologisms, less typical forms of humor based on switching rapidly from meaning to meaning were used as well; least successful the female with HFA was in riddles, teasing, sarcasm and irony but did produce them conspicuously often.

There are only a few existing empirical investigations (e.g., Baron-Cohen, 1997; Emerich et al., 2003; Reddy, Williams & Vaughan, 2002; St. James & Tager-Flusberg, 1994; Van Bourgondien & Mesibov, 1987) which vary greatly in their methods and number of subjects. Van Bourgondien and Mesibov (1987) analyzed jokes told during social-skill meetings (the participants were told to tell as many jokes as they liked) of 9 high-level autistic adults. The jokes were categorized according to humor stages: 1) incongruous actions towards objects, 2) incongruous labelling of objects or events, 3) conceptual incongruity, word play, nonsense words, 4) riddles based on lexical ambiguities, phonological ambiguities, surface structure or deep structure. 40% were pre-riddles or examples of stage 3 humor. 35% were stage 4 riddles, but only based on lexical and phonological incongruities. No riddles depicting surfaces-structure or deep-structure ambiguity were observed. The fact that the majority of riddles were similar to those told by 4- to 9-year-olds is consistent with the social skills of the participants. Here, it has to be annotated that the participants were trained over a long period of time to tell jokes which might limit their generalization on other adults with AS. Furthermore, there wasn't any control group (e.g., individuals with AS without training) available.

Baron-Cohen (1997) investigated 15 school age pupils with autism in comparison to 15 young normally developed children and 15 school age pupils with learning disorder which had to answer questions after false naming tasks. 13 of the normal group and 12 of the subjects in the learning disabled group but only 3 of the subjects with autism gave mental state explanations for the false naming trials. It was concluded that individuals with autism have a persistent failure to "get the joke". In addition, they do not refer to the speaker's intention to joke.

Two studies investigated humor and laughter events in more naturalistic settings: St. James and Tager-Flusberg (1994) found in 6 young children with autism significantly less humor episodes in comparison to 6 children with Down's syndrome. No differences were found in earlier forms of humor (e.g., humor based on tickling, routine song or rhyme, slapstick, funny sounds) but in nonverbal incongruity and riddles (children with autism produced no riddles at all). They interpreted their results in line with deficits related to their social-cognitive deficits in understanding mental states (e.g., Baron-Cohen et al., 1993). Reddy et al. (2002) showed no differences in the frequency of laughter and as a result of tactile, auditory and visual events in 19 pre-school children with autism in comparison to 16 pre-school children with Down's syndrome. Autistic children hat difficulties in humor based on socially inappropriate acts. Furthermore, children with autism laughed more about strange or odd things or inappropriate stimuli, however, they share laughter with others and engage in clowning or teasing less often. The authors interpreted the lack of response to laughter as a result of difficulties in mutual attention and mutual emotional sharing – the underlying deficit is a problem with sharing emotions. The problems involve simple interpersonal and affective aspects of humor rather than only cognitively complex aspects, suggesting support for affective-relatedness theories of autism (Hobson, 1989).

In a more experimental setting, Emerich et al. (2003), similar to Ozonoff and Miller (1996) investigated eight adolescents with AS or HFA and eight normally developed adolescents: they had to choose funny endings for cartoons and jokes out of 5 possible endings: funny correct, straightforward ending, humorous non sequitur ending, associative non sequitur ending and neutral non sequitur ending. Individuals with AS have poorer comprehension of cartoons and jokes: Instead of choosing the correct funny ending, they choose most frequently the humorous non sequitur endings which might be leaded back to a difficulty handling surprise and coherence within humorous narratives. Since they were impaired in coherence building, re-evaluation of the beginning of the joke and in shifting to new interpretations the underlying deficits in relation to humor were interpreted on the basis of impairments in cognitive flexibility.

The general conclusion drawn from these studies is that simple forms of humor in very young children (e.g., tickling, funny sounds, teasing etc.) may be preserved and that some individuals with autism/AS also possess the ability to understand some basic forms of humor, both verbal and non-verbal, i.e., slapstick humor, simple jokes and puns, which, however, is not in accordance with their overall developmental level. However, the existing studies do not come to a clear picture of humor processing skills in individuals with AS, maybe due to the differences in stimulus characteristics—for example, they did not control their stimuli for their LM which might influence.

6 Brain imaging studies on humor processing

Since the present thesis investigates neural correlates of humor processing in dependence on structural properties of humorous stimuli, the actual state of research on brain imaging studies in relation to humor processing is presented here. Most of the studies did not focus on neural activation patterns in relation to stimulus properties. Most often, funny material was contrasted to an unfunny control condition. In general, those fMRI studies showed the following network of neural structures involved in humor processing: areas in the temporal lobe (e.g., temporal pole, anterior superior temporal sulcus, aSTS, e.g., Mobbs et al., 2003, 2005; Moran et al., 2004; Wild et al., 2006) were often associated with the set-up of the joke as bringing stored expectations online. The inferior frontal gyrus (IFG, e.g., Goel & Dolan, 2001; Mobbs et al., 2003; Wild et al., 2006; Bartolo et al., 2006, Watson, Matthews & Allman, 2006,) and regions around the temporal parietal junction (TPJ, Wild et al., 2006) are substantially involved in the humor comprehension process. The IFG is known to be involved in semantic processing and is therefore important for the resolution of incongruity. However, in earlier studies the TPJ was claimed to be involved in the *detection of incongruity* (Mobbs et al., 2003). Wild et al. (2006) was the first who *assumed* that the TPJ might be involved in the incongruity-resolution process. However, there hasn't been a study attempting to verify with an adequate experimental design in which processes the TPJ might be involved during humor processing.

Activations in the anterior medial prefrontal cortex (amPFC) seem to react on the attribution of mental states to the characters of the joke, if this is necessary in order to get the joke (Gallagher et al., 2000; Marjoram et al., 2006). Associated rather with the affective experience components of humor processing are the medial ventral prefrontal cortex (mvPFC), subcortical nuclei (nucleus accumbens) and limbic structures, particularly the nucleus accumbens (Goel & Dolan, 2001; Mobbs et al., 2003; Moran et al., 2004; Sieboerger, Ferstl, Volkmann & von Cramon, 2004).

Some studies differentiated between stimuli that differ regarding structural elements: Goel and Dolan (2001) circumscribed specific areas for different types of verbal jokes. Phonological puns activated areas that help to process sounds, i.e., the left inferior precentral gyrus and insula, whereas semantic jokes activated regions that process word meaning, i.e., the right posterior middle temporal gyrus (pMTG) and left posterior inferior temporal gyrus (pITG). Watson et al. (2006), using captioned cartoons, compared "sight gags", i.e., cartoons, in which the joke is based on elements in the picture (the cartoons remain funny, even if the caption is removed), to language-based humor (the cartoons are only funny when the caption is available). Visual-based humor activates, among others, bilaterally higher order visual cortex, TPJ, middle frontal gyrus (MFG) and precuneus. Language-based humor activates specifically the MTG, IFG and ITG.

Only a few brain imaging studies investigated personality differences in humor processing (Mobbs et al., 2005; Rapp et al., 2008). Mobbs and colleagues (2005) found the right orbital frontal cortex (OFC), the ventrolateral PFC and bilateral temporal cortices to correlate with extroversion, whereas introversion correlated with several regions, particularly with the amygdala. Emotional stability (i.e., the inverse of neuroticism) correlated with increased activation in the mesocortical–mesolimbic reward circuitry, whereas scores on a humor questionnaire (Revised Sense of Humor questionnaire, SHQr, Svebak, 1974) didn't evoke any increased activation. Rapp et al. (2008) found the right inferior parietal lobule (IPL) to be associated with higher cheerfulness scores. This was interpreted as a readiness or tendency to be amused. No area that was found to be related to the understanding of humorous material and the following emotional reaction was activated in relation to the cheerfulness score. Since the IPL belongs to the semantic association areas and individual "sense of humor" relates to the tolerance towards ambiguous stimuli, the authors assume that the IPL reflects the individuals' tendency to deal with ambiguous stimuli.

Individual differences were also investigated by Azim et al. (2005): They analyzed whether males and females process humor differently and found more prefrontal activation and areas associated with reward processing in females. They interpreted their results that females have probably less reward expectations.

All the fMRI studies presented here can be summarized to have found a more left-sided network to be involved in humor processing. The only study that found activation in the right side is Wild et al. (2006): They interpreted the right orbito-frontal cortex (OFC) to be involved in disinhibition of laughter and smiling. This stands in sharp contrast to previous studies that considered the *right hemisphere* to be more involved in humor processing, such as the study by, for example, Johnson (1990), or some lesion studies (e.g., Shammi & Stuss, 1991). Bihrle et al. (1986) demonstrated right hemisphere damaged (RHD) patients to be sensitive to surprising elements of humor but to show reduced ability to establish coherence. Brownell et al. (1983) showed that RHD patients choose surprising endings of possible punch lines as well as more non sequitur endings but not the accurate punch lines. RHD patients have the further impaired ability to distinguish between neutral and humorous cartoons which appeared to be related to difficulties with visual-spatial skills (Dagge & Hartje, 1985). RHD patients focus on irrelevant detail, portray tangential thinking and lack of integration of details in the cartoons. This might come from the difficulty to discriminate funny from unfunny visual stimuli related to poor task integration and concept formation (Gillikin & Derks, 1991). However, two aspects might limit the generalization of the results by the lesion studies: First, most of the studies investigating RHD patients used joke-stem completion tasks: the patients had to choose the correct funny ending out of two or four possible endings. Perhaps, this requires other cognitive skills as well that are impaired and non-specific for humor processing. A further problem is that the stimulus material was not controlled carefully as to whether Theory of Mind abilities were required in order to get the joke. Already Brownell and Stringfellow (2000) assumed that part of the difficulty of RHD patients in comprehending humor may have to do with deficits in Theory of Mind, which is the ability to attribute beliefs and intentions to other people in order to explain or predict their behavior (see also chapter 4).

Before presenting research questions of the present thesis, the method of fMRI shall be described in the next chapter.

7 Introduction into the method of functional Magnetic Resonance Imaging

In order to investigate the relation between cognitive or affective processes and the underlying brain areas, dedicated methods have been developed during the last decades (Raichle, 1994). For example, functional neuroimaging methods like the Positron emission tomography (PET) and functional magnetic resonance imaging (fMRI) made it possible to identify changes in neural activity with regard to specific aspects of, e.g., cognitive processing in particular within parts of the human brain under the assumption that glia cells and neurons conduct an organized sequence of action potentials during information transfer as response to sensoric, motoric, emotional or cognitive processes (Menon & Kim, 1999). Since the seventies PET and since 1992 fMRI are applied. These methods measure local, neuronal caused changes in metabolic activity, and are therefore called metabolic methods (Weiller & Elbert, 1997).

These different methods differ basically concerning their invasivity, whether repetitive measurements are possible, their costs and temporal and spatial resolution. These methods are briefly outlined; others like Natrium-Infrarotspektographie (NIRS) or Optical Imaging and Single Photon Emission Computer Tomography (SPECT) are mentioned here only for the sake of completeness. Simultaneous discharge of neuron groups leads to electric and magnetic fields, which are directly acquired with Electroencephalography (EEG) or Magnetencephalography (MEG). The temporal resolution is very high, but the functional mapping to anatomic structures is sluggish. Both methods are non-invasive. In EEG the overlap of single neural activities can lead to misinterpretation. Whereas in EEG action potentials are measured, MEG measures synaptic activity, which is closer to the actual source. The sources are also more exactly localizable. This instrument is quite expensive and susceptible, reacting on sources of inference such as cable cars. So the sustainability of this instrument implicates some difficulties. In PET, the system detects pairs of gamma-rays emitted indirectly by a positron-emitting radioisotope, which is introduced into the body on a metabolically active molecule. In PET the exposure to radiation limits the repeatability of the measurements. However, an advantage is that dependent on the Tracer it is possible to visualize single receptor systems (Weiller & Elbert, 1997). Figure 2 shows the temporal and spatial resolution of brain mapping techniques related to the size scale of neural features and to the "invasiveness" of the method.

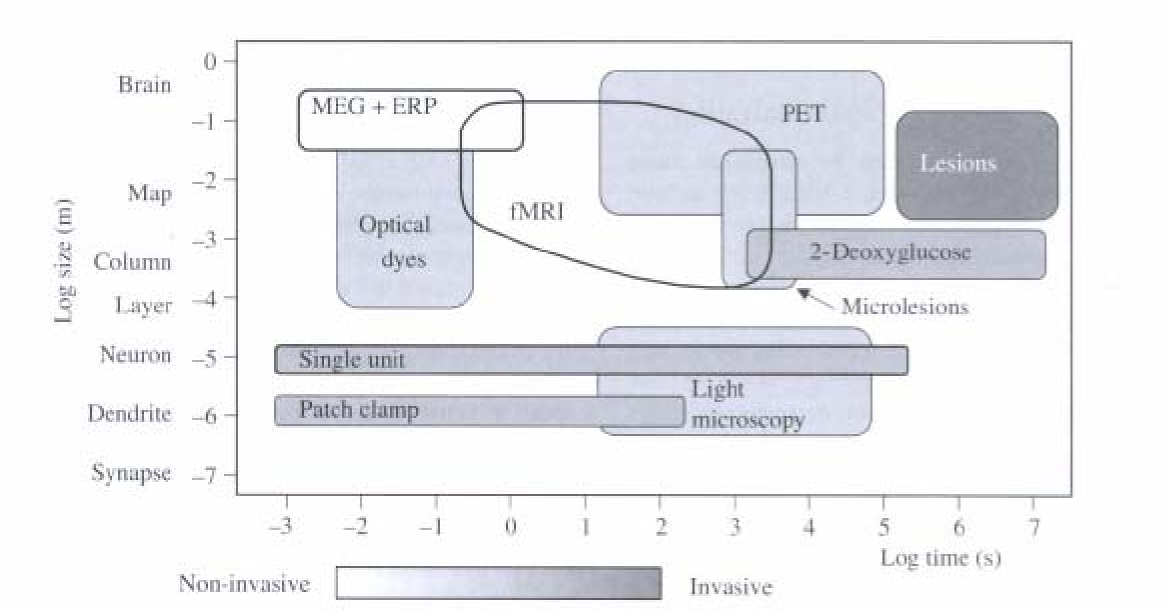

Figure 2: Temporal and spatial resolution of brain mapping techniques related to the size scale of neural features and to the "invasiveness" of the method (adapted from Churchland & Seynovski, 1988, p. 242).

Each method has its advantages and disadvantages. In fMRI, participants are brought into a very high magnetic field usually 1.5 or 3 Tesla (the strength of a magnetic field is measured in Tesla (T) or Gauss (G; 1 T = 10000 G; the strength of the earth magnetic field accounts for 0.3-0.7 G). Because of the strength of the magnetic field, the tomograph is not accessible with magnetic materials, that are pace makers or other metalloid objects inside the bodies of subjects (Weiller & Elbert, 1997). Additional disadvantages are the restricted liberty of movement (the diameter of the scanner accounts only for approx. 70 cm), the great noise exposure (around 120dB without ear protection), the costs and that the temporal resolution is lower than in EEG and MEG (Raichle, 1994). The present experiment was carried out on a 3T scanner (Siemens TRIO, Erlangen, Germany).

Functional MRI is a metabolic method, which measures brain activity indirectly via localizing alterations in blood flow. Interpreting these signals to make deductions about the nervous system requires some understanding of the signaling mechanisms (Logothetis & Wandell, 2004).

7.1 Physical basics of fMRI

In general, magnetic resonance measures how radio frequency electromagnetic waves act upon dipoles in a magnetic field. Magnetic resonance signals arise mainly from the hydrogen nuclei in water (Logothetis & Wandell, 2004). Functional MRI is a non-invasive method and is based on the fact that protons of the water molecules possess a spin, i.e., a rotation around their axis. Protons are electric loaden particles and the rotation causes an electrical circular flow which produces a magnetic dipole moment. A constant magnetic field B_0 of a MRI scanner directs all proton spins in one direction (parallel or antiparallel to the main field; normally the electric charges cancel each other). The net magnetization (sum of the magnetic dipole moments) increases with the strength of the external constant magnetic field (field strength range from1.5 to 8 T) and is directed towards B_0 witch is called the longitudinal direction. If the magnetization is not balanced in direction of B_0, the orthogonal (transversal) component of the magnetization is precessing in the transversal plane to B_0. The frequency of the processing magnetization, the so-called Larmorfrequency, given by $\boldsymbol{\omega_0} = \boldsymbol{y}\ \boldsymbol{B_0}$ x $\boldsymbol{y}$, is the gyromagnetic ratio of the protons, which depends on different materials and describes the coupling of the spin and the magnetic dipole moment. Generally, the precession frequency increases with the strength of the external magnetic field.

In order to receive measurable signals from proton spins, transversal magnetization has to be produced, because if the magnetization is balanced in direction of B_0, no signal is measurable. This is done by exposing the brain to a brief radio-frequency (RF) pulse. The RF impulses must have the same frequency ω as the precessing magnetization so that the protons can receive part of the RF energy. This phenomenon is called resonance. In summary, the RF impulse results in a decline of the longitudinal magnetization and in a generation of the transversal magnetization. The RF excites nuclei away from their resting state into a higher energy state. The signal decays freely after excitation. This is described as the free induction decay (FID), which is determined by the relaxation parameters of T1, T2 and T2* which will be explained subsequently in more detail. Two exponential processes with time constants (T1 and T2) describe the relaxation back to the low-energy state. The T1 constant measures the relaxation of the transverse magnetization towards the direction of the B_0 magnetic field (longitudinal re-growth). As this process is induced by the interaction of the magnetization with the surrounding lattice, it is called the spin-lattice relaxation. The progression of the longitudinal relaxation is slow so that the parameter T1 is usually used for anatomical measurements. The transverse relaxation of the magnetization is described by the parameters

T2 and T2*. The time constant of the exponential signal decay of the transversal relaxation is called T2. The T2 constant measures the transverse relaxation of the dipole in the x-y plane that is perpendicular to the B_0 field. The T2 process describes the coherence loss of the spins due to spin-spin relaxation. In physiological tissue the transverse relaxation is more rapid because of local field inhomogeneities. If they are present, then the decay constant is called T2*. It covers the effect of magnetic field inhomogeneities which are caused by physiological parameters like the blood oxygenation. The latter effect is essential for fMRI (Schild, 1990). The size of these inhomogeneities depends upon the physiological state and in particular the composition of the local blood supply. This physiological state depends, in turn on the neural activity. For this reason, measurement of the T2* parameter is an indirect measurement of neural activity (Logothetis & Wandell, 2004). Dependent on the oxygen concentration in the blood, see also section 7.4, a different signal emerges. It is important to note that desoxyhemoglobin is paramagnetic (i.e., it possesses magnetic properties) as compared to oxyhemoglobin. The latter does not differ in magnetic susceptibility from other tissue or water, thus, resulting in a homogeneous local magnetic field. Accordingly, oxyhemoglobin accounts for the longevity of the signal. In contrast, the presence of paramagnetic desoxyhemoglobin results in an increase of local inhomogeneity which in turn makes the nuclei to precess at slightly different frequencies. Hence, the higher the level of desoxyhemoglobin the faster the signal decays. By changing the oxygenation state of the blood, changes in MRI image contrasts can be obtained. The blood oxygen level dependent changes in the MRI signal are detected via the internal contrast agent deoxyhemoglobin. This method is termed BOLD (blood oxygen level dependent) contrast, see chapter 7.4.

7.2 Gradient-Echo

Several possibilities for the puls sequences to register signals exist. In the present experiment a gradient echo sequence was used (as default setting). Each method has it's advantages and disadvantages. In spin-echo EPI, the functional contrast is lower, but there are no signal losses by dephasing through the slice and therefore signal voids will be eliminated. An advantage is also the superior intrinsic spatial resolution. On the other side, gradient echo EPI has the clear advantage of higher functional contrast, but suffers from susceptibility artefacts (Norris, Zysset, Mildner & Wiggins, 2002).

7.3 The BOLD-phenomenon

In PET as well as in fMRI one is confronted with the circumstance that the measurement is not directly, but indirectly over the blood flow or the state of the blood. To interpret the obtained data correctly, one should know the basics of what is measured. Therefore, an overview over the biological and physiological basis of the fMRI-signal is given here. Also the factors of the temporal and spatial resolution, regional and intersubjective differences will be addressed (Menon & Kim, 1999). As well as PET, fMRI does not directly measure neuronal activity or the fast increase of metabolic activity, but the increase of the regional cerebral blood flow as a response to an increased metabolism (Miezin, Maccotta, Ollinger, Pertersen & Buckner, 2000).

Increase in cerebral blood flow (CBF) is known to accompany neural activation because energy in form of additional oxygen is needed by populations of active neurons. Interestingly, the increase in cerebral blood flow overcompensates for the decrease in oxygen (more as the required oxygen consumption) delivering an oversupply of oxygenated blood (Logothetis & Wandell, 2004, see Figure 3). The main part of the oxygen in the blood is bound to hemoglobin—four oxygen molecules are bound to one hemoglobin molecule. If one oxygen molecule is released, the blood gets deoxygenated and therefore paramagnetic. Dependent on the oxygen concentration the hemoglobin is called oxyhemoblobin (HbO_2) or desoxyhemoglobin (Hb). If in an area of neuronal activity more oxygen is available than needed an oversupply of O_2 occurs. As a result, the concentration of oxygenated blood increases and the concentration of deoxygenated blood decreases (Menon & Kim, 1999).

Local changes of the magnet field homogeneity through deoxygenated hemoglobin lead to a decrease of the fMRI-signal. During neuronal activity the oversupply of oxygenated blood leads to an increase of the signal, because the quantity of the protons is augmented (Menon & Kim, 1999).

The reason for the mismatch between supply and consumption of blood is unclear (see below). In fact, the glucose supply does appear to match the consumption. As a paradoxical result, the oxygen concentration is increased in activated regions compared to regions that are not activated. Already over 100 years ago, it was observed that the venous blood in an activated region turns redder. In 1990 Ogawa found that an oxygen molecule of the hemoglobin is released and that the blood becomes therefore paramagnetic. He discovered the BOLD-effect by examining rats. Two years later, the first investigation with fMRI on a human being was published (Menon & Kim, 1999).

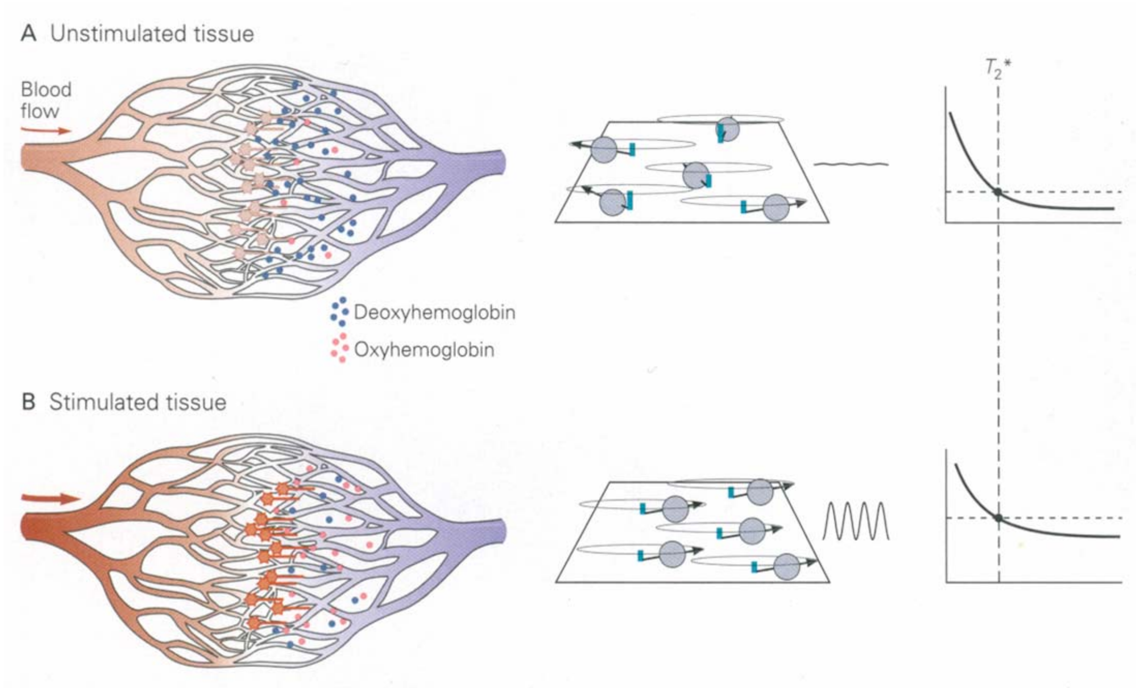

Figure 3: A shows the ratio of oxygenated and deoxygenated blood in unstimulated tissue and the correspondent T2 signal. B shows the increase and oversupply of oxygenated blood after neural activity and its correspondent T2* signal (reprinted from Kandel, Schwartz & Jessel, 2000).*

Through the increased energy demand of the nerve cells due to regeneration of the membrane potentials and for the synthesis of the neurotransmitter, the metabolism increases (Kastrup, Krüger, Glover, Neumann-Haefelin & Moseley, 1999). A consequence of the increased metabolism is the increase of the local cerebral blood flow (rCBF), because more glucose and oxygen is required. If neurons are active, they require more oxygen and glucose for metabolism, the capillary blood vessels enlarge and a change in the regional cerebral blood volume (rCBV) occurs. Subsequently, more oxygen gets into this region (Miezin et al., 2000). Therefore blood flow, blood volume and the oxygenation of the blood change in relation to the neuronal activity—this is the neurovascular or hemodynamic-neuronal coupling.

The coupling mechanism between neuronal activity and the hemodynamic response is not well known yet. It is possible that the increase in blood flow is required for the transport of the transmitters to the synapse, for the removal of the transmitters of the synaptic cleft or for recycling and repacking (Menon & Kim, 1999). In 1985 Raichle and Fox claimed that neural activity does not require more oxygen. They claimed that the required energy is supplied through anaerobic glycolysis (i.e., the transformation of glucose to lactate), for which no oxygen is needed. Although today it is known that active neurons require indeed more oxygen, the debate has not yet come to an end (Barinaga, 1997). Logothetis and Wandell (2004) address some of the possibilities for the oversupply of O_2. One possibility is that the vasculature delivers a fixed ratio of oxygen and glucose that is appropriate for an aerobic process. If both aerobic and anaerobic processes demand glucose, than the result would be an oxygen surplus (Magistretti & Pellerin, 1999). According to that hypothesis, the intensity of BOLD depends on the relative proportion of local aerobic and anaerobic glucose metabolism. As a second possibility oxygen extraction matches the metabolic needs and the excessive oxygen present in the blood supply is due to an inefficient delivery process. Specifically, it has been proposed that this oversupply compensates for the inefficient, passive oxygen diffusion that occurs at high flow rates (Hyder, Shulman & Rothman, 1998). In this hypothesis, oxygen supply is tightly coupled to neural activity, and the anaerobic processes in the astrocytes represent only a negligible amount of energy that is supplied by existing reserves (Mintun et al., 2001). There are some contradictory observations, however, so that the interpretation of these circulatory and metabolic changes remains uncertain. It might be interesting to mention that the BOLD response primarily reflects the input and local processing of neuronal information rather than the output signals, which are transmitted to other regions of the brain by the principal neurons. The long-range projectors' signals from these principal neurons are the measurements that are mainly accessible in single-cell recordings in behavioral animal studies (Logothetis & Wandell, 2004).

7.3.1 Spatial resolution

The spatial resolution of the fMRI-Signal does not only depend on the blood volume, blood flow and oxygen consumption ($CMRO_2$), but also on the blood vessel geometry (Menon & Kim, 1999). Oxygenated blood enters the brain through arteries which end in small capillaries. In the net of capillaries the blood delivers oxygen and enters in small venoles (only of the size of some micrometers) and draining veins (superficial and deep veins). The net of capillaries in the grey matter is very dense, in white matter more wide-meshed. In fMRI the activity in the grey matter is mainly measured (Menon & Kim, 1999).

Functional MRI can be used also to register quite a lot of cerebrovascular information and has therefore in the neuropsychological domain a diagnostical character (blood flow, blood volume and blood oxygenation can be investigated, Weiller & Elbert, 1997).

The blood vessel geometry has an influence on the spatial resolution. It is dependent of the size of the vessels and of the capillary net to the draining veins. Particularly the latter can have a distance of several centimetres to the original activity and therefore, can cause artefacts (Menon & Kim, 1999). Disbrow, Slutsky, Roberts and Krubitzer (2000) investigated the correspondence of fMRI data to cortical maps as results of electrophysiological conductions in dependence on tactile stimulation on hand and face in maccace monkeys. Their regions of interest were somatosensoric areas, as the primary somatosensoric region, 3a, 1 and 2 in the anterior parietal cortex. If the center of activity (fMRI) coincides with the electrophysiological map, then there is correspondence in 55% of the cases. However, there are also displacements up to one centimeter. The correspondence is even worse in anterior-posterior than medial-lateral and superior-inferior regions of in the somatosensoric cortex. The fields of the fMRI data are also more enlarged. These differences can be interpreted as results of the different vessel geometry (particularly venoles and veins). One should consider that the authors used only a Tomograph with a magnetic field strength of 1.5 T. However, higher magnetic fields improve signal-to-noise ratios, which potentially allow for higher resolution BOLD images, since the contributions from the smaller cortical vessels can be enhanced. These are closer to the sites of neuronal activity than the draining veins, which can be centimeters away from the site of activation (Disbrow et al., 2000). In gereral, it is assumed that the increased microvascular sensitivity available with the higher field scanners will be necessary to map at the columnar level (Menon & Kim, 1999).

The spatial resolution also depends on the number of slices, which can be measured within a certain time frame. The resulting voxels have a volume of 3x3x3 millimeters (by a magnetic field strength of 3T). Dependent on the magnetic field strength it is possible to obtain a resolution of 0.5 to 1.5 millimeters (Menon & Kim, 1999).

7.3.2 Temporal course and resolution

The neuronal processes are faster than the blood flow. The cerebral hemodynamic response is indirect and sluggish. Changes in blood flow and volume are accompanied by a small delay. The BOLD signal change in V1, for example, begins with a delay of one to two seconds (Time to onset) and reaches the maximal signal strength after 13 seconds (Time to peak). 5-10 seconds after stimulation, the signal is again 10% over the initial value. Sometimes, a post-stimulus undershoot can also be observed, therefore, the signal decreases under the initial value. In a shorter stimulation the Time to peak takes place in average after 4 to 6 seconds (see, for an example, Figure 4). These delays are again dependent on the blood vessel geometry, which differs regionally (Menon & Kim, 1999). The temporal resolution is also limited through physiological factors. More recent methods get a temporal resolution up to 50 milliseconds (ms). Because of the slow and sluggish hemodynamic response it is difficult to show interactions of single neuron groups. With special techniques an ordinary fMRI scanner (1.5–3 T) gets a temporal resolution of 300 ms (Menon & Kim, 1999).

The duration and sluggishness of the hemodynamic response sets a limit to how fast a stimulus can be repeated. However, again, some statistical methods are available to separate overlapping signals from each other (Menon & Kim, 1999).

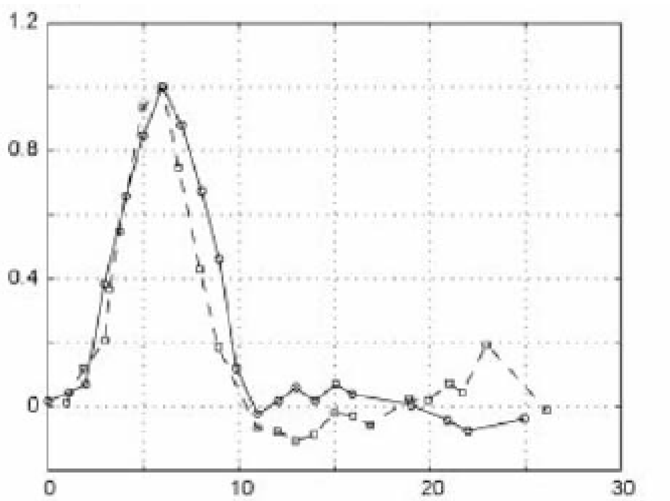

Figure 4: BOLD response from an experiment in motor cortex (open circles) and visual cortex (open squares (adapted from Logothetis & Wandell, 2004, p.740).

7.3.3 Regional and intersubjective variability

Since the BOLD-signal depends from several parameters, such as blood flow, blood volume, oxygen consumption and the micro vascular anatomy, there are differences between regions and subjects. Kastrup et al. (1999) investigated regional differences with a global stimulus (because different stimuli are not comparable, e.g. through an auditive stimulus no activity will be elicited in the visual cortex). Participants had to stop breathing during 30s, which leads to hypercapnia (increased carbonic acid in the blood). Hypercapnia causes an increase of the blood flow. The strongest increase was found in the cerebellum and the visual cortex,

the smallest increase of the BOLD signal was found in the frontal cortex. This is an indirect evidence of regional differences in the BOLD-signal intensity (Kastrup et al., 1999).
Also between subjects there are enormous BOLD-differences. The reasons for this are on the one side differences in the brain morphometry, but also differences in different cognitive strategies (Miezin et al., 2000). Within a region of one subject, the estimates for the hemodynamic response are quite robust: The correlations are high for the amplitude of the BOLD signal, for the amplitude of the hemodynamic response and for Time to Peak also. There are smaller correlations for the Time to Onset (Miezin et al., 2000). In general, interregional and intersubjectiv differences are neglected (Kastrup et al., 1999).

7.3.4 Additional biological and physiological limitations

Besides the factors that are mentioned above, additional ones with influence on the BOLD-signal exist. As mentioned above, the strength of the magnetic field has a strong influence on temporal and spatial resolution: the stronger the field, the better the resolution (Weiller & Elbert, 1997). The BOLD-signal is also influenced by background noise. Even if the movement of the head is limited, signal fluctuations through factors caused in physiology (heartbeat and respiration) distort the signal. With statistical methods it can be filtered reliably, see 7.5.1.

Because excitation and inhibition require the same energy-consuming processes, it is not possible to differentiate between them. It is also not yet known how sub-threshold synaptic activity influences the signal (Menon & Kim, 1999), even if Logothetis and Wandell (2004) postulate that local synaptic voltage (LFP) has more predictive power than multiple-unit spiking activity (MUA). MUA measures regional neuronal spiking, whereas LFP measures slow waveforms, including synaptic potentials, afterpotentials of somatodendritic spikes and voltage-gated membrane oscillations.

Effects of learning, habituation, errors and changes in the cognitive strategy cause changes in the neuronal activity which gets lost through the averaging of the data. Particularly in learning experiments these aspects should be considered. Stimulus duration and repetition have also an effect on the hemodynamic response (Menon & Kim, 1999).

7.4 Analysis of fMRI data

The result of an fMRI study is a time sequence of digital (2D) images taken every n seconds within each defined cubical measuring unit which is termed a voxel (volume element). The main objective of fMRI studies is to obtain a statistical parametric map (SPM) that depicts brain areas significantly responding to a specific experimental condition. This requires several pre-processing and evaluation steps that will be described in the following. All evaluations of the present studies are conducted by using the software package LIPSIA (Leipzig Image Processing and Statistical Inference Algorithm) by Lohmann and co-workers (2001).

The following data types were measured: In order to map the position of the participant 26 anatomical T1-weighted MDEFT-images (Ugurbil et al., 1993; Norris, 2000) parallel to the AC-PC plane and covering the whole brain were acquired prior to the functional run. This data delivers the structural information to the functional data and is scanned with a low resolution. With the same spatial orientation functional data was acquired: The actual functional data consists of a timeline of scans that are parallel 2D-slices. For the present experiment, Echo-Planar-Imaging (EPI) sequences (TE 30 ms, TR 2000 ms and 90° flip angle) are applied. There exists high resolution T1 weighted anatomical data of each participant, which is measured independently for each participant and can be used as a reference. In the following, it is called the 3D-data.

7.4.1 Pre-processing

Several pre-processing steps are required prior to statistical evaluation to improve the data quality and remove artefacts due to motion, slice acquisition, and low frequency drifts (which are due to physiological or technical reasons). Susceptibility artefacts occur specially in tissues bordering air-filled cavities, e.g., in the orbitofrontal or anterior temporal cortex. Affected areas should be excluded from investigation or interpretation. In the present experiment time sequences of 2D images were taken every 2 seconds. Functional data was first corrected for 2D motion artefacts during the measurement. In motion correction, the scans of an fMRI time series are geometrically aligned. Each scan is rotated and shifted until it optimally matches a reference scan. The functional data was offline corrected with the Siemens motion correction protocol (Siemens, Erlangen, Germany). Because slices are usually not acquired simultaneously but sequentially, it is necessary to correct them for the temporal offset between the slices so that they don't affect the statistical analysis. In the present experiment, a cubic-spine-interpolation was used to correct the temporal offset between the slices acquired in one scan. The third step of pre-processing is the baseline correction. This is required to correct inhomogeneities in the signals and to reduce noise. Possible reasons for inhomogeneities are participant dependent fluctuations in respiration, blood pulsation etc., but also scanner dependent fluctuations, e.g. temperature or lower signal values. Changes in the average signal intensity, i.e. baseline drifts, were corrected by using a temporal highpass filter. Temporal filtering and spatial smoothing are used, to map the HRF more exactly. The basic idea is that the signal gets superimposed of data with higher frequency. A smoothing leads to an approach to the original curve. Additionally, noise within the data can be lessened by performing spatial smoothing using a Gaussian filter (here 0.8) kernel over the voxel and corresponded neighbours. A SD of 0.8 corresponds to a voxel size of 3x3x5mm 5.65mm FWHM (Full-width half-maximum). For the temporal filtering a highpass filter, as well as a low-pass filter can be used. Normally, a highpass filter is used that is half as big as the maximal distance of two same events. Slow drifts in the signal-to-noise-ratio over the total length have to be filtered for two reasons. First, to determine the basic signal (β_0 in the General Linear Model, see section 7.4.3) as exactly as possible and second, if later on the average signal shall be used as for a percent signal change (psc). To get a good estimation of β_0, a highpass-filter of 1=120 Hz was used to eliminate slow drifts.

7.4.2 Spatial transformations

Before the analysis of functional data, two further steps are required. First, the data has to be aligned with each other and conform to a standard anatomical space, e.g. the Talairach stereotactic space (Talairach & Tournoux, 1988). This co-registration algorithm geometrically aligns 2D structural slices acquired along with the functional slices with a high-resolution 3D structural reference data set. The reference data set resides in a standard stereotactic coordinate system (the Talairach-system). The algorithm is implemented as an optimization procedure that yields rotational and translational parameters which produce an optimal linear correlation between the two data sets. The rotational and translational parameters can be used to co-register functional time series or 2D statistical parametric maps provided they are geometrically aligned with the 2D structural slices that were used for the co-registration. The y-axis is the straight line from the anterior to the posterior commissure (AC and PC). Orthogonally to that, the x-axis proceeds from left to the right and the z-axis proceeds in the right angle to the x- and y-axes. The origin of the coordinate system is the AC (Talairach & Tournoux, 1988). For each voxel a correlation coefficient is computed from the brightness values from both anatomical data sets. This procedure was verified with a visual program.

Second, the data sets have to be normalized. LIPSIA offers a linear and a non-linear normalization. In linear normalization, the data set is linearly scaled to a standard size. In nonlinear normalization, an anatomical 3D data set is deformed such that it matches another 3D anatomical data set that serves as a model image. The deformation field obtained by this procedure can also be applied to a statistical parametric map provided it is geometrically aligned with the structural data set that was used to compute the deformation field. The normalisation is necessary to make comparable the data from several participants and for the denotation of the Talairach coordinates, which correspond to a brain size of x, y, z = 135, 175, 120mm.

7.4.3 Statistical evaluation

The statistical core routines of LIPSIA are efficient implementations of algorithms used in the SPM package (parts of both SPM96 and SPM99). The main objective of the statistical evaluations is to find and depict areas that are significantly responding to a specified experimental condition via the attainment of a SPM. The general linear model forms the basis of the statistical evaluation in LIPSIA. The basic statistical assumption underlying the GLM is that the observed values of each dependent variable can be written as the measured value (*x*), which is altered through several parameters (*β* and an error *ε*). The GLM is described through the equation:

$$y_i = \beta_0 + \beta x + \epsilon$$

A further basic assumption is that ε_i is assumed to be independent and identically normally distributed with the expected value $E(\varepsilon)$ being zero. In the present case there are not only one value but i several values (voxels) and *k* different conditions, so that the GLM has the form:

$$\begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_i \end{bmatrix} = \beta_0 + \beta_1 \times \begin{bmatrix} x_{11} \\ x_{12} \\ \vdots \\ x_{1i} \end{bmatrix} + \beta_2 \times \begin{bmatrix} x_{21} \\ x_{22} \\ \vdots \\ x_{2i} \end{bmatrix} + \ldots + \beta_k \times \begin{bmatrix} x_{k1} \\ x_{k2} \\ \vdots \\ x_{ki} \end{bmatrix}$$

This model can be seen as regression model, whereas the x-values as single regressors explain the observed values y. In the case of fMRI, y_i are always given and stand for the activation value of the voxel in scan i. β_0 denotes the overall mean of the time series (of all y-values) of this voxel. For all regressors of the GLM, x-values for each individual scan are assigned using an artificial value. These series of values represent the theoretical course of the i-values for one condition *k*. To the calculation of the theoretical values the hemodynamic response function (HRF, Glover, 1999) gets implemented (it gets interposed to the corresponding onsets in the time course). Therefore, the temporal distribution function x_i consists of a convultion of the corresponding onset function with an appropriate function, the HRF. Through regression analysis β values are estimated from the x-vectors and the β_0, in order that as much as possible of the data y is explained through the model, or the error ε gets as small as possible. The validity of the model depends from the number of the valid parameters. One possibility to enhance the explanatory power of the GLM is not only to model the theoretical time course through the HRF but also to include additional models. However, by using more than one basic function, i.e. its first derivative, both stimulus-dependent as well as regionally specific aspects of the response can be taken into account. However, the design matrix was generated utilizing a synthetic HRF without the first derivative (Friston et al., 1995) with reaction time as onset. In the present experiment predictor models were generated for each condition as well as for all conditions together. The construction of a shared predictor model is possible through a fixed effect modulation that enters in all X-vectors as fixed factors. Therefore, in each condition beta values for the HRF and the first derivate as well as the error can be determined.

The GLM of each voxel has to be tested for significance in testing each regression coefficient β_k against 0. The zero hypothesis for each voxel is described as follows: there is no relationship between β_k x X_k and y (that means there is no effect of the condition *k* on the change in the blood flow as correlative of neuronal activity in this voxel). It is problematic to act on the assumption that the error correlates with zero because low frequency noise and temporal smoothing cause an autocorrelation of the error rates, as described by Friston et al. (1995). Therefore, the degrees of freedom are corrected. The verification is carried out with linear contrasts to the t-statistic. A contrast is designed as a row vector with the sum of 0 and contains for each β_k a weighted factor, which is calculated with the β_k, to test them against 0. The presentation of the resulting t-values results usually in two manners: one possibility is the convertation of the t-values of single voxels into z-values (normalisation) to make them comparable in so-called z-maps. A z-map provides therefore information over the significance of the dissimilarity of β of a condition against 0 or—dependent on the chosen linear contrast—over the dissimilarities between conditions. The other possibility is to compute contrast images. They directly portray differences of the β of the tested conditions as contrast values. If next to the theoretical X-distribution ($x_k i$) other parameters get included (derivative functions, changes of convultions, regressors...), it is possible to test them separately or together with the main factors. As above-mentioned, in the present study the first derivative is not modelled and not contrasted. To come to a conclusion, the result of a first level statistical analysis is either a statistical parametric map containing z-values, or a contrast map containing contrast values.

Second level analysis. At the second level of analysis, the individual maps obtained at the first level are subjected to further statistical tests that allow multi-subject comparisons, here, to test whether individual differences in experience seeking influence the neural response. LIPSIA offers one-sample t-tests involving either individual contrast images or individual z-maps. Furthermore, LIPSIA offers a two-sample t-test to compare groups of contrast images. In addition, sphere-shaped regions of interest centered on activation areas can be defined and mean contrasts or z-values within these areas can be entered into a second level ANOVA.

7.5 Visualisation

LIPSIA (Lohmann et al., 2001) offers various visualization methods. Cross-sectional slices, time series, modelling information, power spectra and the like can be visualized using a mouse-driven graphical user interface. Various methods for the volume rendering of individual brains are supported. White matter segmentations and segmentations of sulcal lines are used to support the visualization.

8 Research questions

This dissertation has an interdisciplinary character as it investigates behavioral and neural correlates of processing visual humor stimuli, i.e., cartoons, which are characterized according to parameters derived from cognitive-linguistic (GTVH, Attardo & Raskin, 1991) and psychological humor models (e.g., Suls, 1972; Ruch, 1992, 1995; Ruch & Hehl, 2007). The incongruity-resolution stage of humor processing lies in the main focus of interest. In order to elucidate cognitive processes, structural characteristics of the stimuli are varied, i.e. LMs, which represents the rule for how to resolve an incongruity in order to get the joke, and incongruity-resolution vs. nonsense humor. Through the systematic manipulation and selection of structural aspects of a cartoon it should be possible to manipulate cognitive effort and to investigate cognitive and affective processes. It shall be mentioned here that non-verbal, single-frame cartoons are used in the present studies.

The research questions that are addressed in this dissertation are presented in the following.

8.1 Neural activation involved in pure incongruity-resolution (chapter 10)

First, it shall be clarified which regions in the brain are effectively involved in the incongruity-resolution process without the pre-processing steps such as incongruity-detection. Previous fMRI studies did not create a consistent picture (e.g., Mobbs et al., 2003; Moran et al., 2004; Wild et al., 2006). Therefore, funny cartoons will be compared to a control condition consisting of pictures containing irresolvable incongruities. In this control condition, an incongruity can be detected but not successfully resolved. It is expected that only the areas are activated that are involved in the resolution of the incongruity and not the pre-processing steps such as the encoding of information, retrieving scripts from the Long Term Memory and incongruity detection.

Although there is no consensus about the exact number of processing stages I adhere, in general, to the information-processing model of Suls (1972) and its extension: first, an encoding process (e.g., Attardo, 1997) takes place, then an incongruity has to be resolved in order to appreciate the joke. In this cognitive process semantic comprehension processes take place, including the recognition that the incongruity-resolution process differs from problem solving in the way that it is only a pseudologic, partial resolution or a play with nonsense (Ruch, 2007). Even if the stages of humor processing might temporally not be distinguishable (see Coulson & Kutas, 2001), it is possible to show which brain regions are involved in a successful incongruity-resolution when contrasting funny cartoons (where the incongruity-resolution was successful, even if only) from pictures containing an incongruity which might cause puzzling but doesn't deliver a way to resolve it.

8.2 The influence of Logical Mechanisms on the neural humor response (chapter 10)

Second, the influence of LMs, i.e., the cognitive rule how to resolve an incongruity, on neural activation patterns is investigated. The GTVH (Attardo & Raskin, 1991) described LMs according to which humorous stimuli can be defined. This is the first study that investigates the influence of LMs empirically (i.e., with rating scales and the neural response). The neural patterns of processing visual puns (PUN), semantic cartoons (SEM) and Theory of Mind (TOM) cartoons shall be analyzed. Here, the question about whether mind-reading abilities are always necessary for humor processing (as postulated for example by Howe, 2002) shall be addressed. All three cartoon categories have in common that an incongruity has to be resolved—respectively, that two scripts have to be integrated—be it visually evoked or semantically. Whereas SEM can be seen as common cartoons, PUN and TOM can be described as stimuli that require more specific cognitive processes. It is expected to find more specific activations in PUNs, e.g., in higher order visual areas (extrastriate cortex). The comparison of the PUN and SEM conditions can be seen as a replication of the study by Goel and Dolan (2001) with pure visual, nonverbal material. Because they found specific activation for processing of phonological puns, we can expect to find—in the PUN condition—more activation in areas where visual features are processed. The punch line of TOM cartoons is based on the circumstance that one character does not know what another character thinks or intends to do. In order to understand the punch line, (false) mental states of the characters portrayed in the cartoon have to be attributed. For the processing of TOM cartoons it is expected that areas involved in mentalizing tasks are activated more, e.g., medial prefrontal areas or TPJ.

8.3 Neural correlates of incongruity-resolution and nonsense humor (chapter 11)

Third, the influence of the resolvability of the incongruity on neural patterns shall be investigated. Humorous stimuli can be positioned on the continuum from incongruity-resolution to nonsense jokes. It can be assumed that stimuli can be categorized relatively independent of the LM (see Hempelmann & Ruch, 2005) into incongruity-resolution or nonsense humor. As in incongruity-resolution there is more to be integrated (the joke makes more sense, the scripts can be unified better), it is expected that more brain activation can be found, particularly in those areas that are involved in incongruity-resolution (rather than incongruity detection). It is of interest to investigate whether an increased level of resolution is reflected in the higher activation of certain brain areas. Studies of this kind might enrich the knowledge about humor categories as well as about to which extend particular brain areas are involved in humor processing.

8.4 The influence of experience seeking on the neural response during humor processing (chapter 11)

The neural response shall also be analyzed in dependence on a personality characteristic that was shown to correlate with humor processing (e.g., Forabosco & Ruch, 1994; Deckers & Ruch, 1992; Lourey & McLachlan, 2003): experience seeking, which involves seeking of novel sensations and experiences through the mind and senses, as in arousing music, even psychedelic drugs, art, and travel, and through social nonconformity, (e.g., artists, hippies, homosexuals, see Zuckerman, 1994). Up to now, hardly any fMRI study exists where individual experience-seeking scores were taken into account. As extraversion was shown to correlate with experience seeking (e.g., Aluja, García & García, 2003) and extraversion was shown to provoke more brain reactivity in humor processing (e.g., Mobbs et al., 2005), the same was expected for experience seeking. As experience seekers were shown to prefer nonsense humor over incongruity-resolution humor, neural patterns of incongruity-resolution and nonsense humor shall be analyzed in dependence on experience seeking as well.

8.4 The influence of empathizing and systemizing on cognitive and affective humor processing (chapter 12)

Several personality characteristics, as well as cognitive skills, were postulated to correlate with humor processing. Theory of Mind was described above in relation to cognitive requirements of a certain LM (Theory of Mind, or obvious error, Paolillo, 1998). However, Theory of Mind can be seen as an *ability* to take the perspective of others or to mind-read (e.g., Premack & Woodruff, 1978) which can be seen as the cognitive component of empathy. Theory of Mind and empathy were described in some humor models to be *essential* for humor comprehension (Howe, 2002; Jung, 2003) and some studies focused on the relationship between humor and mind-reading abilities or empathy. Some studies lead to the assumption that mentalizing abilities are not necessary for all jokes or cartoons (e.g., Gallagher et al., 2000; Marjoram et al., 2005) whereas other studies postulated that Theory of Mind (intention attribution, mentalizing) is necessarily required to process humor (e.g., Uekermann et al., 2006, 2007). For example, Bartolo et al. (2006) compared funny and un-funny cartoons, found areas in the brain that are associated with mentalizing and concluded that incongruity-resolution might occur through a process of intention-attribution without including a humorous control condition that does not require mentalizing.

The question emerged here whether the differences between the studies can be explained through *stimulus characteristics* (with specific requirements on the cognitive process)—might it be possible that humor processing that is related to Theory of Mind and empathy is dependent on structural elements of the stimuli, such as different LMs? This question gets even more significant if taking into account that one of the LM, i.e., obvious error, seems to be related to false belief tasks (e.g, recognizing that someone else has a false belief, e.g., Wimmer & Perner, 1983)—tasks that were often used in the literature in order to assess mind-reading skills.

Therefore, a study was designed to investigate humor processing of healthy subjects with varying degrees of empathizing (measuring emotional but also cognitive components of empathy). Since empathizing is one of two cognitive styles described by Baron-Cohen (e.g., 2003) as relatively independent psychological dimensions but systemizing has never been investigated in relation to humor processing, both—empathizing and systemizing—were taken into account. Empathizing and systemizing skills shall be assessed with the German short scales (Samson & Huber, 2008) of the Empathizing Quotient (EQ), and the Systemizing Quotient (SQ), developed by Baron-Cohen and colleagues (Baron-Cohen et al., 2003; Baron-Cohen & Wheelwright, 2004). The question raised is whether empathizers (people known to have high scores on the EQ and low scores on the SQ) and systemizers (scores vice versa) process humor differently. This investigation refers to the same three LM groups as used in the fMRI study. Therefore, stimulus characteristics—whether mentalizing abilities are required or not—as well as interindividual differences are taken into account. Here, not only rating scales are used but the participants were asked to explain why they thought the joke is funny. These explanations shall be analyzed qualitatively in order to elucidate the underlying cognitive processes in humor in more detail.

In summary, the following independent variables were used in the present experiments: three groups of LMs (PUN, SEM and TOM) as well as the two types of humor differing mainly regarding the resolvability of the incongruity (incongruity-resolution and nonsense cartoons). Furthermore, personality differences were taken into account: Experience seeking (Zuckerman, 1994), as well as empathizing and systemizing abilities (e.g., Baron-Cohen, 2002, 2003). As dependent variables, the neural response (i.e., the Blood-level-dependent [BOLD] signal) is used, as well as recognition time, rating scales (comprehensibility, funniness) and explanations why a cartoon is perceived to be funny.

The arch reaching over these studies is on the one end touching stimulus characteristics, such as incongruity-resolution and nonsense humor, but also LMs. On the other end Theory of Mind is in the focus of interest, seen as a cognitive requirement of cartoons based on the LM TOM but also as an ability in relation to empathy which is more or less pronounced in individuals.

Since non-verbal cartoons are used as stimuli in all of the present studies, the first chapter of the main section of this thesis will provide an overview of cartoons in humor research—touching historical aspects—a definition and the attempt to differentiate cartoons from similar media and from verbal jokes (Hempelmann & Samson, 2008). After that, three empirical studies will be presented that address the above-mentioned questions. These studies were run with several co-authors and are partly published (Study 1: Samson, Zysset & Huber, 2008) or in press (Study 2: Samson, Hempelmann, Huber & Zysset, in press; Study 3: Samson, in press).

Part II: Studies

9 An overview on cartoon research

The following chapter is part of the thesis but cannot be reprinted here due to copyright problems. Please see:

Hempelmann, C. F. & Samson, A. C. (2008). Cartoons: Drawn Jokes? In V. Raskin (Ed.). *The Primer of Humor Research.* Pp. 609-640. Mouton de Gruyter: Berlin.

10 Cognitive humor processing: different logical mechanisms in non-verbal cartoons—an fMRI study

This chapter was published as Samson, A. C., Zysset, S. & Huber, O. (2008). Cognitive Humor Processing: different logical mechanisms in non-verbal cartoons—an fMRI study. *Social Neuroscience*, 3(2), 125-140.

Abstract

Although recent fMRI studies on humor have begun to elucidate cognitive and affective neural correlates, they weren’t able to distinguish between different logical mechanisms or steps of humor processing, i.e., the detection of an incongruity and its resolution. This fMRI study aimed to focus in more detail on cognitive humor processing. In order to investigate pure incongruity resolution without preprocessing steps, nonverbal cartoons differing in their logical mechanisms were contrasted with nonhumorous pictures containing an irresolvable incongruity. The logical mechanisms were: (1) visual puns (visual resemblance, PUNs); (2) semantic cartoons (pure semantic relationships, SEMs); and (3) Theory of Mind cartoons (which require additionally mentalizing abilities, TOMs). Thirty cartoons from each condition were presented to 17 healthy subjects while acquiring fMR images. The results reveal a left-sided network involved in pure incongruity resolution: e.g., temporo-parietal junction, inferior frontal gyrus and ventromedian prefrontal cortex. These areas are also involved in processing of SEMs, whereas PUNs show more activation in the extrastriate cortex and TOMs show more activation in socalled mentalizing areas. Processing of pictures containing an irresolvable incongruity evokes activation in the rostral cingulate zone, which might reflect error processing. We conclude that cognitive processing of different logical mechanisms depends on separate neural networks.

Introduction

Humor is an essential human characteristic and can be evoked by verbal (jokes) or visual materials (cartoons or movies), as well as in social situations. Cartoons are one common humor medium, showing pictures containing incongruous elements that have to be resolved in order to understand the punch line. In understanding cartoons, a stage of incongruity detection can be distinguished from a stage of incongruity resolution (e.g., Suls, 1972). First, the incongruity has to be detected in the cartoon, then it has to be resolved in order to understand the punch line of the cartoon. The incongruity resolution can be described as similar to a problem-solving process (e.g., Suls, 1972): A cognitive rule has to be found to bring two incongruous scripts together. Zigler, Levine, and Gould (1967) stated that the humor response depends on the demand that the stimulus makes on cognitive capacities. Cartoons can be classified in relation to formal or structural aspects (i.e., drawing style, resolvability of the incongruity, proportion of visual and verbal elements, etc.). There is evidence from several behavioral studies that formal as well as structural elements of the stimuli influence humor perception and processing (e.g., Herzog & Larwin, 1988; Huber & Leder, 1997; Ruch & Hehl, 1998; Samson & Huber, 2007).

Recent functional magnetic resonance imaging (fMRI) studies have sought to circumscribe areas that are involved in humor processing and its appreciation using jokes, cartoons or funny movies (e.g., Azim, Mobbs, Jo, Menon, & Reiss, 2005; Bartolo, Benuzzi, Nocetti, Baraldi, & Nichelli, 2006; Goel & Dolan, 2001; Mobbs, Greicius, Abdel-Azim, Menon, & Reiss, 2003; Mobbs, Hagan, Azim, Menon, & Reiss, 2005; Moran,Wig, Adams, Janata, & Kelley, 2004; Sieboerger, Ferstl, Volkmann, & von Cramon, 2004; Watson, Matthews, & Allman, 2006; Wild et al., 2006). A wide area around the temporo-parietal junction (temporo-occipital junction, posterior superior temporal sulcus, posterior middle temporal gyrus, in the following called TPJ), temporal pole and inferior frontal gyrus (IFG) is assumed to be involved in cognitive humor processing (e.g., Goel & Dolan, 2001; Mobbs et al., 2003; Moran et al., 2004; Wild et al., 2006). Most of the fMRI studies that have investigated neurologically healthy subjects found a more left-sided network. This might be due to the fact that the stimuli were most often purely verbal or verbal/visual. However, in their study, Wild et al. (2006) also found more left frontal activation with pure nonverbal stimuli.

The role of the TPJ in humor processing is interpreted controversially: Mobbs et al. (2003) claimed it to be involved in the detection of the incongruous element, whereas Azim et al. (2005) and Wild et al. (2006) assumed that the TPJ is involved in incongruity resolution. According to Moran et al. (2004), this area brings stored expectations online, whereas Watson et al. (2006) associated it with processing of social information in general.

The IFG (Goel & Dolan, 2001; Mobbs et al., 2003; Moran et al., 2004;Wild et al., 2006) and the temporal pole (Mobbs et al., 2003) have been claimed to be involved in the incongruity resolution process or generally in humor perception (Wild et al., 2006). Goel and Dolan (2001) circumscribed specific areas for different types of verbal jokes. Phonological puns activated areas that help to process sounds, i.e., the left inferior precentral gyrus and insula, whereas semantic jokes activated regions that process word meaning, i.e., the right posterior middle temporal gyrus (pMTG) and left posterior inferior temporal gyrus (pITG). Watson et al. (2006), using captioned cartoons, compared ‘‘sight gags’’, i.e., cartoons, in which the joke is based on elements in the picture (the cartoons remain funny, even if the caption is removed), to language-based humor (the cartoons are only funny when the caption is available). Visual-based humor activates among others bilaterally higher order visual cortex, TPJ, middle frontal gyrus (MFG) and precuneus. Language-based humor activates specifically the MTG, IFG and ITG.

Some studies segregated cognitive (i.e., comprehension of the humorous material) from affective (i.e., amusement, exhilaration induced by humorous stimuli and measured by funniness ratings) humor processing: The funnier the humor stimuli are perceived to be, the more activity can be found in the left insula, amygdala (Moran et al., 2004), pre-supplementary motor area (pre-SMA), dorsal anterior cingulate cortex (dACC; Mobbs et al., 2003) and in subcortical nuclei that belong to the dopaminergic reward system (Mobbs et al., 2003; Watson et al., 2006). Goel and Dolan (2001) and Sieboerger et al. (2004) found the ventromedian prefrontal cortex (vmPFC) and the cerebellum to be associated with funniness ratings. Several other frontal (i.e., left inferior frontal cortex) and parietal areas (i.e., left lateral parietal cortex) were also correlated with funniness ratings (e.g., Moran et al., 2004; Watson et al., 2006; Wild et al., 2006).

Two recent fMRI studies took individual differences in humor processing into account: Azim et al. (2005) investigated differences between males and females, Mobbs et al. (2005) showed that personality traits play a role in humor processing. This brief summary of previous fMRI studies on humor processing reveals that there is a wide network involved in cognitive humor processing (e.g., the inferior frontal cortex, TPJ or anterior temporal areas). With the exception of the study by Goel and Dolan (2001), who sought to find separate modality-dependent pathways, or Watson et al. (2006), most fMRI studies compared humorous to nonhumorous stimuli without focusing in more detail on formal or cognitive elements of their stimuli. Further, no study attempted to investigate incongruity resolution without preprocessing steps as incongruity detection. Although Moran et al. (2004) distinguished a humor-detection process from a humor-appreciation stage, we have to emphasize, that their humor detection can not be equated to incongruity detection. Their humor detection includes incongruity detection as well as incongruity resolution and could be described as cognitive humor processing in general.

As a first goal of the present study, we attempted to circumscribe the network involved in pure incongruity resolution. Therefore, we separated different steps in humor processing: incongruity detection and its resolution. We presented not only a nonhumorous baseline that contained no incongruities or punch lines, but also an additional baseline condition. This additional condition consisted of pictures that did not contain a punch line, but led to the detection of an incongruity that couldn’t be resolved. If you compare the irresolvable incongruity baseline with funny cartoons, you can contrast incongruity resolution (activity associated with funny cartoons) vs. preprocessing steps (such as the detection of incongruity, see Figure 1), as well as humor appreciation. It should be noted that affective aspects of humor processing were not the main focus of this paper.

A second aim of our study was to investigate cartoons differing in one formal element that determined the incongruity-resolution stage: According to the General Theory of Verbal Humor (GTVH; Attardo & Raskin, 1991), logical mechanisms (LM) describe the cognitive rule, how the incongruity of a joke or cartoon can be resolved. We presented three nonverbal stimuli conditions differing basically in their LM: visual puns (PUN), semantic cartoons (SEM) and Theory of Mind cartoons (TOM).

PUNs are analogous to verbal or phonological puns, as defined by Hempelmann (2004). PUNs are cartoons in which the punch line is based on the fact that one visual element activates two scripts that are incongruent to each other (Hempelmann & Samson, 2007). In the incongruity resolution stage these two scripts have to be integrated, in terms of the GTVH (Attardo & Raskin, 1991), a script overlap has to be created (see Figure 1 for an example).

SEMs are cartoons that are based on pure semantic relationships in contrast to visual resemblance, as in PUNs. In SEMs, the incongruity lies in the opposition of two scripts based on pure semantic/content-related aspects. In order to resolve the incongruity, the perceiver has to recognize the LM that describes the relation of those scripts. In this stimuli group, several LMs are subsumed (e.g., exaggeration, juxtaposition, role exchange; Attardo, Hempelmann, & DiMaio, 2002).

TOM cartoons, as a third stimuli group, are a subgroup of SEM cartoons characterized by the fact that mentalizing abilities have to be involved in order to understand the joke. These cartoons are similar to false-belief tasks in the sense that the perceiver has to attribute mental states to the portrayed characters: The viewer has to recognize that one character does not know what the other character thinks or intends to do. The LM that circumscribes this requirement the best was defined by Attardo et al. (2002) and Paolillo (1998) as obvious error: “A participant in the situation fails to recognize or acknowledge something exceedingly obvious or saliently presented” (Attardo et al., 2002, p. 6; see Figure 1).

All three cartoon categories have in common that an incongruity has to be resolved, respectively, that two scripts have to be integrated, be it visually evoked or semantically. Whereas SEM can be seen as common cartoons, PUN and TOM can be described as stimuli that require more specific cognitive processes. According to Hempelmann (2004) the incongruity of phonological puns and semantic jokes is semantic, whereas the incongruity resolution of semantic jokes is purely semantic and the incongruity resolution of phonological puns is phonological and semantic. Translated into the visual world, the theoretical assumptions of Hempelmann (2004) would lead to the following predictions: Visual puns and semantic cartoons do not differ in their incongruity detection, but they do differ in their incongruity resolution. In contrast to SEM and TOM, for processing of PUNs it is not necessary to build a situation model (Zwaan & Radvansky, 1998) to get the joke, but it might be sufficient to detect and integrate two scripts that are revealed by one visual element. Therefore, PUNs are similar to pure picture play. To understand the joke, deep and complex processing of semantic relations is not necessary (see Hempelmann & Samson, 2007). Therefore, we expect to find more specific activations in PUNs, e.g., in higher order visual areas (extrastriate cortex). The comparison of the PUN and SEM conditions can be seen as a replication of the study by Goel and Dolan (2001) with pure visual, nonverbal material. As they found specific activation for processing of phonological puns, we expect to find in the PUN condition more activation in areas where visual features are processed.

In TOMs we expect to find more activation in typical mentalizing areas, as in the median PFC (mPFC), precuneus and particularly in the TPJ, analogous to Gallagher et al. (2000) or Marjoram et al. (2006). That TOM cartoons do require additional cognitive abilities to non-TOM cartoons is shown in their studies: Only processing of TOM cartoons required activation in the vmPFC, precuneus and TPJ bilaterally (Gallagher et al., 2000), or mPFC, precuneus, and temporal poles (Marjoram et al., 2006). These areas are typically associated with the attribution of mental states, whereas their non-TOM cartoons, described as “physical” (“slapstick”), didn’t require Theory of Mind or mentalizing capabilities for their correct interpretation. We have to underline, that their non-TOM cartoons are neither comparable to our SEM condition nor to our PUN condition. Slapstick humor is probably more based on incongruity than on incongruity resolution.

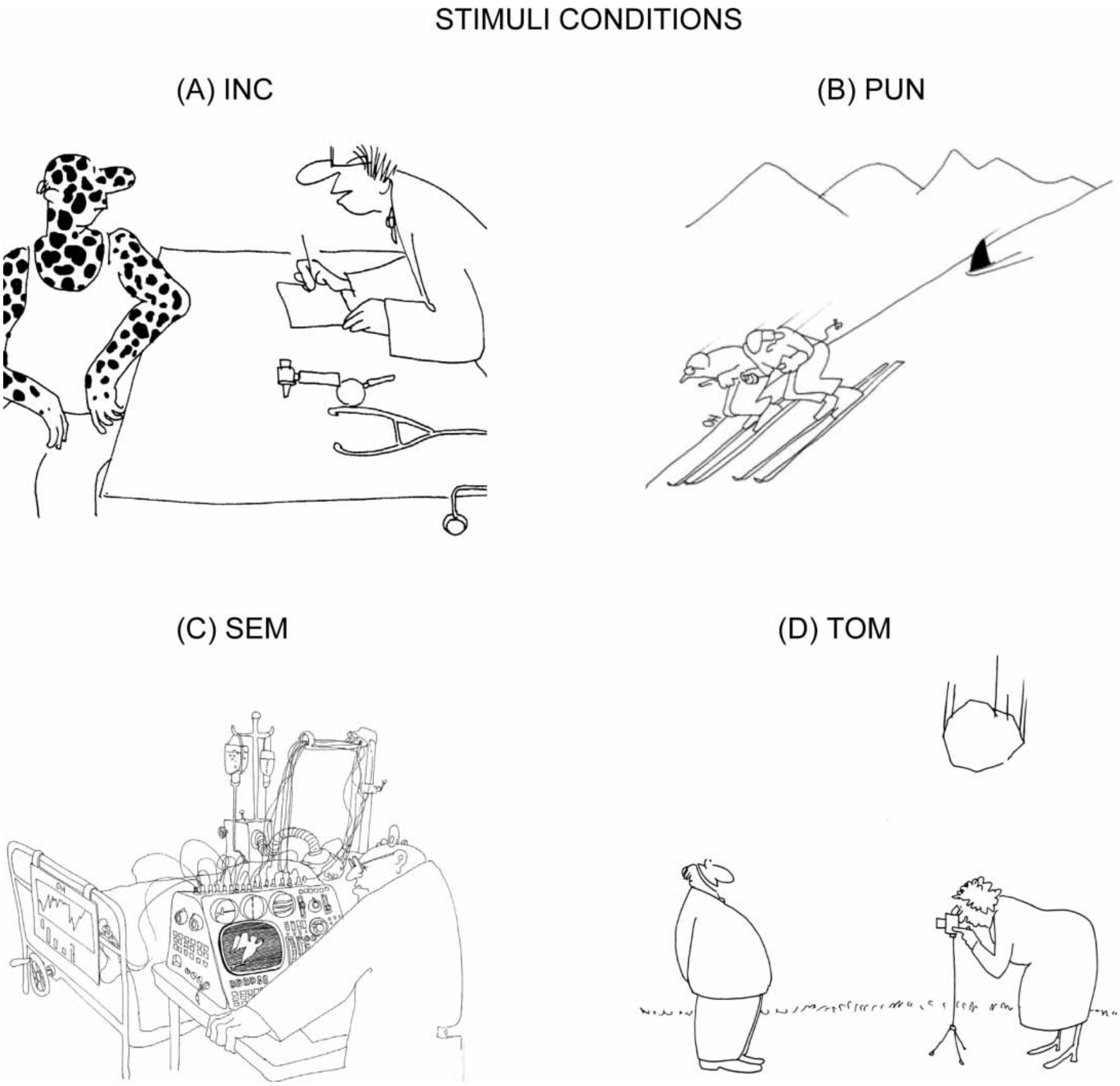

Figure 1: Examples of the stimuli used in the study. (A) A picture containing an irresolvable incongruity (INC). (B) A visual pun (PUN): one visual element (the diagonal line) can stand for the sea (activated through the fin) or the mountain (activated trough the skis). (C) A semantic cartoon (SEM): the joke is based on pure semantic relations and not on visual resemblance, as in PUNs: the patient has died which can be seen on the monitor in form of an angel flying away. There is no visual resemblance between the angel and the line which indicates no heartbeat. In order to understand the joke, no mentalizing abilities are required. (D) A Theory of Mind (TOM) cartoon: In order to get the joke, it is necessary to activate mentalizing abilities: to understand that the women does not know what will happen to her, while the man knows what will happen. Cartoons: Oswald Huber.

Two recent humor models postulated that mind reading is always part of humor processing (Howe, 2002; Jung, 2003). Howe (2002) stated that the essential element of humor is the observation and understanding of thought processes in the mind of the subject of a joke. If this hypothesis is true, typical mentalizing areas should be activated in the processing of any type of cartoons. A recent fMRI study on humor presented funny and unfunny cartoons to healthy subjects (Bartolo et al., 2006). As they found activation associated with the funny cartoons in some of the mentalizing areas (e.g., left superior temporal gyrus; STG), they hypothesized that incongruity resolution occurs with a process of intention attribution or mentalizing. However, they had no adequate control condition in order to prove that mentalizing is always involved in humor processing. In contrast to Howe (2002), Jung (2003) and Bartolo et al. (2006), we assumed that only in the TOM condition is it really necessary to activate mentalizing capabilities. Other humor types, for example visual puns or semantic humor, don't require taking the perspective of others and should therefore portray less activity in so-called mentalizing areas, particularly in medial prefrontal areas or in the TPJ. To summarize, in this event-related fMRI study we focused with pure nonverbal stimuli on regions that are specifically involved in incongruity resolution by means of contrasting "resolvable" cartoons with pictures containing an irresolvable incongruity. Further, we focused on the differentiation of LMs relating to incongruity resolution. In order to investigate this in more detail, we presented three groups of cartoons that differed in their LM: (1) visual puns, where the incongruity resolution process is visual/semantic; (2) semantic cartoons, where the incongruity resolution process is strictly semantic; and (3) TOM cartoons, where additionally Theory of Mind/mentalizing abilities are required to get the joke. The contrast PUN vs. SEM sheds light on different types of incongruity resolution (pure semantic or visual/semantic), whereas TOM vs. PUN/SEM might refute the hypotheses that claim that TOM is always involved in humor processing.

Method

Subjects

Seventeen right-handed and neurologically healthy subjects (9 female, 8 male; mean age 26.06 years; SD = 3.25) participated in this study. Written informed consent from all subjects was obtained prior to the scanning session. The study was conducted in accordance to the guidelines of the local ethics committee. All subjects had normal or corrected-to-normal vision and were native German speakers. None of the subjects were taking medication at the time of the study. Subjects were instructed prior to the actual experimental session. Once they felt comfortable with the task, subjects were positioned supine in the scanner.

Stimuli

In order to find and select appropriate stimuli, several pre-examinations were conducted. First, five subjects searched our own large cartoon collection and in the internet for single-frame, non-verbal cartoons that intended to be primarily funny (not political) without sexual content, because the preference or dislike for sexual cartoons is known to correlate highly with certain personality characteristics (see, e.g., Ruch, 1998). Two hundred cartoons were selected and categorized independently by five raters into the groups of PUN, SEM, TOM and a rest category according to definitions that were given and explained to the raters. If at least four of five raters classified the cartoon into the same group (in 90% total agreement), they were used for further examinations. These 150 cartoons that were categorized into the groups of PUN, SEM or TOM were presented to 21 subjects (mean age = 33.30; *SD* = 11.57) to be rated for funniness, complexity and originality. From these cartoons, 90 were selected for the main investigation. The first criterion was a recognition time under 7 seconds. Second, the three conditions shouldn't differ regarding funniness ratings. However, PUNs were perceived to be less funny than SEMs and TOMs which could be revealed by a repeated measure ANOVA: $F(2, 19) = 31.291$; $p < .001$. For the main investigation, PUNs with higher funniness values and SEMs and TOMs with lower funniness levels had to be selected. PUNs, as well as SEMs and TOMs beneath 7 seconds of recognition time were rank-ordered along mean funniness scores. The 30 funniest PUNs were selcted for the main investiagtion, as well as the 30 unfunniest SEMs and TOMs. Regarding complexity and originality, the three groups didn't differ significantly.

The stimuli for the two baseline conditions were drawn from a previous experiment (Samson, 2005): Pictures that are drawn in a cartoon or comic like manner without containing an incongruity or punch line (BAS) and pictures that contained an irresolvable incongruity (INC). These pictures are perceived to be not funny and to have high values in residual incongruity.

Task Paradigms

The participants had to indicate per button-press whether they understood the joke in the cartoon or not. This procedure was chosen in order to distinguish a) cartoons that were understood but not funny from b) cartoons that are not understood and therefore not funny. This allowed excluding for further analysis the non-understood cartoons or the understood INCs, respectively. Comprehensibility responses were given via button-press with index (understood) or middle (not understood) finger of the right hand. The cartoons and pictures were presented for 6 seconds. The pictures were presented on a black screen (880*600 pxl), whereas the longer side of the picture had a maximum length of 500 pixels. For the stimulation of the visual cortex and the motor response, the baseline condition (BAS) was presented. In this condition, there were horizontal arrows in the right or left direction to indicate that the subjects needn't search for a punch line but had to press the right or left button. All conditions were presented in random order to prevent subjects from developing response tendencies.

All subjects processed 90 humor trials (30 PUNs, 30 SEMs, 30 TOMs) and additionally 30 INCs and 30 BAS. Further, 30 none-events were presented, giving a total of 180 trials for each subject. Trials were presented every 10 seconds on average, and a variable stimulus-onset delay (0, 400, 800, 1200 or 1600 ms) was introduced for trials in order to improve the temporal resolution (Miezin, Maccotta, Ollinger, Petersen & Buckner, 2000) (the stimulus-onset delay was balanced over the stimuli conditions). This gave a total time of 30 minutes for the experiment.

Stimuli were projected with an LCD-Projector onto a translucent screen behind the subjects head. The screen was viewed with mirror lenses attached to the head-coil. If necessary, corrective lenses were mounted.

After the scanning procedure subjects were asked to rate the funniness of the 90 cartoons (PUN, SEM and TOM) on a computer-based experiment (Image_Rating) on a likert-scale from 0 to 6.

MRI scanning procedure

The experiment was carried out on a 3T scanner (Siemens TRIO, Erlangen, Germany).

For the cognitive paradigm, 26 axial slices (3 x 3 x 3 mm resolution, 0.75 mm spacing), parallel to the AC-PC plane and covering the whole brain were acquired using a single shot, gradient recalled EPI sequence (TR 2000 ms, TE 30 ms, 90° flip angle). One functional run with 900 time points was acquired, with each time point sampling over the 26 slices. Prior to the functional run, 26 anatomical T1-weighted MDEFT-images (Ugurbil et al., 1993; Norris, 2000) with the same spatial orientation as the functional data were acquired.

fMRI data analysis

The fMRI data were processed with LIPSIA software (Lohmann et al., 2001). This software package contains tools for preprocessing, registration, statistical evaluation and presentation of fMRI data.

Functional data were motion-corrected offline with the Siemens motion correction protocol (Siemens, Erlangen/Germany). To correct for the temporal offset between the slices acquired in one scan, a cubic-spline-interpolation was applied. A temporal highpass filter with a cut-off frequency of 1=120 Hz was used for baseline correction of the signal and a spatial Gaussian filter with 5.65 mm FWHM was applied.

To align the functional dataslices onto a 3D stereotactic coordinate reference system, a rigid linear registration with six degrees of freedom (3 rotational, 3 translational) was performed. The rotational and translational parameters were acquired on the basis of the MDEFT slices to achieve an optimal match between these slices and the individual 3D reference data set. This 3D reference data set had been acquired for each subject during a previous scanning session. The 3D reference data set with 160 slices and 1mm slice thickness was standardized to the Talairach stereotactic space (Talairach & Tournoux, 1988). The obtained rotational and translational parameters were normalized, i.e., transformed by linear scaling to a standard size. The resulting parameters were then used to transform the functional slices using trilinear interpolation, so that the resulting functional slices were aligned with the stereotactic coordinate system. Subsequently, a non-linear normalization was performed (Thirion, 1998). This step improved the spatial alignment of the individual neuroanatomy onto the neuroanatomy of a reference brain.

The statistical evaluation was based on a least-squares estimation using the general linear model for serially autocorrelated observations (see also Friston et al., 1995; Worsley & Friston, 1995; Aguirre et al., 1997; Zarahn et al., 1997). The design matrix was generated with a box-car function, convolved with a hemodynamic response function (HRF; gamma density function, Glover, 1999). The model equation, including the observation data, the design matrix and the error term, was convolved with a Gaussian kernel of dispersion of 4 sec FWHM to account for the temporal autocorrelation (Worsley & Friston, 1995). In the following, beta-values were estimated for different contrast for each voxel. As the individual functional datasets were all aligned to the same stereotactic reference space, the resulting single-participant contrast-images were then entered into a second-level random effects analysis for the relevant contrasts. The group analysis consisted of a one-sample t-test across the contrast images of all subjects that indicated whether observed differences were significantly distinct from zero (Holmes & Friston, 1998). Subsequently, t values were transformed into Z scores. Images were thresholded at $z > 3.09$ ($p < .001$, uncorrected). Moreover, a region was considered significant only if it contained a cluster of 10 or more continuous voxels in case of the contrasts of the LMs, respectively 19 or more continuous voxels in the main contrast (cartoons vs. INC) (Forman et al., 1995; Braver & Bongiolatti, 2002).

RESULTS

Behavioral data

Table 1 reports the means and standard deviations from recognition time, comprehensibility response and funniness ratings.

Table 1: Means and standard deviations for recognition time (in seconds), comprehensibility (0 = not understood, 1 = understood) and funniness ratings (from 0 = not funny at all, to 6 = very funny).

		Response	
	Recognition Time	**Comprehensibility**	**Funniness**
	M (SD)	***M (SD)***	***M (SD)***
Stimuli conditions			
BAS	1.36 (.52)	.50 (.02)	-
INC	4.62 (.90)	.24 (.17)	-
PUN	3.81 (.72)	.84 (.14)	2.37 (.15)
SEM	4.10 (.83)	.85 (.11)	2.88 (.19)
TOM	4.22 (.77)	.85 (.09)	2.95 (.14)

Recognition time: A repeated measure analysis revealed significant differences between the four stimuli conditions INC, PUN, SEM and TOM (Mauchly's W .216, $\chi^2(5) = 22.537$, $p < .001$; Greenhouse Geisser ($F(1.562, 24.995) = 14.165$, $p < .001$). Bonferroni-corrected single comparisons yielded that INC differed from PUN ($p < .01$), but not from SEM ($p = .053$) and TOM ($p = .109$). PUN was processed significantly faster than SEM ($p < .05$) and than TOM ($p < .001$), whereas there was no difference between SEM and TOM ($p = .450$).

Comprehensibility response: A repeated measure analysis was conducted to investigate the comprehensibility response in dependence of the humor conditions (PUN, SEM and TOM) and the control conditions (BAS and INC) and yielded a significant main effect ($F(3, 48) = 159.755$, $p < .001$). Bonferroni-corrected single comparisons yielded no differences between the humor conditions PUN vs. SEM, SEM vs. TOM and PUN vs. TOM, but INC, as well as BAS differed significantly from all other conditions (for all comparisons $p < .001$), in the sense that they were less well understood.

Funniness: A repeated measure analysis was conducted to investigate funniness ratings in dependence of the three humor conditions ($F(2, 32) = 9.201$, $p < .01$). Bonferroni-corrected single comparisons yielded significant differences for PUN vs. SEM ($p < .05$), PUN vs. TOM ($p < .01$), but not for SEM vs. TOM ($p = 1.000$). As the cognitive processing of humorous cartoons stands in the main focus of our study, we won't report affective neuronal correlates in this article. However, in order to segregate affective from cognitive processing, post-scan ratings of funniness will be analyzed in order to replicate some findings by, e.g., Goel and Dolan (2001) or Moran et al. (2004) and will be reported elsewhere.

To summarize, the behavioral data showed that INCs were processed significantly faster than all three stimuli conditions, as well as PUNs faster than SEM and TOM cartoons. INC and BAS differed significantly from all three stimuli conditions regarding comprehensibility as well as funniness, which was expected. Although the funniest PUNs were selected for the main investigation, they were perceived to be less funny than SEM and TOM cartoons. See the discussion section for possible reasons.

<u>Imaging results</u>

Incongruity resolution vs. irresolvable incongruity

In order to isolate brain structures that are only involved in successful humor processing (incongruity resolution), we contrasted the three humor conditions from the condition that contains an irresolvable incongruity. Figure 2 shows the resulting activation maps for cartoons vs. INC, and Table 2 reports the coordinates, volumes, maximum z-values and Brodman areas (BA) from the group-averaged data.

Table 2: Main activations CARTOONS vs. INC; Brodman areas, Talairach coordinates, volume and Z-maximum of the main activated regions.

AREA	**BA**	**Talairach coordinates**	
		x y z	Volume (Z-max)
Cartoons			
L ventromedian prefrontal cortex (vmPFC)	32	-8 29 -6	1134 (3.69)
L inferior frontal gyrus (IFG)	44	-50 5 18	1080 (4.79)
L inferior frontal gyrus pars orbitalis (IFGo)	10/46	-47 38 18	2268 (4.52)
L temporo-parietal junction (TPJ)	22/39	-59 -55 9	23220 (5.54)
R temporo-parietal junction (TPJ)	22/39	43 -58 18	10962 (5.46)
L supramarginal gyrus	40	-65 -31 36	3348 (4.48)
R supramarginal gyrus	40	61 -28 33	1377 (4.15)
INC			
R anterior middle frontal gyrus (aMFG)	10	31 56 6	1107 (-4.08)
R anterior middle frontal gyrus (aMFG)	9	25 38 27	2133 (-3.86)
R rostral cingulate zone (RCZ)	8/32	7 14 42	1647 (-4.00)
L postcentral gyrus	2/5	-47 -22 54	540 (-3.42)
L posterior cingulate cortex (pCC)	23	-5 -37 24	5616 (-5.43)
L precuneus	7	-8 -76 42	7587 (-4.65)
L collateral sulcus	19/18	-26 -76 9	2808 (-4.19)
R extrastriate cortex	19/18	25 -70 3	3537 (-4.75)
R anterior insula	-	28 17 9	918 (-3.47)
L cerebellum	-	-35 -61 -27	1782 (-3.86)

Note. The volume is reported in mm^3 and z-values were thresholded at $z < 3.09$. Reported clusters contain at least 19 ($513mm^3$) continuous voxels.

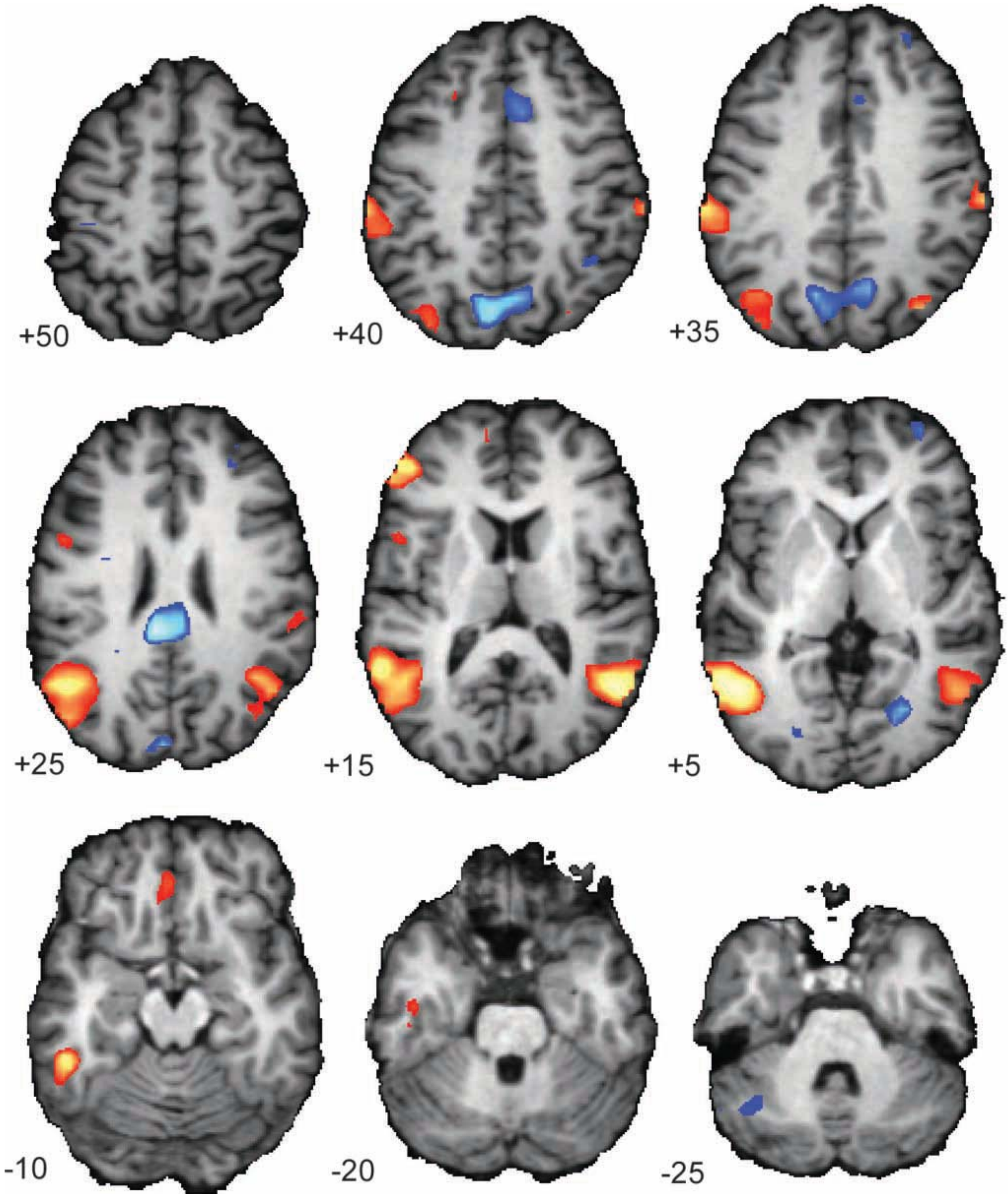

Figure 2. Contrast: Incongruity-resolution (funny cartoons) vs. irresolvable incongruity (INC). Significant regions of activation are projected onto the cortical surface of an average brain, obtained by nonlinear transformation of the participants' individual anatomies. Axial views are shown. All maps are thresholded at z<3.09 (p<.001, uncorrected).

This comparison revealed significant activations for incongruity resolution on the left lateral side in the IFG, orbital part of the IFG and bilaterally (but more pronounced in the left side) in the TPJ (which involves the pMTG and posterior superior temporal sulcus, pSTS) and the supramarginal gyrus. That these areas are involved in incongruity resolution is strengthened through the circumstance that only cartoons that were understood entered the analysis. Likewise, the INC in which the subjects believed to have found a punch line were excluded for the analysis. Further, there was an activation in the vmPFC, which might be involved in the affective part of humor processing (cf. Goel & Dolan, 2001). In contrast, activations involved in the processing of pictures containing an irresolvable incongruity (INC) can be found in the left postcentral gyrus, precuneus, posterior cingulate cortex (pCC), collateral sulcus and left cerebellum. As well as in the rostral cingulate zone (RCZ) and on the right side, activations in the anterior MFG, extrastriate cortex and the anterior insula can be associated with processing of INCs. It is striking that the left frontal cortex is involved in successful humor processing, whereas the INC condition evoked activation only in the right frontal cortex.

SEM vs. PUN

In order to analyze which areas are involved in the different LMs, the PUN condition was contrasted with the SEM condition, which is defined to contain several semantic LMs that are not based on visual elements (as in PUNs). Figure 3 shows the resulting activation maps for PUN vs. SEM and Table 3 reports the coordinates, volumes, maximum z-values and BAs from the group-averaged data. The extrastriate cortex is more involved in PUNs than in SEMs, probably due to the fact that visual elements play a greater role in PUNs. Activations found only in the SEM condition were in the left precuneus, TPJ bilaterally, aSTS bilaterally, as well as the left cerebellum. This implies that the TPJ is much more involved in processing of SEM cartoons.

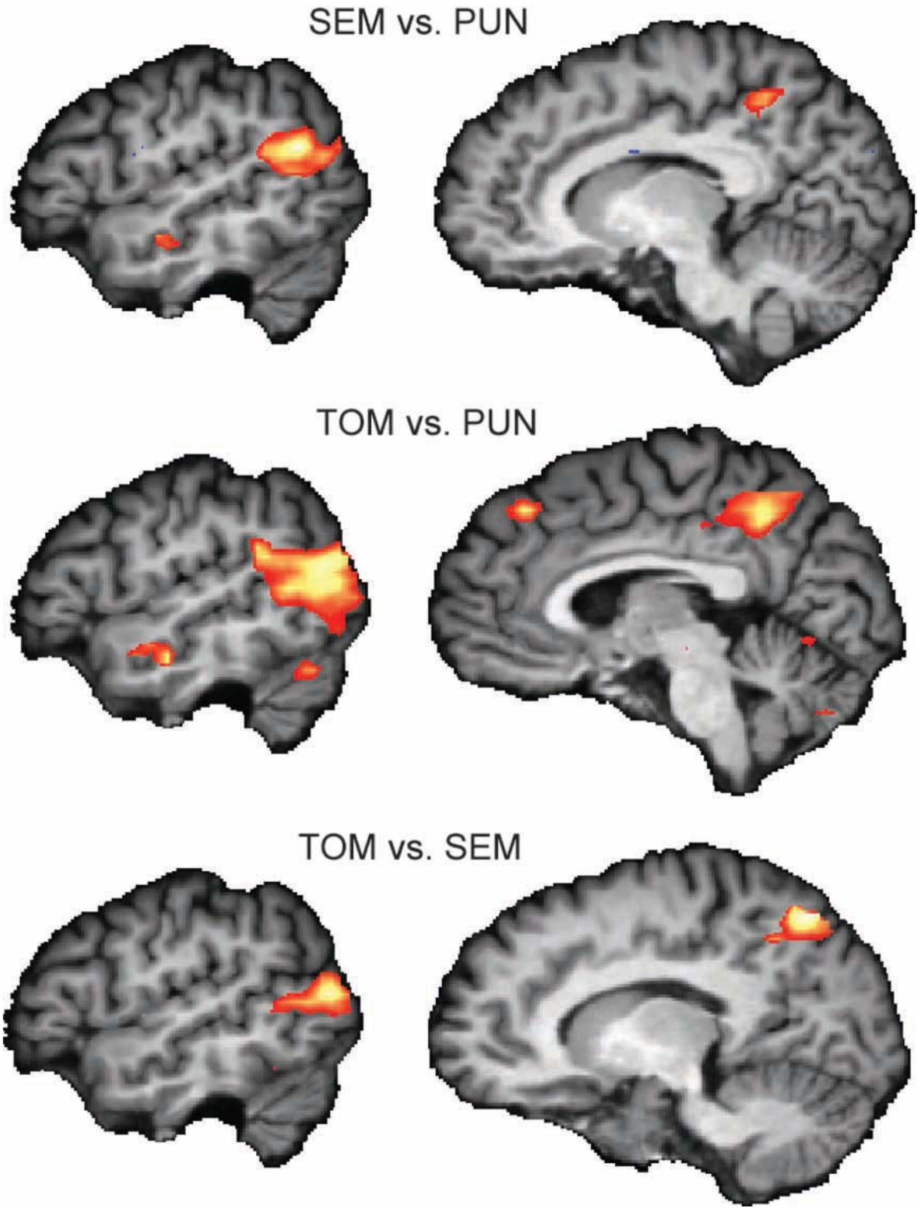

Figure 3. Significant regions of activation are projected onto the cortical surface of an average brain, obtained by nonlinear transformation of the participants' individual anatomies. In all three panels, sagital views of the left lateral and medial cortices are shown. A) SEM vs. PUN, B) TOM vs. PUN, C) TOM vs. SEM. Slices for all lateral views through -50; slices in A medial -11, B medial +4, C medial +12. All maps are thresholded at z > 3.09 (p < .001, uncorrected).

Table 3: Main activations SEM vs. PUN; Brodman areas, Talairach coordinates, volume and Z-maximum of the main activated regions.

AREA	**BA**	**Talairach coordinates**	
		x y z	Volume (Z-max)
SEM			
L precuneus	7	-11 -52 48	1755 (3.76)
L temporo-parietal junction (TPJ)	39	-50 -61 24	6372 (5.05)
R temporo-parietal junction (TPJ)	39	43 -49 24	6696 (5.03)
L anterior superior temporal sulcus (aSTS)	22	-56 -10 -12	918 (4.25)
R anterior superior temporal sulcus (aSTS)	22	46 -22 -6	459 (4.31)
L cerebellum	-	-26 -85 -24	1323 (4.76)
PUN			
R extrastriate cortex	19	-2 -88 36	405 (-4.09)

Notes: The volume is reported in mm^3 and z-values were thresholded at $z < 3.09$. Reported clusters contain at least 10 ($270mm^3$) continuous voxels.

TOM vs. PUN

In order to highlight activations evoked through cartoons in which it is necessary to attribute mental states to portrayed characters in order to get the punch line, TOM was contrasted with PUN. Figure 3 shows the resulting activation maps for TOM vs. PUN and Table 4 reports the coordinates, volumes, maximum z values and BAs from the group-averaged data. The following areas are involved particularly in TOM cartoons: right amPFC, right inferior frontal sulcus (SFS), left MFG and left superior frontal gyrus (SFG), precuneus, TPJ (extending to the extrastriate cortex and pMTG) bilaterally, right anterior lingual and fusiform gyrus as well as left aSTS. Processing of PUNs revealed activation in the left Ncl. caudatus. Interestingly, the right hemisphere is more strongly involved specifically for the TOM condition, compared to the activation maps in the contrast SEM vs. PUN.

Table 4: Main activations TOM vs. PUN; Brodman areas, Talairach coordinates, volume and Z-maximum of the main activated regions.

AREA	**BA**	**Talairach coordinates**	
		x y z	Volume (Z-max)
TOM			
R anterior medial prefrontal cortex (amPFC)	9	4 35 45	6966 (4.86)
R inferior frontal sulcus (IFS)	46	31 23 24	621 (4.22)
L middle frontal gyrus (MFG)	9	-35 29 39	270 (3.24)
L superior frontal gyrus (SFG)	8/9	-17 11 48	1134 (3.86)
R precuneus	31	7 -52 42	12744 (5.11)
L temporo-parietal junction (TPJ)	39	-38 -82 36	44307 (5.98)
R temporo-parietal junction (TPJ)	39	31 -76 33	30699 (6.44)
R fusiform gyrus	37	34 -58 -9	4509 (4.91)
R anterior lingual gyrus	19/37	16 -61 -3	1377 (3.56)
R temporal pole	38	37 14 -24	486 (3.51)
L anterior superior temporal sulcus (aSTS)	22	-50 -13 -15	1107 (4.75)
PUN			
L Ncl. caudatus	-	-11 14 15	270 (-4.02)

Notes: The volume is reported in mm^3 and z-values were thresholded at $z < 3.09$. Reported clusters contain at least 10 ($270mm^3$) continuous voxels.

TOM vs. SEM

The contrast TOM vs. SEM revealed no specific activation for SEM. TOM cartoons evoked activity in the bilateral precuneus, extending into the superior parietal lobe bilaterally and in the right TPJ, left TPJ (extending to the extrastriate cortex), activations in the right and left fusiform gyri and in the left cerebellum. There seems to be no qualitative difference between TOM and SEM, because there is no activation specifically for SEM. Figure 3 shows the resulting activation maps for TOM vs. SEM, and Table 5 reports the coordinates, volumes, maximum z-values and BAs from the group averaged data.

Table 5: Main activations TOM vs. SEM; Brodman areas, Talairach coordinates, volume and Z-maximum of the main activated regions.

AREA	**BA**	**Talairach coordinates**	
		x y z	Volume (Z-max)
TOM			
L precuneus, superior parietal lobe	7	-17 -67 48	1134 (3.87)
R precuneus, superior parietal lobe, TPJ	7	10 -70 51	12366 (5.23)
L temporo-parietal junction (TPJ)	39	-47 -76 15	11205 (4.92)
R fusiform gyrus	37	40 -58 -6	1728 (3.82)
L fusiform gyrus	37	-38 -46 -15	729 (3.76)
L cerebellum	-	-29 -82 -15	297 (3.65)
L cerebellum	-	-11 -79 -30	405 (3.85)

Notes: The volume is reported in mm^3 and z-values were thresholded at $z < 3.09$. Reported clusters contain at least 10 ($270mm^3$) continuous voxels.

To summarize, the contrast of funny cartoons vs. the baseline condition consisting of pictures containing an irresolvable incongruity, revealed activations in the IFG, TPJ and supramarginal gyrus bilaterally (but more pronounced in the left side), as well as in the vmPFC. Among others, activation in the RCZ can be associated with processing of irresolvable incongruity. Further, the results reveal differences in processing of cartoons with different LMs: PUNs evoke more activation in the extrastriate cortex, whereas SEM cartoons show more activation in the precuneus, TPJ, aSTS bilaterally and cerebellum. TOM cartoons reveal more activation in the amPFC, and other prefrontal areas, precuneus, TPJ and aSTS (in contrast to PUNs) as well as more activity in the precuneus, TPJ and fusiform gyri (in contrast to SEMs).

Discussion

This study revealed discrete characteristic patterns of cerebral blood-oxygen-level dependent (BOLD) activity induced by cartoons with different logical mechanisms in comparison to pictures that contain an irresolvable incongruity. Whereas the IFG could be confirmed to be involved in incongruity resolution (e.g., Goel & Dolan, 2001; Watson et al., 2006), we showed that the TPJ is involved in successful incongruity resolution and not in the detection of incongruity (e.g., Mobbs et al., 2003; Moran et al., 2004). Activity in the vmPFC reflects probably the affective response in humor processing, as in the studies by Goel and Dolan

(2001) or Sieboerger et al. (2004). During the attempt to understand cartoons that don't contain a resolvable incongruity, there was activity in the RCZ, which is known to be activated during error processing (e.g., Ullsperger & von Cramon, 2001). The extrastriate cortex is activated particularly during processing of PUNs, whereas SEM cartoons evoked activity mainly in the TPJ, aSTS and precuneus. The TPJ bilaterally, amPFC as well as the precuneus—areas known to be involved in mentalizing—are more strongly activated during processing of TOM cartoons compared to PUNs, as well as to SEM cartoons.

Incongruity resolution vs. irresolvable incongruity

Our results revealed that incongruity detection and successful incongruity resolution are different processes requiring distinct areas. We were able to clarify the humor-associated role of the activity in the TPJ. In contrast to Mobbs et al. (2003) and Moran et al. (2004), we claim that the TPJ is not involved in early stages of humor processing, as in bringing stored expectations online or the detection of incongruity. We have shown the involvement of the TPJ in successful incongruity resolution, as Wild et al. (2006) already assumed. Although the attempt to resolve the incongruity is surely present in the INC condition, this effort does not, however, lead to successful humor processing and activation of the TPJ. This area appears to play a key role in the integration of complex featural information or multisensory integration (see Calvert, 2001, for a review) with connections to the limbic system (Barnes & Pandya, 1992). The TPJ also processes semantic integration of complex visual stimuli. Marjoram et al. (2006) suggested that the TPJ, although known to be one of the mentalizing areas, is involved in humor appreciation. Our contrast of the funny cartoons vs. INC shows that the TPJ is related to successful incongruity resolution. We suggest that this activation doesn't reflect amusement per se—which might be reflected rather in mesolimbic reward areas (see Mobbs et al., 2003) or vmPFC (e.g., Goel & Dolan, 2001)—but reflects the necessary cognitive component, i.e., successful incongruity resolution, of humor processing. Also, even with parametrical analysis of funniness ratings, other studies showed more activation in the TPJ the funnier a cartoon was perceived to be (e.g., Mobbs et al., 2003).

Increased activation in the left lateral PFC is also associated with humor processing (e.g., Goel & Dolan, 2001; Mobbs et al., 2003; Moran et al., 2004; Ozawa et al., 2000; Wild et al., 2006) and is interpreted as reflecting the incongruity resolution process. We were able to confirm that the IFG, known to be involved in language and semantic processing, is involved in incongruity resolution. The data reveal that a left-sided network is involved in successful humor processing (i.e., the resolution of incongruity), which is in agreement with previous fMRI studies with healthy subjects. In particular, the left PFC seems to be essential, although some earlier lesion studies claimed that the right PFC might be involved in humor processing (e.g., Shammi & Stuss, 1999; see Wild, Rhodden, Grodd, & Ruch, 2003, for a review). The more left-sided network is probably due to the fact that nonverbal pictures have to be verbalized during processing and that the same semiotic processes underlie humor processing independent of the presentation of verbal or visual material. Wild et al. (2006) also found more areas activated in the left hemisphere in processing of nonverbal cartoons. Particularly, it is striking that the left PFC is involved in incongruity resolution, whereas the right PFC seems to be involved in the processing of INC.

The RCZ is involved in unsuccessful humor processing or the processing of pictures containing an irresolvable incongruity: This activation might reflect conflict monitoring as described in several studies (see Botvinick, Cohen, & Carter, 2004, for a review) or increasing uncertainty (Volz, Schubotz, & von Cramon, 2003). Activation near our peak is associated with error detection or response competition (Ullsperger & von Cramon, 2001). Therefore, we assume that this activation reflects the conflict in which the several activated scripts are perceived as soon as the new information can't be integrated into the first script anymore, and the script opposition is detected. This might also explain why subjects need more time to process the INC condition: It might reflect cognitive effort required to decide definitively that there is no joke in the picture, or that they didn't understand the joke. Until they make this decision, they are uncertain whether they missed the punch line. An additional explanation for this activation is also drive or motivation: Subjects have to continuously generate new hypotheses as to how the picture could be interpreted as a funny stimulus.

Differences in logical mechanisms

Our results reveal that there are crucial differences for the processing of different LMs or LM groups. Contrasting PUN from SEM, it is striking that there is more activation in the extrastriate cortex in PUNs. The visual element in PUNs evokes two scripts that stand ambiguously and simultaneously next to each other. Activation in the extrastriate cortex might be interpreted as the play with two meanings evoked by one visual element or associated with visual picture play. Further, this activation might be interpreted as reflecting visual adjustment processes for the processing of PUNs and that more visual cognition is involved in this LM. Also, Watson et al. (2006) found activation of higher order visual areas, associated with captioned cartoons in which the joke was based on elements portrayed in the picture and not contained in the caption. IFG activation in the study of Goel and Dolan (2001) was interpreted as being involved in the processing of sounds. Indeed, in our nonverbal paradigm there is no specific activation in the IFG for PUNs. Therefore, the IFG activation found by Goel and Dolan (2001) does not reflect specific activity for puns in general, but only for phonological puns.

Activations specific for SEM in contrast to PUNs are localized in the left precuneus, TPJ and aSTS bilaterally and left cerebellum. This corresponds mainly to the areas involved in incongruity resolution in general (cartoons contrasted with INC) and also replicates the results of Goel and Dolan (2001), who found more activation in the TPJ associated with semantic jokes.

Activity involved in PUN processing contrasted with TOM revealed a significant peak in the left nucleus caudatus. It is striking that in the TOM condition—compared to PUN, but also to SEM—mainly the TPJ bilaterally, precuneus and fusiform gyri are involved. TPJ is known to play a specific role in attribution of mental states of others and not only when reading stories about people in physical detail (Saxe & Kanwisher, 2003). We claim that the TPJ is generally involved in the resolution of incongruity, but more so, when mentalizing is required in order to get the joke. Ferstl and von Cramon (2002) found activation in the TPJ not only during the TOM task, but also in the coherence condition, in which no Theory of Mind or mentalizing abilities were required in order to process the task. Therefore, it is plausible that the TPJ is involved also in the SEM condition. Perner and Aichhorn (2006) showed that the left TPJ is not specific for mentalizing tasks but also shows activity in perspective taking in nonmentalizing tasks. This might be similar to incongruity resolution or to switching between the two activated scripts of the joke.

The amPFC is essential for self-referential mental activity (Gusnard, Abudak, Shulman, & Raichle, 2001; Macrae, Moran, Heatherton, Banfield, & Kelley, 2004; Zysset, Huber, Ferstl, & von Cramon, 2002). The mPFC is engaged when we attend to our own mental states as well as those of others (Frith & Frith, 1999; see Frith & Frith, 2003, for a review). Since we found activation in the amPFC associated with TOM (in contrast to SEM), we assume that self-referential processes are more relevant in TOM cartoons.

Mentalizing and humor processing

As often in Theory of Mind tasks, we showed activation in the TPJ, precuneus and amPFC. As they are not present in the PUN condition, we claim that mentalizing is not always necessary to process humor. This contradicts two humor models that postulated the requirement of mind reading in all humor processing (Howe, 2002; Jung, 2003). We argue against these assumptions, otherwise we should also have found typical mind-reading areas such as the TPJ, precuneus or amPFC in the PUN condition activated to the same amount as in TOMs. This leads to the assumption that in PUNs the essential humorous element is to recognize that one visual element is compatible with two different meanings. Therefore, the activation in PUNs (vs. SEM) could be interpreted to be caused through visual picture play and more visual cognition, similar to logical problem-solving tasks based on physical/visual causality, whereas for SEM and TOM it is necessary to build a situation model. Therefore, capabilities to attribute mental states are required, particularly in the TOM condition. Further, Marjoram and colleagues (2006) suggested that mentalizing abilities and humor appreciation are both aspects of social cognition and therefore might show overlapping activations.

From our results, it can be concluded that different LMs are processed differently—PUNs in particular differ from SEMs and TOMs. Whereas there is a qualitative difference between PUN and SEM (a different processing network), there seems to be a gradational relation between SEM and TOM (the same network). Therefore, we conclude that different LMs require different cognitive processes additionally to a general incongruity resolution process, and it is fruitful to distinguish between different LMs in humor processing, as the GTVH postulates (Attardo & Raskin, 1991).

Interestingly, SEM and TOM don’t differ regarding several rating scales for funniness, originality, complexity, etc. (Samson, 2005), while this study revealed differences in brain-activation patterns. This shows that it is fruitful to consider neuronal data in order to understand the nature of humor processing.

We suppose that the core element of humor is the resolution of an incongruity as described in several incongruity resolution or cognitive-linguistic theories (e.g., Attardo & Raskin, 1991; Suls, 1972), similar to a problem-solving process, whereas mind reading is an important factor that enhances funniness. In PUNs it is not necessary to construct a situation model, activate self-referential processes (e.g., Zysset et al., 2002) or mind-reading in order to get the joke. This might explain why PUNs are perceived to be less funny than SEM and

TOM. We argue that there is less emotional involvement. PUNs can be quite “technical” and their LMs are somehow abstract. PUNs are perceived to be less sophisticated or less profound, or perceived as symbolic play. In further studies it might be interesting to investigate in more detail the group of semantic cartoons that contain several LMs. Is it possible that the LM exaggeration is processed differently from LMs like juxtaposition, potency mappings, etc. (see Attardo et al., 2002)? Further, it would be interesting to compare nonverbal cartoons (particularly PUNs) to non-funny visual riddles or puzzle pictures, to clarify commonalities and differences of problem-solving and humor processing.

Furthermore, in order to better comprehend humor processing, it would be interesting to investigate whether the preference for certain LMs depends on personality traits similar to the fact that incongruity resolution and nonsense jokes depend on personality traits as, for example, conservativism (see, e.g., Ruch, 1998) or whether they score differently on other rating scales than funniness as other perceptual qualities of humor.

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11 Neural correlates of incongruity-resolution and nonsense humor in relation to experience seeking

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Abstract

By means of functional magnetic resonance imaging the present paper analyzes the neural correlates of processing and appreciating incongruity-resolution and nonsense cartoons. Furthermore, the relation between experience seeking and these neural substrates was investigated as this personality characteristic is known to influence humor appreciation. In the processing of incongruity-resolution stimuli the incongruity of the joke is largely resolvable, whereas in nonsense stimuli it is only partially resolvable and more incongruity remains. The anterior medial prefrontal cortex, bilateral superior frontal gyri and temporo-parietal junctions (TPJ) show more activation during processing of incongruity-resolution than of nonsense cartoons. These differences indicate that processing of incongruity-resolution cartoons requires more integration of multi-sensory information and coherence building, as well as more mental manipulation and organization of information. In addition, less self-reference might be established in nonsense cartoons as it is more absurd and more often deals with impossible situations. Higher experience-seeking scores correlate with increased activation in prefrontal, posterior temporal regions and the hippocampus. This might be due to a more intense exploration of the humorous stimuli as experience seekers tend to search novel mental stimulation. Furthermore, experience seeking was positively associated with brain reactivity towards processing nonsense in contrast to incongruity-resolution stimuli, which is in line with behavioral studies that showed a preference for nonsense humor by experience seekers.

Introduction

Laughter-related phenomena, such as humor, emerged probably through non-serious incongruity which is assumed to have been an indicator of social play and safety in early bipedal life (see Davila Ross, 2007; Gervais &Wilson, 2005). The relaxed openmouth or "play" face is revealed in numerous other primate species (Preuschoft & van Hooff, 1997) which, if one accepts recapitulationist reasoning, leads to the idea that it served as a rudimentary precursor to human laughter. Humor as a universal human phenomenon encompasses numerous functions, such as an effective coping mechanism in the struggle with difficult situations throughout life but also as a useful communication tool in social situations. The latter is particularly successful if the communicating subjects are able to laugh about the same style of humor, as well as humorous contents. Laughter is one of the observable behaviors that accompany the humor process which consists of the cognitive processing of a stimulus and, usually, appreciation. Experiencing humor is understood here as amore cognitively sophisticated ability, involving the processing of incongruity with meaningful resolution. The present study investigates humor processing in relation to the resolvability of incongruity as a stimulus characteristic and in relation to experience seeking, as this personality characteristic is known to influence humor processing.

While intuitive and theoretical taxonomies typically distinguish content classes of humor, Ruch and colleagues (e.g., Ruch, 1992; Ruch & Hehl, 2007) used factorial analysis to show that structural aspects of humorous stimuli are at least as important as their content. In their studies, two factors that differ regarding structural characteristics consistently emerged: humor appreciation of incongruity-resolution and of nonsense jokes and cartoons (see below). Jokes and cartoons within each of these two groups may have different content (themes, targets) but are similar with respect to their structural properties and—presumably—in the way they are processed. Incongruity-resolution and nonsense stimuli (e.g., jokes and cartoons) put different loads on of different cognitive capacities which even influence the preference of one over the other depending on personality characteristics (see Ruch & Hehl, 2007). Thus, it is likely that the differentiation between stimuli that require incongruity-resolution and nonsense processing—which differ mainly regarding the resolvability of the incongruity—has an influence on the neural substrate of humor processing. The influences of these two types of humor stimuli as well as the influence of personality characteristics are investigated in the present fMRI experiment.

Most cognitive humor theories claim that humorous stimuli are processed in steps, although they do not agree about the nature and number of these steps (Attardo, 1997; Coulson & Kutas, 2001; Shultz, 1976; Suls, 1972). But they all assume that the initial information activates stored expectations or a script. Further information leads to the detection of an incongruity, constituted by the relation of the first script to another. In order to understand the punch line of the joke (either verbal jokes or visual jokes, i.e., cartoons) the incongruity has to be at least partially resolved. According to Ruch and colleagues (e.g., Ruch, 1992; Ruch & Hehl, 2007) the resolvability of the incongruity is a structural characteristic of humorous stimuli that strongly influences the perceived funniness but also other reactions such as aversion. In fact, this characteristic explains more variance of the funniness ratings than the content of a joke. Thus, the authors showed that humorous stimuli can be categorized according to the resolvability of their incongruity: On the one extreme of a continuum, incongruity-resolution jokes contain an incongruity that is (almost) completely resolvable. The common element of these humorous stimuli is that in their processing the recipient first discovers an incongruity, which is then playfully resolvable upon reinterpretation of the information available in the joke or cartoon. Fig. 1A is an example of an incongruity-resolution cartoon: The incongruity lies in the circumstance that the patient does not know that the psychotherapist is exercising instead of listening carefully. The incongruity is resolved if the psychotherapeutic session is reinterpreted as so boring for the psychoanalyst that he engages in another activity. It is also a comment on the prejudiced assumption that psychotherapists merely pretend to be empathic. On the other end of the continuum are humorous stimuli based on nonsense, which also have a surprising or incongruous punch line. However, the punch line may provide no resolution at all, provide a very partial resolution (leaving an essential part of the incongruity unresolved), or actually create new absurdities or incongruities. Fig. 1B is a nonsense cartoon that we used in the present experiment: Two skiers are chased by a shark which seems to swim in the snow. The incongruity is only partially resolvable through the visual analogy of one visual element (the diagonal line) that designates a mountain in connection with the skiers and the sea with respect to the shark. It cannot be both, so this situation is actually impossible and has more residual incongruity than the incongruity-resolution example (in which the situation is unusual, but most likely possible). Several issues, such as why there is a shark on the slope, remain unanswered (residual incongruity).

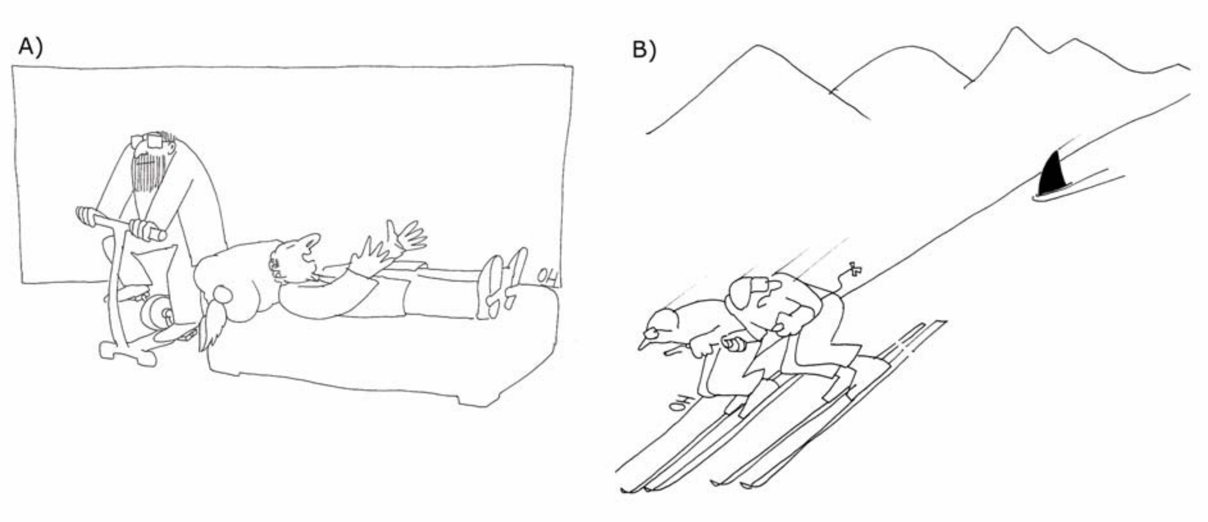

Figure 1: Stimulus examples for an incongruity-resolution cartoon (A) and for a nonsense cartoon (B). Cartoons by Oswald Huber.

The preference for incongruity-resolution or nonsense stimuli can be measured with the 3 WD ("3 Witz-Dimensionen") humor test (Ruch, 1992, 1995). Besides stimuli that require incongruity-resolution and nonsense processing, a third stimuli group consistently emerged as a factor in factorial analyses: those with sexual content (e.g., Ruch, 1992; Ruch & Hehl, 2007). As only formal or structural and not content-related aspects are of interest in this study, the preference for sexual content is not considered further[3].

As already mentioned, personality traits, such as openness, conservativism or intolerance of ambiguity, were shown to influence humor processing and appreciation (see, for example, Forabosco & Ruch, 1994; Ruch, 1988; Ruch, Accoce, Ott, & Bariaud, 1991; Ruch & Hehl, 2007). One of the personality characteristics that appears to influence humor appreciation is experience seeking, one of the subscales of the sensation seeking scale (Zuckerman, 1994).

[3] The stimuli presented in this study were not of sexual content either. Since it is known that humor with sexual content is perceived differently and personality characteristics influence how this type of humor is perceived, sexual cartoons were explicitly excluded already in the pre-examinations: ". . .[it was]. . .searched. . . for single-frame, nonverbal cartoons that intended to be primarily funny (not political) without sexual content, because the preference or dislike for sexual cartoons is known to correlate highly with certain personality characteristics. . ." (Samson et al., 2008, p. 129).

Experience seeking involves a search for novel sensations, stimulation and experiences through the mind and senses, through art, travel, music, and the desire to live in an unconventional style (see Ruch & Zuckerman, 2001). There is evidence that experience seeking is closely related to the novelty and complexity of stimuli (Zuckerman, 1984; see also Ruch, 1992; Ruch & Hehl, 2007). Experience seekers are characterized as having a high need for mental stimulation related to the pursuit of unfamiliar and complex environmental stimuli. Biological and social factors shape sensation seeking (Zuckerman, 2006). People with higher scores in sensation seeking show a larger responsiveness of the brain to novel stimuli, coupled tomuch faster habituation of brain responses on repeated stimulation. The volume of the right hippocampus (and a tendency on the left side) was shown to correlate with experience seeking, which is suggested to play a central role for processing of novel stimuli (Martin et al., 2007). It is suggested that the hippocampus compares incoming information with stored memories in order to index if a stimulus or information is novel (e.g., Lisman & Grace, 2005, see Nyberg, 2005).

Humorous stimuli can be seen as complex stimuli, since novelty has to be processed in the way that an incongruity has to be detected and playfully resolved (e.g., Suls, 1972; Shultz, 1976). Individuals with higher scores in experience seeking were found to search for more situations that make them laugh and might even explore humorous stimuli more intensely (Deckers & Ruch, 1992) and were reported to perceive a variety of situations s being funnier and to display more overt expression to humor (Lourey & McLachlan, 2003). Some studies showed that high experience seekers prefer nonsense humorous stimuli, whereas for low experience seekers the pattern was reversed. Experience-seeking scores correlated positively with appreciation of nonsense stimuli and negatively with appreciation of incongruity-resolution (e.g., Ruch, 1988; Forabosco & Ruch, 1994).

Previous fMRI studies showed several neuronal structures that are part of the network which is involved in humor processing: areas in the temporal lobe (e.g., temporal pole, anterior superior temporal sulcus, aSTS, e.g., Mobbs, Greicius, Abdel-Azim, Menon, & Reiss, 2003; Mobbs, Hagan, Azim, Menon, & Reiss, 2005; Moran, Wig, Adams, Janata, & Kelley, 2004; Wild et al., 2006) were associated with earlier steps of humor processing, such as the set-up of the joke for bringing stored expectations online. The following areas are substantially involved in cognitive humor processing, i.e., the comprehension process or incongruity-resolution, and are of particular interest in this study: the inferior frontal gyrus (IFG; see Bartolo, Benuzzi, Nocetti, Baraldi, & Nichelli, 2006; Goel & Dolan, 2001; Mobbs et al., 2003; Wild et al., 2006) and the temporal parietal junction (TPJ, e.g., Samson, Zysset, & Huber, 2008; Wild et al., 2006). The role of prefrontal areas is not yet clear, as they showed activation only in some of the existing studies (e.g., Wild et al., 2006). The ventromedial prefrontal cortex (vmPFC) as well as subcortical areas, i.e., the nucleus accumbens, were associated with humor appreciation, i.e., the affective aspect of humor processing (e.g., Goel & Dolan, 2001, 2007).

Despite the growing number of fMRI studies on neural correlates of humor processing only a small number of them took formal or structural aspects of the humorous stimuli into account: Goel and Dolan (2001) showed that the processing of phonological puns and semantic jokes evoked different brain activation patterns. In another study, Watson, Matthews, and Allman (2006) used verbal and visual material to show that humor processing is dependent on these modalities. Samson et al. (2008) demonstrated that different logical mechanisms are processed differently. The logical mechanism is the cognitive rule which determines how the incongruity of the joke has to be resolved in order to understand the punch line (e.g., one has to recognize that the punch line is based on role exchange; Attardo, Hempelmann, & DiMaio, 2002; Attardo & Raskin, 1991). In their study, the processing of three types of jokes differed according to their logical mechanisms—visual puns, semantic cartoons and Theory ofMind cartoons—and evoked different activation patterns. For example, visual puns provoked increased activation of the extrastriate cortex and Theory of Mind cartoons lead to increased activation of so-called mentalizing areas such as the anterior medial prefrontal cortex (amPFC) and the TPJ. Semantic cartoons did not differ from the network known to be involved in the incongruity-resolution process (i.e., IFG and TPJ). Other studies also showed differences in the processing of Theory of Mind cartoons vs. cartoons for which it is not necessary to attribute mental states to joke characters in order to get the joke (Gallagher et al., 2000; Marjoram et al., 2006).

Up to now, only one brain imaging study investigated personality differences in humor processing: Mobbs et al. (2005) found the right orbital frontal cortex, the ventro lateral prefrontal cortex and bilateral temporal cortices to correlate with extraversion, whereas introversion correlated with several regions, particularly with the amygdala. Emotional stability (i.e., the inverse of neuroticism) correlated with increased activation in the mesocortical–mesolimbic reward circuitry, whereas a humor questionnaire was not associated with an increase or decrease in brain activation. Extraversion was shown to be associated with positive emotional experience (e.g., Costa & McCrae, 1980, 1991) and Canli et al. (2001; see also Canli, 2006) showed greater brain reactivity of extraverts to positive stimuli.

The aim of the present study is twofold. First, it focuses on the resolvability of the incongruity in non-verbal cartoons as a structural characteristic that influences cognitive components of humor processing that, in turn, might lead to different neuronal activation patterns. It contrasts the two assumed extremes on this dimension of resolvability: incongruity-resolution and nonsense stimuli. In a recently published study, Samson et al. (2008) showed that humorous cartoons activated the vmPFC, the left IFG, TPJ and supramarginal gyrus bilaterally. Because the latter three regions in particular are involved in the incongruity-resolution process, we assumed to find differences in their activation for incongruity-resolution and nonsense jokes. In particular, we expected to find these areas to be more strongly activated in the processing of incongruity-resolution stimuli because more incongruity-resolution is possible, i.e., more sense can be made and more explanation and integration of information is feasible. We assume, on the other hand, that as a result of processing of nonsense humor stimuli people laugh about the absurdity of the two (almost) incompatible scripts rather than about the result of a playful and successful incongruity-resolution process.

The second aim of this study is to investigate the influence of individual experience-seeking scores on humor processing in general (i.e., humorous stimuli vs. non-funny pictures containing an irresolvable incongruity). Humorous stimuli can be meaningfully investigated in relation to the neural response and individual experience-seeking scores because they can be seen as complex stimuli containing novel elements (such as the incongruity) which might be more attractive to explore for high experience seekers. As extraversion was shown to be associated with increased brain activation in humor processing (Mobbs et al., 2005) and extraversion (particularly the subscale excitement-seeking) is known to correlate with experience seeking (e.g., Aluja, García, & García, 2003) we expect increased brain activations in individuals with higher experience-seeking scores. Furthermore, the experience-seeking scores shall be analyzed in relation to the neural correlates of the processing of nonsense vs. incongruity-resolution cartoons, as experience seekers were shown to prefer humorous stimuli based on nonsense over stimuli based on incongruity-resolution (e.g., Forabosco & Ruch, 1994). The question here is whether experience seekers demonstrate a different pattern of activation for types of humor that they usually prefer or dislike. Finally, the preference for incongruity-resolution or nonsense humorous stimuli was measured with the 3 WD (Ruch, 1992, 1995). Whether the preference for one over the other type of humor influences the neural response during humor processing will be analyzed as well.

Method

Subjects

Seventeen neurologically healthy and right-handed subjects (nine female, eight male, mean age 26.06, years, S.D. = 3.25) participated in this study. Written informed consent from all subjects was obtained prior to the scanning session. All subjects had normal or corrected-to-normal vision and were native German speakers. None of the subjects was on medication at the time of the study. Subjects were instructed prior to the actual experimental session. Once they felt comfortable with the task, subjects were positioned supine in the scanner.

Stimuli

The data reported in this paper originate from the same experiment as reported in Samson et al. (2008). For the first analysis of incongruity-resolution and nonsense humorous stimuli, only a part of the 90 presented humorous stimuli were considered (see below). For the influence of personality characteristics on humor processing, humorous cartoons with varying degrees of resolvability were first contrasted to a non-funny control condition (INC, these cartoon-like pictures contained irresolvable incongruities), then, nonsense cartoons were contrasted to incongruity-resolution cartoons. For a more detailed account of stimuli and design, see Samson et al. (2008).

In the study by Samson et al. (2008), three different types of cartoons that differ regarding their logical mechanism were presented. As these three types showed differences in brain activation, it was important for the present analysis to have them equally distributed over incongruity-resolution and nonsense humorous stimuli. In order to categorize the 90 cartoons into the groups of incongruity-resolution and nonsense stimuli, they were rated by 19 subjects (10 male, 9 female, mean age 26.89, S.D. = 5.12) for grotesqueness, subtleness and residual incongruity, as these ratings differentiated between incongruity-resolution and nonsense humorous stimuli: nonsense jokes, for example, are perceived to be more grotesque and subtle (Samson & Ruch, 2005) and evoking more residual incongruity (Hempelmann & Ruch, 2005).

A 2 means cluster analysis (with max. 10 iterations) for the 90 cartoons used in the fMRI experiment revealed two clusters with N= 32 and N= 58 cartoons. The final cluster centers are for grotesque (cluster1: 3.30; cluster2: 2.74; $F(1, 88) = 25.322$, $p < .001$), for subtleness (cluster1: 1.80; cluster2: 2.41; $F(1, 88) = 30.137$, $p < .001$) and for residual incongruity (cluster1: 1.92; cluster2: .90; $F(1, 88)= 107.557$, $p < .001$).

Because nonsense humorous stimuli are known to have low values in subtleness and high values on grotesqueness and residual incongruity, cluster1 can be described as nonsense stimuli (N= 32), whereas cluster2 can be described as incongruity-resolution stimuli (N= 58). The results from the cluster analysis were verified with a canonical discriminant analysis. The canonical discriminant function yielded an Eigenvalue of 1.984, a canonical correlation of .815, Wilks' Lambda .335, $\chi^2(3) = 94.580$, $p < .001$. Only one cartoon was not correctly classified and was excluded for further analyses.

In a next step 30 cartoons for each condition were selected (see Fig. 1 for examples): With the aim not to confound the groups of incongruity-resolution and nonsense stimuli and the three types of logical mechanisms (visual puns, semantic cartoons, Theory of Mind cartoons), the three logical mechanisms were to be equally distributed among the two groups of incongruity-resolution and nonsense humor. For this, first, the number of cartoons per group was determined. As there were only seven semantic and seven Theory of Mind cartoons in the group of nonsense humorous stimuli, all of these had to be selected. Therefore, approximately the same number of semantic cartoons and Theory of Mind cartoons, respectively, which were categorized to be incongruity-resolution had to be randomly selected for this group.

The visual puns were selected according to high grotesqueness and low subtleness ratings, as well as high residual incongruity ratings for the nonsense group. The criteria were reversed for the incongruity-resolution group. Finally, the nonsense group consisted of 15 visual puns, 8 semantic cartoons and 7 Theory of Mind cartoons. The incongruity-resolution group consisted of 13 visual puns, 9 semantic cartoons and 8 Theory of mind cartoons. Thus, the logical mechanisms were equally distributed over incongruity-resolution and nonsense cartoons ($\chi^2(2) = .268$, $p = .874$).

Table 1 summarizes the ratings of grotesqueness, subtleness and residual incongruity for the selected incongruity-resolution and nonsense cartoons and shows that for all three ratings, the two stimuli groups differ significantly, as one-way ANOVAs revealed.

Table 1: Means and standard deviations of the ratings for the two stimuli groups (30 stimuli in each condition).

	Incongruity-resolution cartoons **Mean (S.D.)**	**Nonsense cartoons** **Mean (S.D.)**
Grotesqueness [a]	2.73 (.44)	3.25 (.52)
Subtleness	2.47 (.48)	1.92 (.51)
Residual incongruity	.98 (.43)	1.78 (.43)

Nonsense cartoons are perceived to be more grotesque, less subtle and having more residual incongruity.
a One-way ANOVAs yielded significant differences between the two stimuli conditions for grotesqueness ($F(1, 57) = 16.774$, $p < .001$), subtleness ($F(1, 57) = 15.141$, $p < .001$) and residual incongruity ($F(1, 57) = 51.167$, $p < .001$).

Personality measures

The *Sensation Seeking Scale* (Zuckerman, 1994) consists of four different subscales and a total score. Here, only the subscale experience seeking was of interest. Experience seeking is characterized by a search for novel sensations and experiences through the mind and senses, in several domains and the desire to live in an unconventional style.

The *3WD (“3Witz-Dimensionen”) humor test* (Ruch, 1992, 1995) was designed to assess appreciation of jokes and cartoons of the three humor categories that were labelled incongruity-resolution, nonsense, and sexual humor. They contain 50 jokes and cartoons, which are rated on funniness and aversiveness using two 7-point scales. Here, only the funniness ratings of incongruity-resolution (INC-RES) or nonsense (NON) humorous stimuliwere of interest, aswell as the relative preference for humorous stimuli based on nonsense over incongruity-resolution, i.e., the Structure Preference Index (SPI; obtained by subtracting INC-RES from NON).

Task paradigms

By pressing a button the participants had to indicate whether they understood the joke in the cartoon or not, while recognition time was measured. This procedure allowed for the distinction between cartoons that were understood but not considered funny and cartoons that were not understood and therefore not funny. Cartoons that were not understood were excluded from further analysis. Comprehensibility responses were given via a button press with either the index (understood) or middle (not understood) finger of the right hand.

The cartoons and pictures were presented for 6 s. The pictures were presented on a black screen (880×600 pixels), whereas the longer side of the picture had a maximum length of 500 pixels. For the stimulation of the visual cortex and the motor response, the baseline condition (BAS) was presented. In this condition, there were horizontal arrows in the right or left direction to indicate that the subjects need not search for a punch line but had to press the right or left button. All conditions were presented in random order to prevent subjects from developing response tendencies. All subjects processed a total of 180 trials (90 humorous stimuli, 30 control pictures containing irresolvable incongruities, 30 BAS and 30 null-events were presented). Trials were presented every 10 s on average and with variable stimulus onset delays (0, 400, 800, 1200 or 1600 ms). The experiment lasted a total of 30 min. Stimuli were projected with an LCD-Projector onto a translucent screen behind the subject's head. The screen was viewed with mirror lenses attached to the head coil. If necessary, corrective lenses were mounted.

After the scanning procedure subjects were asked to rate the funniness of the humorous stimuli on a scale from 0 = not funny at all to 6 = very funny. Furthermore, the participants were asked to fill in the Sensation Seeking Scale (Zuckerman, 1994) and the 3WD (Ruch, 1992).

MRI scanning procedure

The experiment was carried out on a 3T scanner (Siemens TRIO, Erlangen, Germany) at the Max-Planck-Institute for Human Cognitive and Brain Sciences, Leipzig, Germany. For the cognitive paradigm, 26 axial slices (3mm×3mm×3mm resolution, .75mm spacing), parallel to the AC–PC plane and covering the whole brain were acquired using a single shot, gradient recalled EPI sequence (TR 2000 ms, TE 30 ms, 90◦ flip angle). One functional run with 900 time points was acquired, with each time point sampling over the 26 slices. Prior to the functional run, 26 anatomical T1- weighted MDEFT-images (Norris, 2000; Ugurbil et al., 1993) with the same spatial orientation as the functional data were acquired.

<u>fMRI data analysis</u>

The fMRI data was processed with LIPSIA software (Lohmann et al., 2001). This software package contains tools for preprocessing, registration, statistical evaluation and presentation of fMRI data.

Functional data was motion-corrected offline with the Siemens motion correction protocol (Siemens, Erlangen, Germany). To correct for the temporal offset between the slices acquired in one scan, a cubic-spline-interpolation was applied. A temporal highpass filter with a cutoff frequency of 1 = 120 Hz was used for baseline correction of the signal and a spatial Gaussian filter with 5.65mm FWHM was applied.

To align the functional data slices onto a 3D stereotactic coordinate reference system, a rigid linear registration with six degrees of freedom (three rotational, three translational) was performed. The rotational and translational parameters were acquired on the basis of the MDEFT slices to achieve an optimal match between these slices and the individual 3D reference data set. This 3D reference data set had been acquired for each subject during a previous scanning session. The 3D reference data set with 160 slices and 1mm slice thickness was standardized to the Talairach stereotactic space (Talairach & Tournoux, 1988). The obtained rotational and translational parameters were normalized, i.e., transformed by linear scaling to a standard size. The resulting parameters were then used to transform the functional slices using trilinear interpolation, so that the resulting functional slices were aligned with the stereotactic coordinate system. Subsequently, a non-linear normalization was performed (Thirion, 1998). This step improved the spatial alignment of the individual neuroanatomy onto the neuroanatomy of a reference brain.

The statistical evaluation was based on a least-squares estimation using the general linear model for serially autocorrelated observations (see also Aguirre, Zarahn, & D'Esposito, 1997; Worsley & Friston, 1995; Zarahn, Aguirre, & d'Esposito, 1997). The design matrix was generated with a box-car function with reaction time as onset, convolved with a hemodynamic response function (HRF; gamma density function, Glover, 1999). The model equation, including the observation data, the design matrix and the error term, was convolved with a Gaussian kernel of dispersion of 4 s FWHM to account for the temporal autocorrelation (Worsley & Friston, 1995). In the following, beta-values were estimated for different contrast for each voxel. As the individual functional datasets were all aligned to the same stereotactic reference space, the resulting single-participant contrast-images were then entered into a second-level random effects analysis for the relevant contrasts. The group analysis consisted of a one-sample *t*-test across the contrast images of all subjects that indicated whether observed differences were significantly distinct from zero (Holmes & Friston, 1998). Subsequently, *t* values were transformed into *Z* scores. Images were thresholded at $z > 3.09$ ($p < .001$, uncorrected). Moreover, a region was considered significant only if it contained a cluster of 11 or more continuous voxels (Braver & Bongiolatti, 2002; Forman et al., 1995).

Furthermore, the individual contrast images were used for a random-effects second-level analysis with an additional regressor coding the experience-seeking scores or the SPI, respectively. To protect against false positive activations, only regions with a *Z*-score greater than 2.58 ($p < .005$, uncorrected) and with a volume greater than 297mm3 (11 voxels) were considered (Braver & Bongiolatti, 2002; Forman et al., 1995).

Finally, a time course analysis of the fMRI signal was calculated. Trial-averaged time courses (stimulus onset locked) were obtained on a voxel-by-voxel basis for each subject at a sampling rate of .2 s for the incongruity-resolution cartoons aswell as for the nonsense cartoons. The mean signal intensity of the entire time course was taken as baseline for the calculation of the percent signal change. The time course of the null events was subtracted from the time course of the two task conditions (Burdock, Buckner, Woldorff, Rosen, & Dale, 1998). Further, the maximum percent signal change was extracted for each subject and condition.

Results

Behavioral data

The behavioral data showed that incongruity-resolution cartoons were better understood than nonsense cartoons, which was revealed by a paired sample *t*-test ($t(16) = 3.011$, $p < .01$). However, the two stimuli groups did not differ regarding recognition time and funniness ratings. See Table 2 for descriptive statistics.

Table 2: Means and standard deviations for comprehensibility (0 = not understood, 1 = understood), recognition time (in seconds), and funniness ratings (from 0 = not funny at all, to 6 = very funny, N= 17) the two types of humorous stimuli.

	Incongruity-resolution cartoons Mean (SD)	**Nonsense cartoons Mean (SD)**
Comprehensibility [a]	.89 (.06)	.80 (.14)
Recognition Time	4.67 (.73)	4.30 (.52)
Funniness	3.30 (.70)	3.51 (1.39)

[a] Incongruity-resolution cartoons were better understood than nonsense cartoons ($t(16) = 3.011$, $p < .01$).

Experience-seeking scores had a mean of 6.94 (S.D. = 1.50). The SPI had a mean of −3.18 (S.D. = 6.57). There was no effect of gender on the experience-seeking scores or the SPI. The participants did not significantly prefer incongruity-resolution over nonsense cartoons, as measured with the 3WD. In previous studies experience seeking was shown to correlate positively with funniness ratings of nonsense and negatively of incongruity-resolution humorous stimuli, measured with the 3 WD (Ruch, 1992). However, with these 17 subjects, no significant correlations were found between experience seeking and incongruity-resolution or nonsense stimuli, measured neither with the 3WDnor with the stimuli used in the present study, as well as no correlation with the SPI. Further analysis revealed that only the incongruity-resolution cartoons of our experiment correlated positively with the incongruity-resolution stimuli of the 3WD ($r(17) = .503$, $p < .05$). The lack of significant correlations might be due to the limited number of subjects and the fact that they did not clearly prefer one type of humor over the other.

Imaging results

Comparison of incongruity-resolution vs. nonsense cartoons

In order to analyze which brain structures react to the degree of resolvability of the incongruity, incongruity-resolution cartoons (incongruity is almost completely resolvable) were contrasted to nonsense cartoons (incongruity not completely resolvable, high degree in residual incongruity). Only the understood cartoons entered the analysis. This comparison revealed significant activations for incongruity-resolution jokes, but no specific areas for nonsense jokes: The superior frontal gyrus (SFG) bilaterally, amPFC and several activations around the left and right temporo-parietal junction (left angular gyrus, temporo-parietal junction bilaterally and right posterior middle temporal gyrus, pMTG) were more strongly involved in processing of incongruity-resolution cartoons.

Fig. 2A shows the resulting activation maps for incongruity-resolution vs. nonsense cartoons and Table 3 reports the coordinates, volumes and maximum *z*-values from the group averaged data. Fig. 2B shows the underlying haemodynamic response in the left and right TPJ during processing of incongruity-resolution and nonsense cartoons.

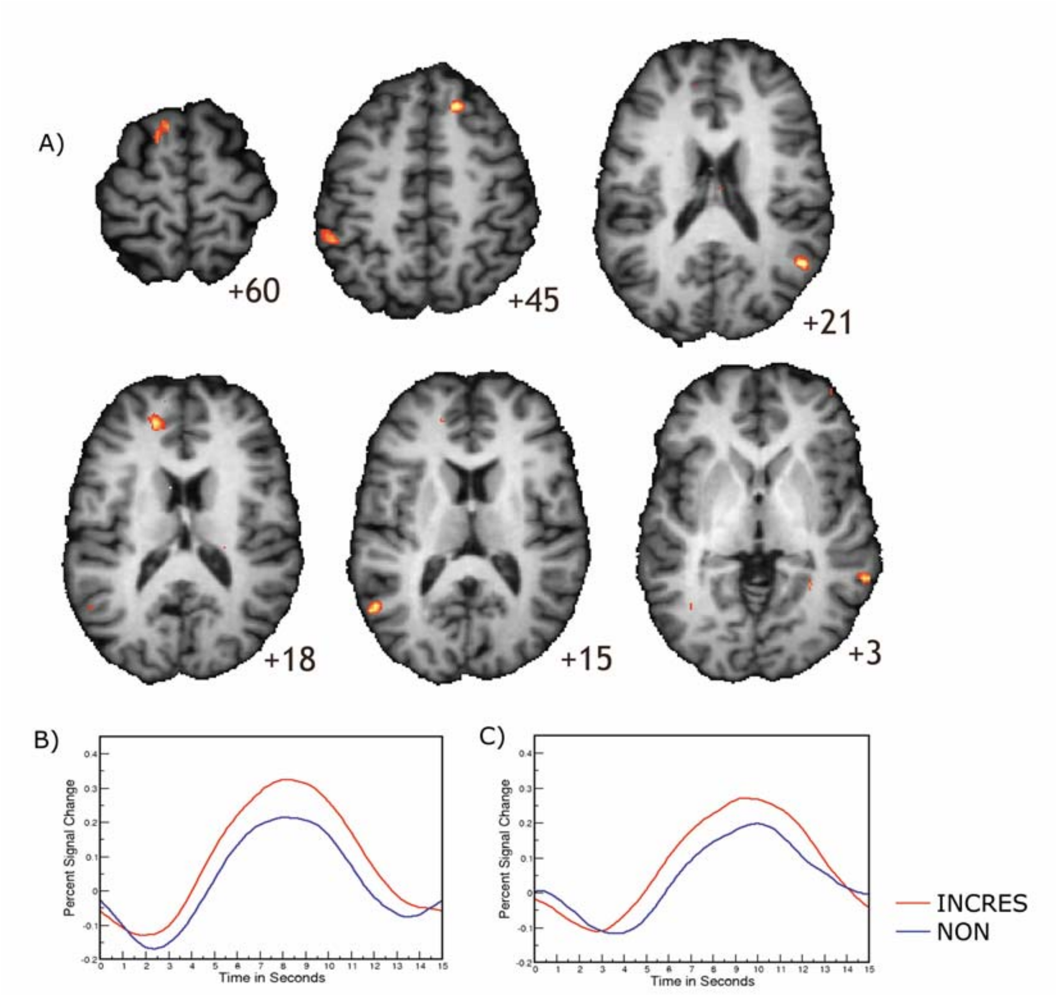

Figure 2: (A) Main activations for incongruity-resolution cartoons vs. nonsense cartoons. Significant regions of activation are projected onto the cortical surface of an average brain, obtained by nonlinear transformation of the participants' individual anatomies. Axial views are shown. All maps are thresholded at $z > 3.09$, $p < .001$, uncorrected. Event-related hemodynamic response in (B) left TPJ and (C) right TPJ during processing of incongruity-resolution (INCRES) and nonsense (NON) cartoons. Presentation of stimuli occurred at 0 s.

Table 3: Main activations for incongruity-resolution cartoons vs. nonsense cartoons, N = 17; Brodman areas (BA), Talairach coordinates, volume and Z-maximum of the main activated regions.

AREA	**BA**	**Talairach coordinates**	
		x y z	**Volume (Z-max)**
Incongruity-resolution humor			
R superior frontal gyrus (SFG)	8/9	13 32 42	594 (3.97)
L superior frontal gyrus (SFG)	8/9	-11 14 60	324 (3.47)
L anterior medial prefrontal cortes (amPFC)	10	-17 41 18	405 (3.78)
L angular gyrus	39/7	-53 -46 45	405 (3.45)
L temporo-parietal junction (TPJ)	39	-53 -61 15	324 (3.69)
R temporo-parietal junction (TPJ)	39	49 -58 21	621 (3.91)
R posterior middle temporal gyrus (pMTG)	37	58 -49 3	297 (3.64)

The volume is reported in mm3 and z-values were thresholded at $z < 3.09$. Reported clusters contain at least 11 (297mm3) continuous voxels.

Experience seeking and humor processing

Higher experience-seeking scores correlated positively with brain activation during humor processing in the following areas: the left middle frontal gyrus (MFG) and the right IFG in the frontal cortex, and small activations in the right aSTS and pSTS/TPJ and angular gyrus, left inferior parietal lobe and occipital gyri. Furthermore, the right medial occipitotemporal gyrus and left hippocampus showed stronger activation corresponding to experience-seeking scores.

Fig. 3 shows the resulting activation maps for funny cartoons vs. pictures containing an irresolvable incongruity in relation to the individual experience-seeking scores and Table 4 reports the coordinates, volumes and maximum z-values from the group averaged data. Fig. 4 shows the correlation of experience-seeking scores with activation in the hippocampus.

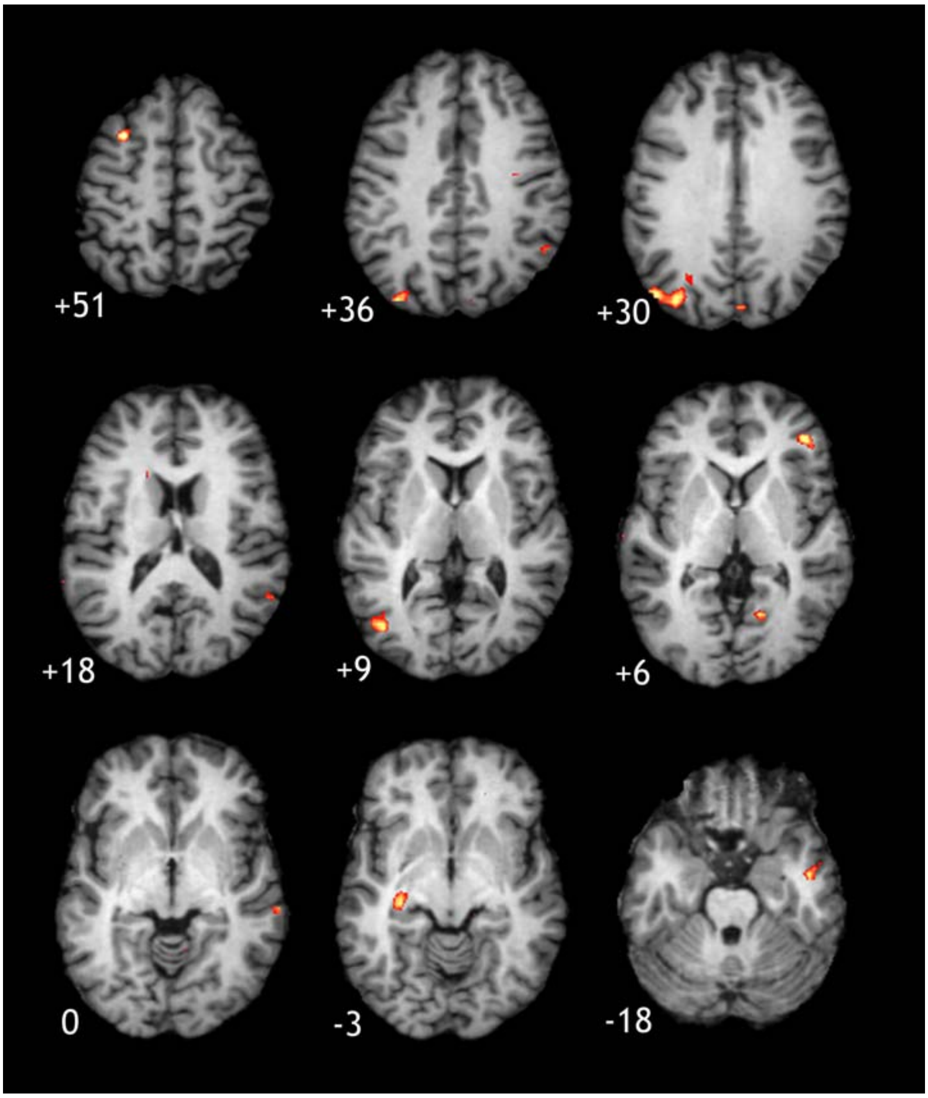

Figure 3: Humor processing in relation to experience seeking: main activations funny cartoons vs. control condition (irresolvable incongruities). Significant regions of activation are projected onto the cortical surface of an average brain, obtained by nonlinear transformation of the participants' individual anatomies. Axial views are shown. All maps are thresholded at z > 2.58, p < .005, uncorrected.

Table 4: Humor processing in relation to experience seeking: main activations for funny cartoons vs. control condition (irresolvable incongruities), N = 17; Brodman areas (BA), Talairach coordinates, volume and Z-maximum of the main activated regions.

AREA	**BA**	**Talairach coordinates**	
		x y z	**Volume (Z-max)**
Incongruity-resolution humor			
L middle frontal gyrus (MFG)	6/8	-29 11 51	486 (3.90)
R inferior frontal gyrus (IFG)	9	40 35 6	486 (3.34)
R anterior superior temporal sulcus (aSTS)	21	43 -10 -18	864 (3.34)
R posterior superior temporal Sulcus (pSTS)	21	61 -31 0	324 (3.04)
R temporo-parietal junction (TPJ)	22/39	52 -55 18	405 (2.80)
R angular gyrus	40	49 -58 36	459 (2.83)
L inferior parietal lobe	39/40	-47 -79 30	4212 (3.51)
L occipital gyri	37/19	-41 -76 9	1080 (3.36)
R medial occipitotemporal gyrus	37/19	13 -64 6	1107 (3.25)
L hippocampus		-29 -28 -3	405 (3.32)

The volume is reported in mm3 and z-values were thresholded at $z < 2.58$. Reported clusters contain at least 11 (297mm3) continuous voxels.

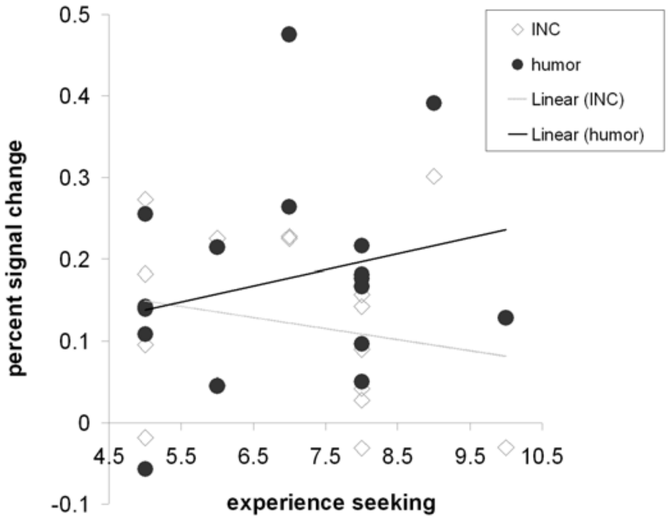

Figure 4: Percent signal change in relation to experience seeking for humor processing and the control condition (irresolvable incongruities = INC) in the left hippocampus (−29 −28 −3).

<u>Comparison of nonsense vs. incongruity-resolution and experience seeking</u>

The left anterior IFG, inferior frontal junction (IFJ) and right IFG, as well as in the extrastriate cortex showed different activations in processing of nonsense vs. incongruity-resolution cartoons in relation to experience seeking.

Fig. 5A shows the resulting activation maps for nonsense vs. incongruity-resolution cartoons in relation to individual experience-seeking scores and Table 5 reports the coordinates, volumes and maximum *z*-values from the group averaged data. Fig. 5B shows the correlation with experience-seeking scores in the left IFJ.

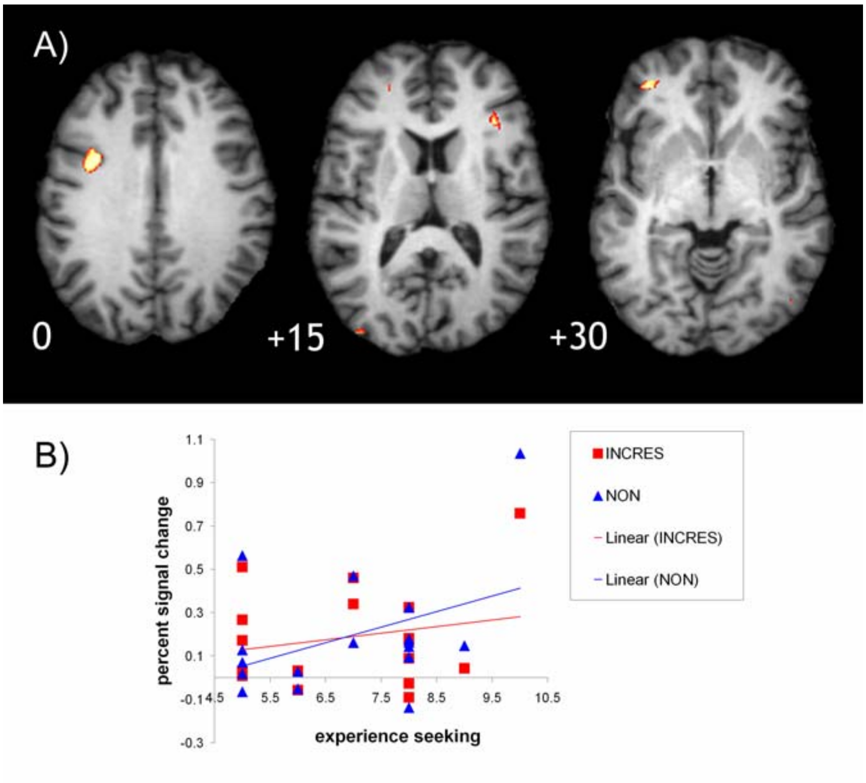

Figure 5: (A) Main activations nonsense (=NON) vs. incongruity-resolution (=INCRES) cartoons in relation to individual experience-seeking scores; significant regions of activation are projected onto the cortical surface of an average brain, obtained by nonlinear transformation of the participants' individual anatomies. Axial views are shown. All maps are thresholded at z > 2.58, p < .005, uncorrected. (B) Percent signal change in relation to experience seeking for processing of nonsense and incongruity-resolution cartoons in the left inferior frontal junction (−32 2 30).

Table 5: Nonsense vs. incongruity-resolution cartoons in relation to experience seeking: main activations, N= 17; Brodman areas (BA), Talairach coordinates, volume and Z-maximum of the main activated regions.

AREA	**BA**	**Talairach coordinates**	
		x y z	**Volume (Z-max)**
Nonsense humor			
L anterior inferior frontal gyrus (IFG)	46	-35 41 0	324 (3.06)
L inferior frontal junction (IFJ)	44/6	-32 2 30	1026 (3.00)
R inferior frontal gyrus (IFG)	44	34 23 15	621 (2.92)
L extrastriate cortex/occipital gyri	37/19	-38 -91 15	324 (2.70)

The volume is reported in mm3 and *z*-values were thresholded at $z < 2.58$. Reported clusters contain at least 11 (297mm3) continuous voxels.

<u>The influence of the structural preference index (SPI)</u>

The relative preference for nonsense over incongruity-resolution humorous stimuli (SPI, measured with the 3 WD) showed no significant activations neither in humor processing in general nor in nonsense vs. incongruity-resolution.

Discussion

The first aim of this study was to investigate differences in the processing of incongruity-resolution and nonsense cartoons that differ with respect to the resolvability of their incongruity: Whereas in incongruity-resolution cartoons the incongruity of the joke can be almost completely resolved, nonsensical humorous stimuli are characterized by high residual incongruity of the joke (Hempelmann & Ruch, 2005), which cannot be resolved (completely), while new incongruities may even emerge in the attempt to resolve the main incongruity. Our results show that processing of incongruity-resolution cartoons, in contrast to nonsense cartoons, leads to more activation in areas around the TPJ bilaterally, the SFG bilaterally and the right amPFC. On the other hand, no specific activation was found for processing of nonsensical humorous stimuli.

As the TJP was also found to be involved in the incongruity-resolution process in funny cartoons but not in non-funny pictures containing an irresolvable incongruity (Samson et al., 2008), we claim that this area is relevant for the resolution of the incongruity: the more information can be integrated and the more sense a joke makes (as incongruity-resolution cartoons do), the more activation can be found in the TPJ. This is in line with interpretations of the TPJ as involved in integration of multi-sensory information and coherence building (see Ferstl & von Cramon, 2002) and inferring knowledge (Goel, Grafman, & Hallett, 1995), as well as a multimodal convergence zone with connections to the limbic system (Barnes & Pandya, 1992). In a meta-analysis, Decety & Lamm (2007) recently showed that this area is activated not only during high-level social-cognitive processes but also in lower-level computational processes, such as attention orientation. Therefore, the TPJ may contribute to generating, testing and correcting internal predictions about external sensory events, which is crucial for the resolution of incongruity in humor processing. In nonsense cartoons, the search for a possibility to resolve the incongruity will still be initiated, but less information can be integrated (since often only a partial resolution is possible, which generates more residual incongruity). However, the mere *search* for a possibility to resolve the incongruity does not lead to more activation in the TPJ.

With an increase of incongruity that can be resolved, also more activation is found in the SFG bilaterally. One study showed that a patient laughed when the SFG was stimulated. The patient gave different explanations for the laughter each time, attributing it to any element or object she was presented with (Fried, Wilson, MacDonald, & Behnke, 1998). It might be possible that the SFG is therefore involved in (attempting to) “making sense” or “attribution”. Furthermore, this area is also involved in higher processes described under the concepts of monitoring and manipulation, executive processing and is thought to contribute to higher cognitive functions and particularly to working memory (see, for example, Owen, 2000; Petrides, 2000). As the SFG was shown to be involved in higher levels of working memory processing (monitoring and manipulation) and to react to an increase in executive demand (Du Boisgueheneuc et al., 2006), we claim that management or integration of concurrent information in incongruity-resolution cartoons needs more executive processing than in nonsense cartoons. Probably, humorous stimuli based on incongruity-resolution require more mental manipulation of information and mental organization. Furthermore, the processing of incongruity-resolution stimuli provokes more activation in the amPFC than processing of nonsense cartoons[4].2 It is possible that in nonsense cartoons less self-referential mental activity can be established (e.g., Gusnard, Akbudak, Shulman, & Raichle, 2001; Zysset, Huber, Samson, Ferstl, & von Cramon, 2003) as this type of humor is known to be more absurd and grotesque (see Samson & Ruch, 2005) and therefore less reference to reality or to one's own experiences might be required. In addition, humorous stimuli based on incongruity-resolution were described to be more open for interpretation (Ruch, 1981), which might facilitate more self-referentiality.

Although the IFG is shown to be involved in cognitive humor processing (e.g., Goel & Dolan, 2001; Mobbs et al., 2003; Moran et al., 2004; Samson et al., 2008; Wild et al., 2006), it does not seem to react to the degree of the resolvability of the incongruity. Therefore, it might be involved in processes that are required for processing of humorous stimuli based on either incongruity-resolution or nonsense.

One very interesting question is why processing of nonsense jokes does not evoke the same activation pattern as non-funny pictures containing an irresolvable incongruity. These pictures evoked activation, for example, in the rostral cingulate zone (BA 8), indicating conflict monitoring or error processing (Samson et al., 2008), presumably since the incongruities were not resolvable or made no sense at all. However, that nonsense cartoons were perceived to be different from pictures containing irresolvable incongruities can also be seen in the ratings: In contrast to the control condition, nonsense cartoons were rated to be understood and perceived to be funny. That is, unresolved incongruity that is understood as humorous is different from non-humorous unresolved incongruity.

Why do incongruity-resolution cartoons require more involvement of the TPJ and prefrontal areas? In humor processing in general, an incongruity first has to be detected and then, in a process similar to problem-solving, a cognitive rule has to be found that resolves the incongruity in order for the joke to make—at least partial—sense. Ruch (1981) defined incongruity-resolution jokes as open for interpretations, offering more possibilities to explain

[4] Samson et al. (2008) found the amPFC to be involved in Theory of Mind cartoons, but not in visual puns, semantic cartoons or in humor processing in general. The same amount of Theory of Mind cartoons was found among the incongruity-resolution and nonsense cartoons. Thus, the amPFC activation found in the present study has more likely to do with self-referential processes than with attributing mental states to others. According to Frith and Frith (1999) (see Frith and Frith, 2003, for a review) the mPFC is engaged when we attend to our own mental states as well as those of others.

the punch line than humorous stimuli based on nonsense. As there are more possibilities to explain the punch line of the joke in incongruity-resolution than in nonsense jokes subjects have to continuously generate new hypotheses about the relation of the of the incongruity is required. The appreciation of these kinds of jokes emerges rather from a play with thoughts and with imagination. The perceiver enjoys absurd, complex incongruities that are not or only partially resolvable. Therefore, one might say that incongruity-resolution cartoons make more sense and are more easily explained.

The second aim of the study was to investigate the influence of inter-individual differences in experience seeking on neural correlates of humor processing: Experience seeking was positively correlated, inter alia, with humor processing in the left IFG, MFG and activations around the bilateral TPJ. As experience seekers tend to engage in investigatory behaviors such as exploring unknown locations, trying new food, etc., it is conceivable that they prefer to explore stimuli that require more cognitive processing to be found humorous: The cartoons are possibly more intensely searched for funny elements. Due to the more intense exploration of humorous stimuli high experience seekers might be more capable to make sense of the incongruities contained in the cartoons. Already Watson et al. (2006) showed the MFG to be involved in visual imagery related to humor processing. Furthermore, experience seekers show more activation in the hippocampus during humor processing. This area was shown to play a central role in processing novel stimuli (e.g., Legault &Wise, 2001, see Nyberg, 2005). The hippocampus is capable of comparing incoming information with stored memories in order to index whether that information is novel (Lisman & Grace, 2005). An observed relationship between experience seeking and hippocampal volume reflects either an association between this volume and the tendency to pursue novelty, or a more general tendency to pursue any form of mental stimulation (e.g., any form of sensation seeking, Martin et al., 2007). As the experience-seeking scale (Zuckerman, 1994) measures the tendency to pursue novel behavioral and cognitive experiences, we interpret the hippocampus activation to be involved in processing the novelty of humorous stimuli (i.e., incongruities, but also the result of an incongruity-resolution process), which is more pronounced in experience seekers.

Furthermore, it was analyzed whether individuals with different scores on the experience-seeking scale react differently to incongruity-resolution and nonsense cartoons. Although incongruity-resolution provokes more activation of the amPFC, SFG bilaterally, left angular gyrus, TPJ bilaterally and right pMTG than nonsense cartoons—if no individual differences are taken into account—more brain reactivity was found in the processing of nonsense than in incongruity-resolution cartoons in individuals with higher experience-seeking scores: More activation around the bilateral IFG and left extrastriate cortex was found. This is in line with the above-mentioned interpretation of the activations found in relation to humor processing: obviously, experience seekers tend to process nonsense cartoons semantically deeper and explore them more intensely. Although not reflected in the behavioral data within these 17 subjects, interestingly, high sensation seekers show more activation during processing of nonsense cartoons, for example in the left IFJ. The pattern seems to be reversed in low experience seekers. This is in line with previous findings that experience seekers prefer nonsense over incongruity-resolution (e.g., Ruch, 1988; Forabosco & Ruch, 1994). That experience seeking alters the neural humor response is a promising result. However, further studies are needed to confirm the relation between experience seeking and its neural correlates during processing of humorous stimuli based on incongruity-resolution and nonsense.

In our study, experience-seeking scores did not correlate significantly with funniness ratings. This might be due to the limited number of participants. However, other possibilities for interpretation should be considered: As two studies showed that sensation seekers tend to portray smiles and laughter more often and perceive more events as being funnier (this was measured with humor self-report questionnaires, see Deckers & Ruch, 1992; Lourey & McLachlan, 2003), it is possible that they search more intensely for funny events. But it is also possible that the same stimulus is rated the same by high and low experience seekers (as in the present study): due to constant underarousal, experience seekers have to explore stimuli more deeply in order to appreciate them to the same degree as low experience seekers. It is also conceivable that high experience seekers require more intense stimulation to reach an optimal level of arousal (see also Zuckerman, 2006). Furthermore, it remains unclear why in our study experience seeking did not correlate with the relative preference for humorous stimuli based on nonsense over incongruity-resolution as it did in the study by Forabosco and Ruch (1994) who found even a negative correlation between experience seeking and appreciation of incongruity-resolution stimuli. Possibly, the individual differences are too subtle to be investigated with only 17 subjects with varying scores of experience seeking. Further studies have to be run, for example with participants with extreme scores on experience seeking who also differ in their preference for humorous stimuli based on nonsense and incongruity-resolution. Investigating individuals with more extreme scores on the SPI might also evoke neural correlates during humor processing for individuals who clearly prefer incongruity-resolution or nonsense humorous stimuli.

In conclusion, the neuronal data of our study supports that humorous stimuli based on incongruity-resolution and nonsense are processed differently: The circumstance that in incongruity-resolution cartoons more information can be integrated and more sense can be established leads to higher activation in the TPJ, the manipulation of this information (scripts) leads to more activation of the SFG and closer reference to reality leads to more activation of the amPFC. In nonsense humorous stimuli, on the other hand, people laugh more about the absurdity of rather incompatible scripts. This corresponds to less activation in frontal and temporo-parietal regions. Furthermore, the TPJ is confirmed to be involved in the incongruity-resolution process, and not in the *detection* of incongruity in humor, as some of the previous studies have claimed (e.g., Moran et al., 2004). Experience seeking seems to be a personality characteristic that influences the neural correlates of humor processing. Experience seeking correlates positively with activation in areas that are involved in humor processing (i.e., IFG, TPJ), but also with activation in the hippocampus. High experience seekers seem to process complex and novel stimuli—one type being humorous stimuli—more deeply and explore them more intensely than low sensation seekers.

Whenever new imaging studies unravel the cognitive and affective neural correlates of humor processing, further questions arise in turn: For example, nonsense jokes seem to consist of three different groups: those that are not resolvable, are only partially resolvable and those in which new incongruities are introduced for the resolution of the main incongruity (e.g., Ruch & Hehl, 2007). Altogether, these three subgroups of nonsense-based humorous stimuli have in common that they show more residual incongruity and that less incongruity-resolution is possible. In further studies, these three subgroups might be differentiated in more detail. Further studies might also concentrate more on affective aspects of humor processing or integrate a social partner in order to investigate for example the moderating effects of the use of humor in social interaction.

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12 The influence of empathizing and systemizing on humor processing: Theory of Mind and humor

This chapter is in press: Samson, A. C. (in press). The influence of Empathizing and Systemizing on humor processing: Theory of Mind and humor. *Humor: International Journal of Humor Research.*[5]

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Abstract

This paper investigates the influence of empathizing and systemizing on cognitive and affective humor processing in two studies. Three cartoon types differing in their logical mechanisms (LMs) and cognitive requirements were presented to participants with high scores on one scale, but low scores on the other (empathizers and systemizers): visual puns, semantic cartoons and Theory of Mind cartoons. Empathizers and systemizers were expected to process these cartoon types differently. While empathizers and systemizers did not differ in recognition time and comprehensibility in study one (N=33), empathizers portrayed higher funniness scores in study two (N=55). Furthermore, empathizers more often give emotional/motivational explanations as well as more mentalistic explanations as to why they think a cartoon is funny. In addition, Theory of Mind cartoons provoked the highest number of mentalistic explanations. This shows that stimulus characteristics (such as LMs) as well as inter-individual differences influence whether mentalizing is required and applied to processing humor, and that empathizing and systemizing influence humor appreciation.

Introduction

Cognitive and affective humor responses have been shown to be influenced by individual characteristics such as metalinguistic skills, social competences (see Emerich et al. 2003) or personality (e.g., Ruch 1992; Ruch and Hehl 1998). Some models of humor explicitly claim that Theory of Mind, the ability to represent other people's mental states, such as beliefs, desires, emotions and goals in order to predict their actions (Baron-Cohen et al. 1985; Premack and Woodruff 1978), is necessary to process humor (Howe 2002; Jung 2003). Theory of Mind, also called *mentalizing*, has been described as the cognitive component of empathy (e.g., Baron-Cohen 2003).

Several studies that investigated Theory of Mind and humor have arrived at mixed results. Some studies support the so-called mind-reading hypothesis by Howe (2002): For example, the ability to comprehend humor is affected by a decrease in mentalizing in normal aging (Uekermann et al. 2006), and alcoholic patients who have reduced humor processing skills also show mentalizing deficits (Uekermann et al. 2007). Studies on individuals with Asperger syndrome (AS) and autism known to have affected mind-reading abilities present evidence that their humor processing is impaired: for example, they less often recognize when something is intended to be funny (Baron-Cohen 1997a) or their comprehension of humorous materials is poorer in that they more often chose a non-funny ending out of several possible endings for a joke setup (Ozonoff and Miller 1996; Emerich et al. 2003).

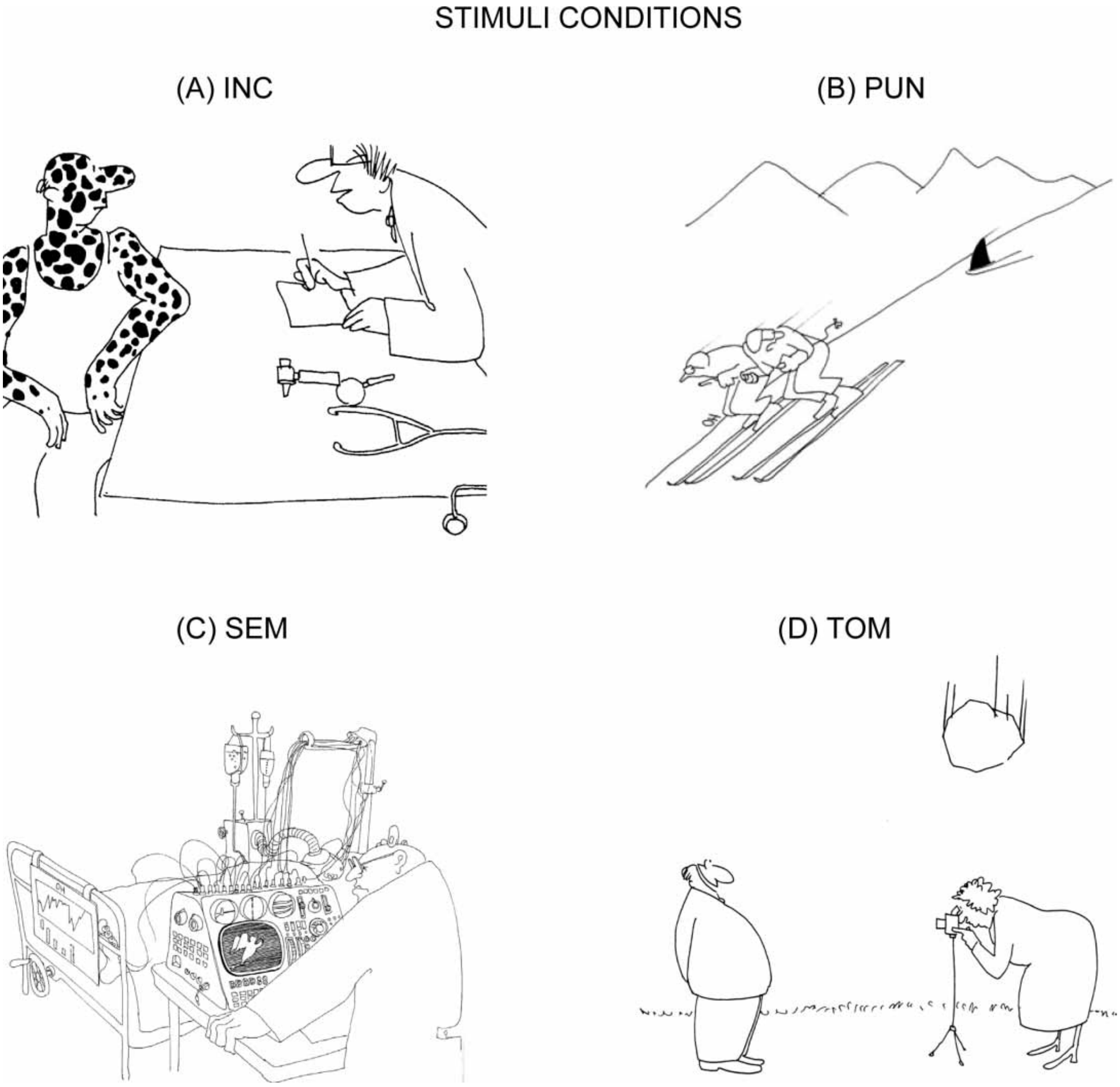
However, other studies do not support a close relationship between Theory of Mind and humor: Humor appreciation can be impaired even if Theory of Mind abilities are preserved in patients with frontal lobe epilepsy (Farrant et al. 2005). Another study showed that empathy had no influence on processing neither of friendly humor (wit) nor of hostile humor (witticism). However, perspective taking (cognitive empathy) was positively correlated to wit and negatively to witticism (Gessner and Kashdan 2006). Forsyth et al. (1997) only partially support the mind reading hypothesis: emotional empathy was negatively correlated with humorousness of jokes with negative ethnic stereotypes, but there was no correlation between empathy and jokes with other negative stereotypes. Moreover, a case report study by Werth et al. (2001) supports the view of a dissociation of humor and Theory of Mind abilities. An autistic person showed the ability to understand, produce and share humor with other people, despite limited mind-reading skills. It is assumed that some individuals with AS and autism who have highly developed linguistic and cognitive abilities approach humor from a more cognitive/intellectual perspective and are able to grasp the cognitive basis of humor (for a review, see Lyons and Fitzgerald 2004). However, in individuals with AS, other reasons such as a weak central coherence or less cognitive flexibility (e.g., Frith and Happé 1994; Happé 1999) might influence humor processing as well. This literary overview shows that the relation of Theory of Mind abilities, empathy and humor processing is not yet clear.

Theory of Mind or mentalizing has been described as the cognitive component of empathy or empathizing. Apart from systemizing, empathizing is one of two relatively independent psychological dimensions or cognitive styles (Baron-Cohen et al. 2003; Baron-Cohen and Wheelwright 2004), defined as the drive to identify emotions and thoughts in others and to respond to these with an appropriate emotion. Systemizing refers to the drive to construct systems (including a wider range of systems, such as mechanical, abstract, mathematical; or organizational), to predict their behavior and to control them. Empathizing is used to make sense of an agent's behavior, whereas systemizing is mostly used to predict the behavior of non-agentive events or objects. Understanding (intentional) agency and non-agentive (causal) events are two fundamental aspects of human cognition (e.g., Leslie 1994; Premack 1995; Baron-Cohen 1997b). These two psychological dimensions can be measured by means of the empathy quotient (EQ) and systemizing quotient (SQ) (Baron-Cohen et al. 2003; Baron-Cohen and Wheelwright 2004).

The Empathizing–Systemizing (E-S) theory assumes that empathizing and systemizing are two-dimensional coordinates on which individuals differ. Baron-Cohen et al. (2003) used the term ''brain types'' to describe three basic cognitive types: Individuals with high values on the EQ and low SQ values belong to the Type E (the Empathizing brain type: E > S), Type S individuals have low values on the EQ, and high SQ values (the Systemizing brain type: S > E). Type B ("balanced") individuals have similar values on both dimensions (the Balanced brain type: E = S). For example, more men belong to Type S, whereas more women belong to Type E (e.g., Goldenfeld et al. 2005). With respect to these dimensions, the present study focuses on the influence of empathizing and systemizing on humor processing, since mentalizing is related strongly to empathizing, while systemizing has not yet been investigated in relation to humor.

However, individual differences are not the only influence on humor processing, but also stimulus characteristics such as the resolvability of the incongruity (e.g., Ruch 1981, 1992; Ruch and Hehl 1998) or Logical Mechanisms (LM). According to the General Theory of Verbal Humor (GTVH, Attardo and Raskin 1991), LMs describe the cognitive rule by which the incongruity of a humorous stimulus (jokes, cartoons, etc.) has to be resolved. Attardo et al. (2002) claim that different LMs exist, such as mirrored roles (two scripts invoking similar roles being juxtaposed so that they mirror each other), juxtaposition (two scripts are presented simultaneously in the same situation), or exaggeration (an element of a script is rendered unusually salient by exaggerating its size or other characteristics). Samson et al. (2008) used functional Magnetic Resonance Imaging (fMRI) to show that different LMs evoke different networks in the brain. Their results support the view that different LMs require different cognitive abilities, although there is not much difference in behavioral data such as recognition time or funniness ratings. To process a certain group of LMs, Theory of Mind abilities were required as these humorous stimuli can only be understood when an individual can attribute false mental states to the characters portrayed (e.g., the perceiver has to understand that one character does not know what the other character thinks or intends to do): This LM has been described by Paolillo (1998) or Attardo et al. (2002) as "obvious error", and Theory of Mind (TOM) cartoons or jokes (e.g., Samson et al. 2008) in other studies. Some studies using fMRI showed that TOM cartoons are processed differently from non-TOM cartoons (e.g., Gallagher et al. 2000; Marjoram et al. 2004; Samson et al. 2008).

In the present paper it shall be investigated whether the processing of cartoons that differ in LMs is influenced by empathizing and systemizing abilities. Three types of non-verbal cartoons shall be presented that differ in their LM and are expected to require more or less mentalizing abilities to be processed: Visual Puns (PUN) are based on visual resemblance and do not require mentalizing or empathizing abilities to be understood. Semantic cartoons (SEM) are based on purely semantic (not visual) relationships and can be understood by using either empathizing or systemizing, whereas the punch line of TOM cartoons can only be understood adequately if the participant attributes false mental states to the characters portrayed. It is expected that mentalizing or mind-reading abilities are required to process and appreciate particularly TOM cartoons (see Figure 1).



<u>Figure 1:</u> Examples of the stimuli used in the study. (A) A picture containing an irresolvable incongruity (INC – only used in study 2). (B) A visual pun (PUN): one visual element (the diagonal line) can stand for the sea (activated through the fin) or the mountain (activated trough the skis). (C) A semantic cartoon (SEM): the joke is based on pure semantic relations and not on visual resemblance, as in PUNs: the patient has died which can be seen on the monitor in form of an angel flying away. There is no visual resemblance between the angel and the line which indicates no heartbeat. In order to understand the joke it has not be referred to (false) mental states. (D) A Theory of Mind (TOM) cartoon: In order to get the joke, it is necessary to activate mentalizing abilities: to understand that the woman does not know what will happen to her, while the man knows what will happen. Cartoons: Copyright by Oswald Huber.

It is assumed that empathizers and systemizers (with extreme high values on one, but low values on the other scale—this corresponds to the brain types E and S) perform differently when having to process these three groups of cartoons. However, not only rating scales but also explanations as to why the participants think a cartoon is funny have to be taken into account as explanations might be a more accurate indicator of cognitive processes (see also Loizou 2006, McGhee 1971). It is possible that when only considering data from rating scales, there might be no differences between empathizers and systemizers as they may well focus on different aspects of the cartoons but nevertheless arrive at similar funniness ratings (e.g., systemizers may focus more on illogical aspects than on social aspects). Following the theoretical assumptions by scholars such as Howe (2002) or Jung (2003), systemizers might have greater difficulty in understanding and appreciating humor independently of the LM. In particular, systemizers should have the greatest difficulty with TOM cartoons. In the two studies presented here, differences in humor processing are expected particularly on the explanation level. Three aspects were coded: the correctness of the explanation of the punch line (according to a GTVH-based expert analysis, Attardo and Raskin 1991), whether the participants refer to emotions or mental states of the characters portrayed in the cartoon, and whether they explicitly refer to false mental states, i.e., Theory of Mind or mentalistic explanations. Empathizers are expected to refer more often to the characters' emotions, motivations and intentions and more often give mentalistic explanations (e.g., stating that one character does not know what the other character thinks or intends to do).

Study 1

Method

Participants

In order to find empathizers and systemizers, as many participants as possible were recruited via e-mail, mail, personal communication, notices around the University, etc., to fill in the EQ and SQ in a paper and pencil version. Participants were instructed to judge how strongly they agreed or disagreed with each item. The participants were asked to provide contact information (email, phone number) in case they were interested in participating in a further study which allowed inviting individuals with extreme scores to participate in the main experiment. 182 participants replied to all items (113 students and 71 non-students; 117 females and 65 males; mean age 29.56 years, *SD*=12.19). The EQ and the SQ did not correlate significantly (*r*=-.06). As in previous studies on the EQ and SQ females had higher EQ scores than males ($F(1, 181)=6.14$, $p<.05$) while males had higher SQ scores than females ($F(1, 181)=39.40$, $p<.001$; see table 1).

Table 1: Means and standard deviations on the EQ and SQ of all subjects that filled in the questionnaire and those who were selected and participanted in the main experiment on the empathizing and systemizing scales in study 1.

		EQ ***M (SD)***	**SQ** ***M (SD)***
Whole sample	Males (N=65)	13.03 (5.23)	14.06 (4.77)
	Females (N=117)	14.73 (3.91)	9.25 (5.06)
	Total (N=182)	14.17 (4.43)	10.97 (5.46)
Selected participants	Empathizers (N=17)	18.06 (3.90)	4.53 (3.30)
	Systemizers (N=16)	7.00 (3.16)	18.50 (4.10)
	Total (N=33)	12.70 (6.62)	11.30 (7.97)

In order to select empathizers (brain type: E > S) and systemizers (brain type: S > E), those individuals who had an EQ above one standard deviation and a SQ below one standard deviation were counted as empathizers, while those who had a SQ above one standard deviation and an EQ below one standard deviation were counted as systemizers. With these strong criteria there were not enough participants for the main experiment. Therefore, ultimately those were selected who had only one value above/below one standard deviation and the other value half of one SD above/below the average.

39 individuals were found to fit the criteria of empathizers or systemizers, but only 33 were available to participate in the main experiment (mean age=28.36, *SD*=10.15 years). All of them were native speakers of German. 17 participants (15 female, two male) having high values on the EQ and low values on the SQ were categorized as empathizers. 16 participants (15 male, one female) had high values in the SQ and low values in the EQ (see table 1) and

were categorized as systemizers. One-way ANOVAs yielded significant differences in the EQ ($F(1, 32)=79.53$, $p<.001$) and SQ ($F(1, 32)=117.03$, $p<.001$) between these two groups.

Empathizing and systemizing scales

The EQ and SQ are two scales to measure differences in empathizing and systemizing (Baron-Cohen et al. 2003; Baron-Cohen and Wheelwright 2004). Here, short German versions were used (Samson and Huber 2008) consisting of 13 EQ items (e.g., "I can easily tell if someone else is interested in or bored with what I am saying.") and 13 SQ items (e.g., "I do not enjoy games that involve a high degree of strategy."). In order to prevent response tendencies the items were presented in a mixed questionnaire, which consisted of 37 items in total: 13 EQ, 13 SQ and 11 filler items. The EQ and SQ have a forced-choice format and are self-administered. As in the original versions, the agreement towards an item can be given on a 4 point scale from "strongly disagree" to "strongly agree". Each of the items scores one point if the respondent records the described behaviour mildly, or two points if strongly (see also Baron-Cohen et al. 2003; Baron-Cohen and Wheelwright 2004).

Stimuli

Three non-verbal types of cartoons with different LMs were investigated: visual puns (PUN), semantic cartoons (SEM) and Theory of Mind cartoons (TOM) (see Figure 1).

PUN cartoons are analogous to verbal or phonological puns, as defined by Hempelmann (2004). PUNs have in common that the punch line is based on the fact that one visual element activates two scripts that are incongruent with each other. The joke is understood if the person detects and integrates the two scripts (see also Hempelmann and Samson 2007).

SEMs are cartoons that are based on purely semantic relationships in contrast to visual resemblance as in PUNs. Several LMs are subsumed in this stimulus group (e.g., exaggeration, juxtaposition, role exchange, see Attardo et al. 2002).

The third stimulus group, TOM cartoons, is characterized by the fact that mentalizing abilities have to be activated to understand the joke correctly. These cartoons are similar to false belief tasks in the sense that the perceiver has to attribute mental states to the portrayed characters: It has to be recognized that one character does not know what the other character thinks or intends to do.

The stimuli were selected and pre-tested by Samson et al. (2008). In order to reduce the length of the experiment and to constrain the associated work load and humor fatigue effect (i.e., a decrease in the funniness response with increasing number of stimuli, see Forabosco 1994), only 60 of the 90 cartoons used in the previous study were selected randomly (20 per condition). For the explanations of the punch lines, five cartoons were randomly selected per each condition. All participants had to explain the same 15 cartoons.

Design and procedure

The independent variable *stimulus conditions,* i.e., the types of cartoons that differed regarding their LM, was varied within subjects and categorization of the participants into empathizers and systemizers is an organismic variable that varied between subjects. The dependent variables were recognition time, comprehensibility and funniness ratings and the explanations given by the participants for why they think the cartoon is funny.

Participants were tested individually. After instruction on the procedure, 60 non-verbal cartoons (20 PUNs, 20 SEMs, 20 TOMs) were presented randomly on a computer screen. The participants were instructed to press a button as soon as they were sure that they did or did not understand the cartoon to record recognition time. They then had to indicate whether they understood the cartoon or not with two buttons (this procedure allowed the exclusion of non-understood cartoons from further analysis). Subsequently, the participants rated the perceived funniness on a seven-point-scale. After having rated all cartoons participants were asked to verbally explain the punch line of each of the 15 cartoons (five per condition) which were presented randomly on single paper sheets. The explanations were recorded by the experimenter.

Results

In the results section, the coding procedure of the explanations and its reliability will be reported first, before the ratings and codings of the explanations will be analyzed.

Coding System

The explanations were coded binomially (yes/no) along the following criteria: The *correctness of the explanation* follows the descriptions of the LMs by Attardo et al. (2002)

for the SEM and TOM cartoons and by Hempelmann and Samson (2007) for the PUN condition. A correct explanation of a punch line in the PUN condition always refers to the visual ambiguity—the participant has to mention, for example, that one visual element evokes two meanings (e.g., "…the line represents two things simultaneously: waves and furrows…"). In the SEM condition, the specific LM has to be mentioned, for example that the cartoon is based on role exchange (e.g., "…the man and the dog changed roles…"). In order to get a correct score in the TOM cartoon condition, the specific LM for the TOM cartoon has to be mentioned (e.g., "…person X does not know what person Y is doing behind his back…") that is, the participant has to refer to the false belief of a character portrayed in the cartoon.

Since it might be possible to give a wrong mentalistic explanation or even give a mentalistic explanation for a PUN or SEM cartoon, it was coded independently of a correct explanation whether participants gave a *mentalistic explanation*.

Furthermore, it was coded (again independent of correctness) whether the participant gave an *emotional/motivational explanation*, i.e., whether they referred in any way to the emotional or motivational states of the portrayed characters (e.g., "…the dog feels good in the position of the man, whereas the man feels bad in the position of the dog…" or "…the man *desires* to do xy…") in contrast to an explanation without emotion or motivation (e.g., "…this is based on role exchange…" or "…the man does xy…").

A random sample of 120 explanations per coding (correct explanations, motivational/emotional explanations and mentalistic explanations; in total 360 codings, which are 24.24% of the in total 1485 codings) was coded additionally by a second rater in order to test the reliability of the coding procedure. Interrater reliability was satisfactorily high (for *correct explanations* in general (κ=.83), as well as for PUNs (κ=.93), SEM (κ=.76) and for TOM cartoons (κ=.80); for *emotional/motivational explanations* in general (κ=.94), as well as for PUN (κ=1.00), SEM (κ=.93), and TOM cartoons (κ=.90); for *mentalistic explanations* in general (κ=.83), as well as for PUN (there was 100% agreement), SEM (κ=.79) and for TOM cartoons (κ=.79)—usually, a Kappa (κ) of .70 is considered as very satisfactory. Neither of the coders knew whether the participants were systemizers or empathizers.

<u>Humor ratings</u>

Comprehensibility, recognition time and funniness ratings were analyzed by means of repeated measure ANOVAs with the three stimulus conditions as within-subjects factor and empathizers vs. systemizers as between-subjects factor, followed by Bonferroni-adjusted single comparisons. One-way ANOVAs were computed in order to analyze differences between empathizers and systemizers independent of the cartoon types. Table 2 reports means and standard deviations and Cronbach α's of the humor ratings, as well as the statistical analyses. The Cronbach α's show that the independent variables are stable constructs with respect to the dependent variables. The intercorrelations where high regarding recognition time (PUN–SEM: r=.94, p<.001; PUN–TOM: r=.89, p<.001; SEM–TOM: r=.88, p<.001), comprehensibility (PUN–SEM: r=.50, p<.01; PUN–TOM: r=.57, p<.01; SEM–TOM: r=.75, p<.001) and funniness (PUN–SEM: r=.91, p<.001; PUN–TOM: r=.90, p<.001; SEM–TOM: r=.89, p<.001).

<u>Table 2:</u> *Means, standard deviations and Cronbach α's of recognition time, comprehensibility and funniness ratings for all PUN-, SEM-, and TOM-cartoons (20 per condition) in dependence on the two groups (empathizers and systemizers) in study 1 (N=33).*

		Empathizers	**Systemizers**	**Cronbach α**
Recognition time	PUN	6.55 (4.21)	6.89 (2.92)	.926
(in seconds)[1]	SEM	6.26 (3.51)	6.92 (3.13)	.933
M (SD)	TOM	6.93 (3.69)	7.62 (2.92)	.917
Comprehensibility	PUN	0.89 (.14)	0.90 (.15)	.811
M (SD)	SEM	0.92 (.09)	0.92 (.10)	.657
	TOM	0.91 (.10)	0.94 (.09)	.732
Funniness	PUN	2.43 (.98)	2.67 (.94)	.910
M (SD)	SEM	2.46 (.95)	3.05 (.94)	.903
	TOM	2.59 (.94)	3.06 (.87)	.887

[1] For all dependent variables, 3 x 2 repeated measure analyses were computed with the three stimulus conditions as within-subject variable and the groups (empathizers vs. systemizers) as between-subject variable. Furthermore, a one-way ANOVA was computed for the groups independently of the stimulus conditions. Only recognition time revealed a significant effect for the stimulus conditions (*Mauchly's* W=.73, $\chi^2(2)$=9.28, p<.05; Greenhouse Geisser: $F(1.58, 48.97)$=8.93, p<.001).

Recognition time: After excluding the non-understood cartoons, a repeated measure ANOVA showed a significant main effect for the cartoon condition. SEMs were processed faster than TOMs ($t(32)$=2.90, p<.05), PUNs were processed faster than TOMs ($t(32)$=3.59, p<.01). The interaction stimulus condition x group as well as the one-way ANOVA over all conditions was not significant.

Repeated measure ANOVAs, as well as one-way ANOVAS over all three stimulus conditions, revealed no significant effects regarding the *comprehensibility response* and *funniness ratings.* That there were no differences in the comprehensibility response might be due to the fact that most of the cartoons were understood (on average, 91.15% of the cartoons).

Humor explanations

For each participant, the sums of correct explanations, emotional/motivational and mentalistic explanations were computed for the three stimulus conditions independent of subjective comprehensibility. Repeated measure ANOVAs were computed with the three stimulus conditions as repeated factors and empathizers vs. systemizers as between-subjects factor, followed by Bonferroni-adjusted single comparisons and one-way ANOVAS for the difference between the two groups (see table 3 for means, *SD* and statistics).

Table 3: Means and standard deviations for the correctness of the explanation, whether an emotional/motivational or a mentalistic explanation was given for the 5 cartoons of each stimulus condition (PUN, SEM, and TOM) in dependence on the two groups (empathizers and systemizers) in study 1 (N=33).

		Empathizers	**Systemizers**
Correctness[1]	PUN	4.00 (1.00)	3.94 (1.12)
	SEM	3.76 (1.25)	3.75 (1.18)
	TOM	2.59 (1.33)	1.75 (1.29)
Emotional/ motivational	PUN	.82 (1.13)	.06 (.25)
explanation[2]	SEM	.82 (.85)	.81 (.75)
	TOM	2.00 (1.37)	1.44 (1.09)
Mentalistic explanation[3]	PUN	.06 (.24)	.06 (.25)
	SEM	.53 (.51)	.38 (.62)
	TOM	3.18 (1.07)	1.81 (1.22)

1 For all dependent variables, 3 x 2 repeated measure ANOVAs were computed with the three stimulus conditions as within-subject variable and the groups (empathizers vs. systemizers) as between-subject variable. Furthermore, a one-way ANOVA was computed for the groups independently of the stimulus conditions. For the *correctness of the explanations*, a repeated measure ANOVA yielded a significant effect for the stimulus conditions ($F(2, 62)=18.64$, $p<.001$).

2 A repeated measure ANOVA yielded a significant effect for the stimulus conditions ($F(2, 62)=18.64$, $p<.001$).

3 A repeated measure ANOVA yielded a significant effect for the stimulus conditions (*Mauchly's W*=.56, $\chi^2(2)=17.38$, $p<.001$; Greenhouse Geisser: $F(1.39, 43.07)=102.43$, $p<.001$) and a significant interaction for stimulus conditions x group ($F(1.39, 43.07)=8.39$, $p<.001$). A one-way ANOVA yielded a significant difference between empathizers and systemizers ($F(1,32)=11.62$, $p<.001$).

Correctness of the explanation: A repeated measure ANOVA yielded that the three stimulus conditions differ significantly: More correct answers were given for PUNs in comparison to TOMs ($t(32)=7.07$, $p<.001$), as well as for SEMs in comparison to TOM cartoons ($t(32)=6.72$, $p<.001$). The interaction as well as the one-way ANOVA was not significant.

Following this, the subjective comprehensibility ratings and the correct explanations of the 15 cartoons were compared: It is remarkable that the sums of the correct explanations (mean sum=9.91, $SD=2.83$) were slightly lower than the subjective comprehensibility responses (mean sum=13.55, $SD=1.92$); this can be explained by the circumstance that in some cases participants indicated that they subjectively understood the cartoon but gave an incorrect explanation according to the definitions of the LM.

Correlations were computed for the mean subjective comprehensibility response (whether the participants indicated that they had understood the cartoon or not) of the five PUNs, SEMs and TOMs that had to be explained and the mean correctness of the explanation (whether they referred to the correct LM in their explanation). For the five PUNs, there was a high correlation ($r=.67$, $p<.001$). For the five SEM cartoons, the correlation was also positive ($r=.40$, $p<.05$). Interestingly, there was no significant correlation for the correctness of the explanation and the comprehensibility response in TOM cartoons ($r=.29$, $p=.103$). This means that the participants gave explanations that sometimes had nothing to do with the real LM. Therefore people found some aspect of the cartoon funny, but not necessarily the correct LM.

Emotional/motivational explanations: A repeated measure ANOVA revealed a significant main effect for the stimulus conditions. The participants referred to emotional or motivational states significantly more often in TOMs than in PUNs ($t(32)=6.06$, $p<.001$) and more often in TOMs than in SEMs ($t(32)=3.73$, $p<.01$). Although the interaction was not significant, empathizers were compared to systemizers in order to identify tendencies in the response patterns: Empathizers referred significantly more often to emotional or motivational states in PUNs ($F(1, 32)=6.91$, $p<.05$).

Mentalistic explanations: A repeated measure ANOVA showed a significant main effect for the stimulus condition. Single comparisons yielded significant differences for PUN vs. SEM ($t(32)=3.71$, $p<.01$), SEM vs. TOM ($t(32)=8.65$, $p<.001$) and PUN vs. TOM (*t*(32)=10.46, *p*<.001). The interaction was significant. Empathizers give significantly more mentalistic explanations in the TOM condition than systemizers (*F*(1,32)=11.62, *p*<.01). Independent of the stimulus conditions, empathizers and systemizers did not differ.

Funniness and correctness of the explanation: Although not in the scope of the main questions of this paper, the effect of the correctness of the explanation on the perceived funniness was also analyzed by comparing the mean funniness of correctly explained cartoons to the mean funniness ratings of incorrectly explained cartoons. As only a part of the participants had both correctly and incorrectly explained cartoons for each of the three cartoon types, three separate paired sample t-tests were computed (had an ANOVA been administered most participants would have had to be excluded due to missing data). The comparison of the funniness ratings of the PUNs that were explained correctly (*M*=2.16, *SD*=1.34) with the funniness ratings of the PUN cartoons that were not explained correctly (*M*=2.01, *SD*=1.33) showed no significant effect (*t*(19)=.40, *p*=.691). It has to be mentioned here that only those participants were included in the analysis who gave at least one wrong or at least one correct explanation (N=20).

Correctly explained SEM cartoons (*M*=3.00, *SD*=1.12) were perceived to be funnier than incorrectly explained SEM cartoons (*M*=1.65, *SD*=1.54) (*t*(21)=3.96, *p*<.001), whereas correctly explained TOM cartoons (*M*=3.19, *SD*=1.17) were not perceived to be funnier than incorrectly explained TOM cartoons (*M*=2.79, *SD*=1.37) (*t*(27)=1.61, *p*=.120). Although there is a tendency that correctly explained cartoons are perceived as funnier, this cannot be confirmed for all three conditions.

Discussion

The main results of the first study can be summarized as follows: whereas there were no significant differences in recognition time and in the comprehensibility and funniness ratings between empathizers and systemizers, they gave different explanations as to why a cartoon was perceived as funny. In particular, empathizers more often give mentalistic explanations in Theory of Mind cartoons. Furthermore, empathizers tend to give emotional/motivational explanations in visual puns more frequently. This is remarkable, because PUN cartoons can actually be explained without taking into account emotional or motivational states—the joke is based essentially on visual ambiguity. However, as the interaction was not significant it cannot be claimed that this effect is stable, so it needs to be investigated with a second sample.

LMs seem to influence humor processing: The three groups of LMs differed on all dependent variables except for subjective comprehensibility and funniness ratings. A previous study showed that social aspects in SEM and particularly TOM cartoons, in contrast to PUNs, which are mainly based on visual ambiguities, lead to an increase in the funniness response (Samson et al. 2008). As the present study does not confirm this (although there is a tendency for it) a further study with more participants will investigate this effect. However, it can be shown here, that TOM cartoons provoke significantly more mentalistic explanations than SEM cartoons, and the latter more than PUNs. It might be concluded that not all humorous stimuli require mentalizing to the same degree.

It is striking that the group of empathizers consists of 88% females, whereas the group of systemizers consists of 94% males, but in line with E-S Theory: Sex differences are found in empathizing (stronger in females) and systemizing (stronger in males). A growing body of evidence suggests that males spontaneously systemize to a greater degree than do females, while females spontaneously empathize to greater degree than do males (Baron-Cohen et al. 2003; Lawson et al. 2004). In this study we were not interested in gender differences in humor processing, but in the absolute values on the EQ and SQ. However, some studies have shown that males and females do not show differences in cognitive humor processing (e.g., the preference for incongruity-resolution humor, see Ruch and Hehl 1998, or Lowis 2002). To clarify the influence of gender on humor explanations, a second study that considers explanations given by empathizers and systemizers will pay attention to the amount of males and females in the two groups.

Although systemizers did not perform worse than empathizers on the rating scales and the correctness of explanations in this experiment, it might be possible that systemizers have difficulties recognizing when something (an utterance or action) is intended to be funny. This is suggested in a study by Baron-Cohen (1997a) that showed that autistic children (normally having higher systemizing and lower empathizing abilities) have a persistent failure to "get jokes". The participants in the present experiment knew that they had to judge and explain humorous cartoons, therefore this aspect was not tested. This could be taken into account in a further study, for example, by including pictures that resemble cartoons but contain only incongruities that can not be resolved (see, for an example, Samson et al. 2008). If systemizers really have difficulties recognizing when something is intended to be funny, they might not realize that a non-funny cartoon (i.e., a stimulus without the possibility of being resolved) does not contain resolvable incongruities and therefore is not funny.

Study 2

In order to back up the results of the first study, a second sample was investigated with several alterations. First, the aim was to find a group of empathizers and systemizers that does not differ in the distribution of genders. Thus, the selection criteria were different from the first study. The data presented here are part of a study that aimed to investigate humor processing of individuals with AS in contrast to healthy controls with varying degrees on the EQ and SQ (Samson and Hegenloh 2008). Here, only healthy individuals with extreme scores on the EQ and SQ were taken into account. As the data were collected online, several differences exist between the first and second study: As the participants had to explain *each* cartoon in writing, the number of the stimuli had to be reduced in order to reduce the overall length of the experiment. Furthermore, no recognition times were collected as the program did not allow for that. The online study again presented PUNs, SEMs and TOMs, but also an additional control condition which consisted of unfunny pictures containing an irresolvable incongruity (INC). This made it possible to identify whether systemizers are worse in distinguishing between humorous and non-humorous stimuli.

Method

Participants

Participants were recruited via mailing lists at Swiss and German universities. In total, 113 healthy participants (mean age 25.37 years, *SD*=6.21) completed the online experiment. 61% of them were female. The EQ and SQ did not correlate significantly (r=-.13, p=.171).

The aim was to determine and select empathizers and systemizers according to their median split for males and females separately (see table 4 for means, *SD* and median). 18 females and 8 males were identified as empathizers, 11 males and 18 females were identified as systemizers. The distribution of males and females over empathizers and systemizers differed not significantly ($\chi^2(1)=.31$, $p=.577$). Empathizers and systemizers differed significantly on the EQ ($F(1, 54)=100.30$, $p<.001$, as well as on the SQ ($F(1, 54)=47.16$, $p<.001$).

Table 4: Means and standard deviations on the EQ and SQ of all subjects that filled in the questionnaire and the selected subjects (empathizers and systemizers) for the main experiment in study 2.

		EQ ***M (SD); median***	**SQ** ***M (SD); median***
Whole sample	females (N=69)	13.94 (5.27); 14	7.09 (3.91); 7
	males (N=44)	11.54 (6.20); 13	11.70 (5.25); 10
	total (N=113)	13.01 (5.57); 14	8.89 (5.00); 9
Empathizers	females (N=18)	18.22 (3.06)	3.06 (1.80)
	males (N=8)	17.99 (3.63)	8.25 (2.60)
	total (N=26)	17.85 (3.22)	4.65 (3.17)
Systemizers	females (N=18)	8.28 (4.08)	9.67 (2.63)
	males (N=11)	7.00 (4.22)	14.64 (4.41)
	total (N=29)	7.79 (4.10)	11.55 (4.14)

Stimuli

As humorous stimuli, the same conditions (PUN, SEM and TOM cartoons) as in study 1 were investigated. In order to avoid humor fatigue effects (Forabosco 1994) and because for *each* cartoon an explanation had to be given, only eight stimuli per cartoon condition were presented. Additionally, four pictures containing an irresolvable incongruity served as a control condition (INC). These cartoon-like pictures are perceived to be non-funny and have high residual incongruity (see Samson et al. 2008).

Design and procedure

In the mailing lists people were invited to participate in an online humor experiment. In the beginning of the experiment, they received instructions to rate each cartoon for comprehensibility (yes/no), for funniness on a 6 point scale (from 0 to 5) and to explain in writing why they thought a cartoon was funny as well as to explain the punch line. Before the humor experiment started, participants were asked to fill in the EQ and SQ (as in study 1) online. In total, 29 stimuli (24 funny cartoons and four control stimuli and one warm-up) were presented in random order.

Results

After the description of interrater reliability, 4 x 2 repeated measure ANOVAs for the humor ratings with the four stimulus conditions as within-subjects factor and empathizers vs. systemizers as between-subjects factor will be reported. For the humor explanations, 3 x 2 repeated measure ANOVAs with PUN, SEM and TOM will be computed. These analyses will be followed by Bonferroni-adjusted single comparisons and one-way ANOVAS to compare empathizers vs. systemizers independent of the stimulus conditions.

Coding System

As in the first study, the explanations were coded for the correctness of the explanation, the reference to emotional or motivational states and for mentalistic explanations.

In order to test the reliability of the coding procedure, a random sample of 110 explanations per coding (in total 330 codings, 25% of the 1320 codings) was coded by a second rater. Interrater reliability was satisfactorily high: For correct explanations in general (κ=.98), for PUNs (κ=1.00), SEM (κ=.94) and for TOMs (κ=.99); for reference to emotional/motivational states in general (κ=.98), for PUNs (κ=.98), SEM (κ=.98) and for TOMs (κ=.97); for mentalistic explanations in general (κ=.92), PUN (κ=.73), SEM (κ=.86) and TOMs (κ=.94). Neither of the coders knew whether the participants were systemizers or empathizers.

Humor ratings

Table 5 reports means, standard deviations and Cronbach α's of the humor ratings, as well as the general statistics. Computing of Cronbach α's showed that the independent variables are stable constructs except of the INC condition. This is probably due to the number of stimuli in the control condition (four). The intercorrelations were high on comprehensibility for the cartoon conditions (PUN–SEM: r=.56, p<.001; PUN–TOM: r=.50, p<.001; SEM–TOM:

r=.46, *p*<.001), but not between the control and the cartoon conditions (INC-PUN: *r*=.16; INC-SEM: *r*=.32, *p*<.05; INC–TOM: *r*=.15) and high on funniness (INC-PUN: *r*=.55, *p*<.001; INC-SEM: *r*=.44, *p*<.01; INC–TOM: *r*=.42, *p*<.01; PUN–SEM: *r*=.84, *p*<.001; PUN–TOM: *r*=.69, *p*<.001; SEM–TOM: *r*=.78, *p*<.001).

<u>Table 5:</u> *Means, standard deviations and Cronbach α's of the comprehensibility and funniness ratings for the INC (4 per condition), PUN, SEM and TOM cartoons (8 per condition) in dependence on the two groups (empathizers and systemizers) in study 2 (N=55).*

		Empathizers	**Systemizers**	**Cronbach α**
Comprehensibility[1]	INC	.39 (23)	.43 (.34)	.336
M (SD)	PUN	.73 (.18)	.67 (.23)	.591
	SEM	.84 (.14)	.80 (.17)	.570
	TOM	.82 (.16)	.82 (.18)	.623
Funniness[2]	INC	1.91 (1.04)	1.67 (.82)	.547
M (SD)	PUN	3.68 (1.00)	2.98 (1.08)	.763
	SEM	4.15 (1.03)	3.27 (.97)	.759
	TOM	4.41 (1.10)	3.57 (.97)	.801

[1] For all dependent variables, 4 x 2 repeated measure ANOVAs were computed with the four stimulus conditions as within-subject variable and the groups (empathizers vs. systemizers) as between-subject variable. Furthermore, a one-way ANOVA was computed for the groups independently of the stimulus conditions. There was a significant effect of the stimulus conditions (Mauchly's *W* =.45, $\chi^2(5)$=41.30, *p*<.001; Greenhouse Geisser (*F*(1.93, 102.37)=61.94, *p*<.001) in *comprehensibility.*
[2] Significant effect of stimulus conditions (Mauchly's *W* =.64, $\chi^2(5)$=21.52, *p*<.01; Greenhouse Geisser (*F*(2.38, 116.53)=122.49, *p<.001)* on funniness. Furthermore, a one-way ANOVA yielded a significant difference between empathizers and systemizers (*F*(1, 49)=7.95, *p*<.001).

Comprehensibility: The four stimulus conditions differ significantly in their comprehensibility (all *p*<.001): INC vs. PUN: *t*(54)=6.36; INC vs. SEM: *t*(54)=10.49; INC vs. TOM: $t(54)=9.50$; PUN vs. SEM: $t(54)=4.99$; PUN vs. TOM: $t(54)=4.75$, except for the comparison SEM vs. TOM. The interaction was not significant. Furthermore, there was no significant group difference independent of the four stimulus conditions.

In order to investigate if systemizers have difficulties recognizing when something is intended to be funny a difference score was computed between the three cartoon conditions minus the control condition. A one-way ANOVA showed that empathizers and systemizers did not differ in their ability to discriminate between humorous and non-humorous stimuli ($F(1, 54)=.68$, $p=.413$).

Funniness: For the analysis of the funniness response, mean funniness ratings of the subjectively understood cartoons and of the non-understood (in contrast to misunderstood) INCs were computed. The stimulus conditions differed significantly (Mauchly's $W = .64$, $\chi^2(5)=21.52$, $p<.01$; Greenhouse Geisser ($F(2.38, 116.53)=122.49$, $p<.001$). All stimulus conditions differed significantly from each other (all $p<.001$: INC vs. PUN: $t(50)=11.33$; INC vs. SEM: $t(50)=12.74$; INC vs. TOM: $t(50)=14.19$; PUN vs. SEM: $t(54)=5.71$; PUN vs. TOM: $t(54)=5.71$), except for SEM vs. TOM. The interaction of stimulus conditions x groups was marginally non-significant ($F(2.38, 116.53)=2.74$, $p=.059$). However, there was a significant group effect independent of the stimulus conditions: Empathizers have significantly higher funniness scores than systemizers ($F(1, 49)=7.95$, $p<.01$).

Humor explanations

For each participant, the sums of correct explanations, emotional/motivational and mentalistic explanations were averaged for each humorous stimulus condition. The codings were analyzed with 3 x 2 repeated measure analyses with the three cartoon conditions as within-subjects variable and empathizers vs. systemizers as between-subject variable, followed by Bonferroni-adjusted single comparisons (see table 6 for statistics).

Table 6: Means and standard deviations for the correctness of the explanation, whether an emotional/motivational and a mentalistic explanation was given for the 8 cartoons of each stimulus condition (PUN, SEM, and TOM) in dependence on the two groups (empathizers and systemizers) in study 2 (N=55).

		Empathizers	**Systemizers**
Correctness[1]	PUN	5.38 (2.23)	5.24 (2.05)
	SEM	6.38 (1.77)	6.41 (1.82)
	TOM	5.42 (1.50)	4.93 (1.44)
Emotional/motivational	PUN	1.54 (1.50)	.72 (1.11)
Explanation[2]	SEM	1.85 (1.26)	1.66 (.97)
	TOM	4.00 (1.60)	2.66 (1.56)
Mentalistic explanation[3]	PUN	.35 (.56)	.03 (.19)
	SEM	.42 (.70)	.03 (.19)
	TOM	3.18 (1.07)	2.31 (2.01)

[1] For all dependent variables, 4 x 2 repeated measure ANOVAs were computed with the four stimulus conditions as within-subject variable and the groups (empathizers vs. systemizers) as between-subject variable. Furthermore, one-way ANOVAs were computed in order to analyze the difference between empathizers and systemizers independently of the stimulus conditions. There was a significant main effect for stimulus conditions $F(2, 106)= 17.10$, $p<.001$) regarding the correctness of the explanations.

[2] There was significant main effect for stimulus conditions (Mauchly's $W=.85$, $\chi^2(2)= 8.55$, $p<.05$, Greenhouse Geisser: $F(1.74, 92.04)=61.92$, $p<.001$) regarding the reference to emotional and motivational states, as well as a significant interaction ($F(1.74, 92.04)=4.03$, $p<.05$). Furthermore, empathizers give more emotional/motivational explanations ($F(1,53)=7.95$, $p<.01$).

[3] There was significant main effect for stimulus conditions (Mauchly's $W=.32$, $\chi^2(2)=59.46$, $p<.001$; Greenhouse Geisser ($F(1.19, 63.05)=88.03$, $p<.001$) regarding mentalistic explanations. Furthermore, empathizers give more mentalistic explanations ($F(1, 53)=8.91$, $p<.001$).

Correctness of the explanation: A repeated measure analysis revealed a significant effect for the stimulus conditions ($F(2, 106)=17.10$, $p<.001$). SEM cartoons provoked more correct explanations than PUN ($t(54)=5.32$, $p<.001$) and TOM ($t(54)=5.50$, $p<.001$), whereas PUN and TOM did not differ from each other. As in the first study, the interaction of stimulus conditions x groups was not significant. There was a no significant group effect independent of the stimulus conditions.

Emotional/motivational explanations: A repeated measure analysis revealed a significant main effect for the stimulus conditions: In TOMs, the participants referred to emotional or motivational states significantly more often than in PUNs ($t(54)=9.45$, $p<.001$) and in SEMs ($t(54)=6.89$, $p<.001$), as well as more often in SEMs as compared to PUNs ($t(54)=3.86$, $p<.001$). Furthermore, the interaction was significant. Empathizers gave more emotional/motivational explanations independent of the stimulus conditions, as well as in PUNs ($F(1, 54)=5.34$, $p<.05$) and in TOMs ($F(1, 54)=24.79$, $p<.01$). Therefore, the tendency for empathizers to refer more often to emotional or motivational states found in the first study was confirmed.

Mentalistic explanations: The stimulus conditions differed significantly from each other: TOM cartoons provoked significantly more mentalistic explanations than PUNs ($t(54)=9.40$, $p<.001$) and more than SEMs ($t(54)=9.63$, $p<.001$). The interaction was not significant. However, empathizers gave significantly more mentalistic explanations than systemizers independently of the stimulus conditions.

Discussion

Overall, the replication sample revealed comparable results to study one, as well as some new findings: First, no differences in comprehensibility were found between the two groups of empathizers and systemizers, which is in line with the first study. Second, empathizers show a higher emotional response (i.e., funniness scores) than systemizers, which is in contrast to the first study. A reanalysis of all 113 participants of the second study showed that funniness scores correlated significantly with the difference of empathizing-systemizing scores in all three cartoon conditions (PUN: $r=.29$, $p<.01$, SEM: $r=.27$, $p<.01$ and TOM: $r=.29$, $p<.001$). As this sample was bigger than in the first study, it is very possible that empathizing and systemizing do indeed influence the emotional response towards humorous stimuli. Third, empathizers and systemizers did not significantly differ in the number of correct explanations, as in the first study. However, empathizers refer to emotional or motivational states (in PUNs and TOMs) more often, which was assumed on the basis of the first study. Concerning the mentalistic explanations, the results of the first study could be replicated: Empathizers give more mentalistic explanations and, again, TOM cartoons provoked more explanations that refer to false mental states.

General Discussion

These are the first studies to investigate the influence of the two cognitive styles empathizing and systemizing (e.g., Baron-Cohen 2003) on cognitive and affective humor processing in non-verbal cartoons with different Logical Mechanisms (LMs) or LM groups (visual puns, semantic cartoons and Theory of Mind cartoons). That the three groups of LMs provoke different brain activation patters had already been shown in a previous study (Samson et al. 2008). The present paper shows that stimulus characteristics, such as the LM, also influence response patters that can be seen in rating scales, but mainly in explanations why the participants think a cartoon is funny. The requirement for mentalizing to understand the punch line in TOM cartoons leads to longer recognition times, as well as more emotional and mentalistic explanations. Furthermore, TOM cartoons, as well as SEM cartoons are perceived to be funnier than PUNs based on visual ambiguity. This confirms that social cognition and involvement, such as mentalizing, can be seen as factors that enhance funniness (Samson et al. 2008). Visual puns seem to be more difficult to understand and provoke less emotional/motivational and mentalistic explanations.

However, not only stimulus characteristics influence the humor response: As the second study revealed, systemizers are not less able to discriminate between potentially funny and unfunny material. Furthermore, empathizers and systemizers differ on none of the comprehensibility variables (neither the subjective comprehensibility nor the correctness of the explanation). Therefore, the conclusion can be drawn that empathizers—known to have better Theory of Mind abilities than systemizers—do not understand humor *better,* which would have been predicted by the mind-reading hypothesis (Howe 2002), but *differently*: For example, it seems to be a characteristic of empathizers—known to have stronger emotional and cognitive empathy—to refer more often to emotional or motivational states even if the joke is abstract (as in visual puns) and although emotional/motivational states are not the main incongruity or LM of the joke. This is remarkable, because PUN cartoons actually can be explained without emotional or motivational states, since the joke is based mainly on visual ambiguity. Systemizers, on the other hand, tend to give logical or abstract explanations more often, while they give less emotional or motivational explanations. That empathizers and systemizers differ in their reference to emotions and mental states is in line with the assumptions of Baron-Cohen's E-S theory (2003), which predicts that empathizers tend to focus on making sense of an agent's behavior and have the drive to identify another person's emotions and thoughts, whereas systemizers tend to focus on the behavior of non-agentive events or objects or non-emotional aspects of agents.

The second study showed that empathizers show even higher funniness ratings than systemizers. This effect might be due to higher emotional responsiveness related to higher emotional empathy. Emotional responsiveness influences the humor response was already shown by Herzog and Anderson (2000). However, the instrument (empathizing and systemizing scales) used here is not sensitive to different components of empathizing (e.g., more cognitive or more emotional components). Future studies might investigate the relationship between emotional and cognitive empathy in relation to different LMs in more detail. However, it has to be mentioned here that the present study did not investigate the relation between EQ, SQ and other cognitive measures (e.g., verbal IQ, executive function)—again, future studies might address this question.

Interestingly, the affective response was largely independent of the correctness of the explanation (only in SEM cartoons were the funniness ratings higher when the participants referred to the correct LM; see study 1). More important is that the participant has the impression that he or she understood the cartoon. In other words: it is important to resolve an incongruity in any way and to make sense *subjectively*, but it is not important whether the intended LM is recognized. Even if a certain cartoon is based on "obvious error" (Paolillo 1998; Attardo et al. 2002) or (as in our study) TOM, it does not necessarily mean that all individuals perceive exactly this cognitive rule. Individuals may sometimes apply other cognitive rules. Ruch (1981) has already shown participants who have the impression that they understand the punch lines correctly but give totally different explanations. According to Hempelmann and Attardo (in press), a joke or cartoon may consist of several incongruities, but have a salient one that must be resolved in order to understand the punch line of the joke or cartoon. The other incongruities, called backgrounded incongruities, may or may not additionally influence the perceived funniness. It might be interesting to investigate whether participants who refer to the backgrounded incongruities instead of the foregrounded incongruity show lower amusement.

The second study included a control condition was included in order to investigate participants' discrimination ability between humorous stimuli and stimuli that can not be meaningfully resolved. It nevertheless remains open whether systemizers have more difficulties recognizing that an utterance is intended to be funny in a *social situation*. Whether systemizers understand humor less well in daily life or whether they might have similar difficulties as described for individuals with AS or autism (Baron-Cohen 1997a) has not yet been investigated. Therefore, it is conceivable to design an experiment that investigates humor more specifically in a social setting.

Taken together, the studies in this paper show that cognitive as well as affective humor processing is influenced, on the one hand, by stimulus characteristics such as the LM, and, on the other hand, by inter-individual characteristics such as empathizing and systemizing. As the present study shows, it depends on stimulus characteristics as well as inter-individual differences whether mentalizing or Theory of Mind is required or applied in humor processing, the view that humor processing *always* requires mentalizing is too simplistic (e.g., Howe 2002). This has the important implication that if future research focuses on Theory of Mind in relation to humor, it is important to select or control the stimuli carefully for their LM and the resulting cognitive requirements. Differences in stimulus characteristics might explain why some of the previous studies support a tight relation between Theory of Mind and humor (e.g., Uekermann et al. 2006) while others do not (e.g., Werth et al. 2001). Furthermore, the present study revealed that it is fruitful to analyze explanations as to why someone thinks a cartoon is funny. As these were not reflected in rating scales and recognition times alone, it is suggested to include explanations more often in further studies in order to gain deeper understanding of cognitive mechanisms underlying the humor response.

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13 General Discussion

This dissertation aimed to contribute to the disentangling of humor processing, in particular the core process of humor appreciation—incongruity-resolution—with a multi-method approach, namely, functional Magnetic Resonance Imaging (fMRI), explanations on why a stimulus seems to be funny and rating scales, against the background of psychological and cognitive-linguistic humor theories. Cognitive and affective processes with their neural correlates were analyzed in dependence on structural aspects of humorous stimuli and in dependence on individual differences in experience seeking, empathy and Theory of Mind in healthy subjects. An important part of this thesis is the focus on the relationship between humor processing and Theory of Mind as a stimulus characteristic but also as an ability (as part of empathy) that varies between individuals.

The most important results can be summarized as follows: a neural network could be circumscribed which is involved in the incongruity-resolution process (e.g., ventromedial prefrontal cortex, vmPFC, temporo-parietal junction, TPJ, inferior frontal gyrus, IFG). Furthermore, the neural correlates in processing of incongruity-resolution and nonsense humor were investigated—two types of humor that differ regarding the resolvability of the incongruity (e.g., Ruch, 1992, 2007). The contrast of these two types of humor confirmed the TPJ to be involved in the process of integrating information or making sense out of incongruities: incongruity-resolution humor provoked more activation in the TPJ than nonsense humor. But also other formal properties of cartoons influence humor processing, such as Logical Mechanisms (LMs), i.e., cognitive rules on how two scripts are related to each other and which ones have to be recognized in order to understand the punch line of the joke. This is the first empirical investigation that focuses on the influence of LMs on the humor response, e.g., such as the neural response. LMs were shown to evoke different networks: particularly visual puns (PUNs) and Theory of Mind cartoons (TOM) evoke different activation patterns. PUNs require more activation in the extrastriate cortex, whereas TOM cartoons require more “mentalizing areas” such as the anterior medial PFC (amPFC) or areas around the TPJ. From these results it can be concluded that not all humorous stimuli require mind-reading to the same degree. Another study confirmed that it is the dependency on LMs that determines whether mind-reading is required in order to understand the punch line which can be shown by analyzing the explanations on why a certain stimulus seems funny to someone. Furthermore, the study also showed that it doesn’t only depend on stimulus characteristics whether people mentalize, but also on individual differences: higher scores on an empathy scale lead to more emotional/motivational and mentalistic explanations of the punch line. Therefore, different methods showed that LMs influence humor processing. But also another personality characteristic revealed its influence on neural activation patterns during humor processing: individual scores on experience seeking (Zuckerman, 1994) moderated the neural response. Most intriguing here was the activation in the hippocampus which is known to process novelty of stimuli.

On the stimulus side, structural elements were varied in these studies, rather than the content, because structural elements, such as the resolvability of the incongruity, were shown to be at least as important as the content (e.g., Ruch & Hehl, 2007). As the stimuli used in the present studies are cartoons—i.e., non-verbal, one-panel and, to a varying degree, funny pictures—the main part of this dissertation starts off with an overview of cartoon research. Studies that focused mainly on formal aspects of visual humor and its effects on humor response were presented in this chapter. Cartoons were defined as humor-carrying visual/visual-verbal pictures, containing at least one incongruity that is playfully resolvable in order to understand the punch line. Whenever they share the same humor-related core-elements (incongruity, incongruity-resolution) with jokes, there are crucial differences between verbal humor and (verbal-)visual humor—such as cartoons: cartoons are not read in a linear way, as we know from research in reading and eye tracking experiments (e.g., Mitchell et al., 2008). In the picture part of a cartoon, usually no clear order of processing is forced in the way a text does, but there is the tendency to follow a general order, which can crucially be directed by the artist creating entry points and paths in their picture. In jokes, information is given in a very restrictive way (without semantic ornament). In contrast to jokes, cartoons have almost unlimited room for the placement of details, which may not be related to the central elements of the humor at all or provide even further non-focus incongruities. These additional pieces of information (e.g., additional fully backgrounded incongruities) can also help to enhance the suspension of disbelief (cf., Hempelmann & Attardo, in press). Other additional information, which can be given in cartoons but not so easily in jokes, are facial expressions or emotions of the characters. A general difference to cartoons is that verbal jokes work on the textual semiotic level, while cartoons use the iconic visual one—maybe even with textual support. This leads to the possibility of distributing humorous elements differently in cartoons: within the picture, in the text, or between text and picture, etc. Finally, another intriguing difference between jokes and cartoons is the iconicity which can be reflected best in *visual puns*—they represent one distinct subgroup of cartoons—and which are of particular interest in the present dissertation (see also Hempelmann & Samson 2007, Mitchell 2007). In visual puns one visual element signifies two meanings simultaneously, or in other words, activates two scripts at the same time. As one visual element is related to two meanings, visual puns are difficult to translate into verbal jokes. Visual puns function because a visual symbol must always resemble that which it stands for—this is called iconicity. Their iconicity leads to the circumstance that different levels of abstraction bring about different degrees to which a visual pun is compatible with both of its meanings (see also McCloud, 1993; Hempelmann & Samson, 2007). Given that formal aspects of visual humor affect humor response decisively, the stimuli of the studies presented in this thesis were carefully controlled for several formal aspects (e.g., color, resolvability of the incongruity, etc.).

The present dissertation measured humor processing and appreciation by using different methods; recognition times, comprehensibility and funniness ratings. Furthermore, explanations on why someone perceives a certain stimulus to be funny were included as well. The neural response was measured by means of functional magnetic resonance imaging (fMRI). Especially for cognitive processes that are not necessarily expressed in overt behavior, imaging techniques such as fMRI are suitable, as they are not dependent on reactions, but can even picture pre-steps of reactions.

As already briefly mentioned, one important finding of the present thesis is the network that is involved in the incongruity-resolution process merely without pre-processing steps (such as the setup stage or the detection of an incongruity). This was revealed by creating a control condition that contained irresolvable incongruities and contrasting it to humorous cartoons. The following areas are only involved in incongruity-resolution: mvPFC—probably associated with the affective part of humor processing or with the integration between cognition and affective states (Adolphs, Tranel & Damasio, 2003; Damasio, 1994, 1996; Damasio, Tranel & Damasio, 1990)—bilateral supramarginal gyrus, bilateral (but more pronounced in the left) TPJ and left IFG. The latter area was confirmed to be involved in the comprehension stage (semantic and language related processes) of humor processing, as in all the previous fMRI studies. A crucial result here is that the TPJ was shown to be involved in the resolution of the incongruity and not in incongruity-detection which was suggested in earlier studies (e.g. Mobbs et al., 2003). The TPJ seems to play an important role during information integration which is crucial for the incongruity-resolution stage where the incongruity of the joke has to be re-interpreted in order to make (partially) sense. Therefore, this study helped to understand in more detail what the underlying neuronal correlates of humor processing are. Previous studies—in contrast— did not have control conditions that made it possible to distinguish the resolution stage from previous stages as they presented funny stimuli and contrasted them with a non-funny control condition (e.g., Mobbs et al., 2003; Bartolo et al., 2006; Wild et al., 2006).

An area that was associated with unsuccessful humor processing, i.e., processing of pictures containing an irresolvable incongruity, is the rostral cingulate zone. This area is probably involved in conflict monitoring, error processing or processing under increasing uncertainty (see Botvinick, Cohen & Carter, 2004, for a review; Volz, Schubotz & von Cramon, 2003). As this area was also shown to be activated during response competition (Ullsperger & von Cramon, 2001), it is conceivable that this activation reflects the conflict in which the activated scripts (that cannot be integrated) are perceived to be during the attempt to understand the joke of a picture that does not contain a punch line.

Another important result is that groups of LMs evoke slightly different brain activation patterns. Whereas processing of semantic cartoons (SEM) requires the same pattern as humor processing in general, there were differences to PUNs, as well as TOM cartoons. As already mentioned, PUNs have in common that one visual element evokes two scripts simultaneously. This stimulus group provoked more activation in the extrastriate cortex which might reflect a play with several meanings evoked by one visual element. As in PUNs, visual elements themselves are of great importance for the punch line and the activation in the extrastriate cortex might also be due to more visual attention as well as visual cognition. In further studies, it would be interesting to investigate several groups of PUNs in more detail. Hempelmann and Samson (2007) described several subgroups of PUNs, e.g.: perfect puns (one visual element has effectively two possible meanings) or imperfect puns (the second meaning or scripts is only evoked through the context, no complete visual identity). It might be interesting to investigate whether the extrastriate cortex is involved to a different degree in processing various groups of PUNS.

TOM cartoons, the third group of LMs, had in common that false mental states had to be attributed to the characters portrayed in the cartoon in order to understand the punch line.

These cartoons provoked more activation in so-called mentalizing areas[6] (amPFC, areas around the TPJ and the fusiform gyrus). As these areas were not activated (or in the case of the TPJ: to a lesser degree) in SEM cartoons, and particularly not in PUNs, it is suggested that mentalizing is not always involved in humor processing such as Howe (2002) or Jung (2003) claimed. From this analysis it can be concluded that it depends on stimulus characteristics (such as the LM) whether mentalizing is required or not (for more about the relation of Theory of mind and humor processing, see below).

This study is the first empirical investigation of the influence of LMs on humor processing which confirms the GTVH (Attardo & Raskin, 1991). Up to now, only a few studies analyzed humorous stimuli regarding their LMs (e.g., Paolillo, 1998; Tsakona, 2006, in press; Hempelmann & Ruch, 2005) but no study focused on the influence of LMs on humor processing. The method of fMRI is very useful here as it demonstrates that LMs require slightly different neural circuits although LMs do not necessarily force differences revealed on ratings scales (comprehensibility, funniness). In the pre-examinations, differences in funniness between the three groups were not found, or in other words: the stimuli were selected in a way that they did not differ on funniness, for example. This was necessary in order to exclude differences in funniness ratings to influence the neural response. In order to understand humor processing, it is therefore rewarding to integrate brain imaging techniques such as fMRI.

The second analysis of the neuronal data showed that incongruity-resolution humor evoked more brain activity than nonsense humor in several areas that are associated with working-memory processes, but also with the integration of information (incongruity-resolution). Making sense out of opposed scripts and to integrate information (as in incongruity-resolution) can be interpreted as a more complex process in contrast to laughing rather about irresolvable incongruities (as in nonsense humor). Incongruity-resolution humor seems not only to require more integration of multi-sensory information and coherence building but also more mental manipulation and organization of information. This is not evident at first glance, as nonsense humor was postulated to be the more complex and the

[6] The author does not intend to claim that in the so-called mentalizing areas only Theory of Mind related processes are associated with. A recent meta-analysis by Decety and Lamm (2007) showed that, for example, in the TPJ, not only mentalizing processes are localized, but also lower computational processes that might be associated with attention shifts. With “mentalizing areas” the author refers here to the areas that are typically activated during Theory of Mind (attribution of [false] mental states) tasks, without claiming that those areas are only involved in mentalizing: the TPJ (sometimes also called posterior superior temporal sulcus), amPFC and fusiform gyrus.

more superior form of humor (e.g., Ruch, 1999). However, the more information can be integrated, the more activation can be found in areas that are involved in the incongruity-resolution process (e.g., TPJ).

One might ask which structural properties are more important for the humor process: LMs or the categories of incongruity-resolution vs. nonsense humor? Although this thesis did not aim to answer this question, some thoughts about the relationship between LMs and incongruity-resolution humor vs. nonsense humor shall be presented here. Factorial analysis revealed two factors that can be distinguished in relation to the resolvability of the incongruity: incongruity-resolution and nonsense humor (e.g., Ruch, 1992). The dependent variables used for factorial analysis were subjective funniness and aversiveness ratings of jokes and cartoons. It is indisputable that incongruity-resolution and nonsense humor have a big impact on the preference of humorous stimuli, particularly if personality characteristics such as openness or experience seeking are taking into accout (see Ruch, 2007). However, the present fMRI study shows that for the neural correlates of humor processing, not only incongruity-resolution vs. nonsense humor, but also and particularly LMs play an important role. It can even be said that the three groups of LMs investigated in the present study provoke much bigger differences in neural activation patterns than incongruity-resolution vs. nonsense humor. However, the question of generalization on all humorous stimuli remains open. That the LMs evoke bigger differences in neural activation patterns might be also influenced by the circumstance that the selection criteria for the stimuli of the present study were in a clear order: first, stimuli were selected that belonged to PUN, SEM, and TOM and in a second step (for the second analysis) those cartoons were positioned according to ratings on residual incongruity, subtleness and grotesqueness on the continuum from incongruity-resolution jokes to nonsense jokes. This procedure might have had the consequence that the into incongruity-resolution and nonsense humor classified cartoons are not necessarily on the high and low end of the continuum. As this question remains open it can, of course, not be judged as to which of the structural properties have a bigger impact in general. However, it is possible that incongruity-resolution and nonsense humor have a bigger impact on the preference of jokes, but on the neural correlates the LM of a particular joke has a bigger impact.

The third analysis of neural correlates for humor processing concerned individual experience-seeking scores. Previous studies showed that experience seekers more often search for situations that make them laugh and humor offers them an additional mode of experiencing intensive stimulation (Deckers & Ruch, 1992; Lourey & McLachlan, 2002). In the present study, individuals with higher experience-seeking scores showed more brain reactivity towards humorous stimuli in general (independently of stimulus characteristics, such as the resolvability of the incongruity) and towards nonsense humor. This might be due to more intense exploration of humorous stimuli by experience seekers as those are a source of mental stimulation and the incongruity of a joke provides sensations through novelty. The most intriguing result here is the activation of the hippocampus—an area known to be involved in novelty processing (see Nyberg, 2005). In a previous study experience seekers were shown to have more hippocampal volume (Martin et al., 2007). Novelty is interesting in relation to humorous stimuli in two ways: first, the detection of incongruity can be seen as a violation of what was expected (e.g., Suls, 1972) and it was occasionally associated with a feeling of surprise. Second, the result of the incongruity-resolution process can be seen as a potential source of novelty. For further fMRI studies, it might be interesting to present humorous stimuli that vary in their surprisingness or incongruity and therefore probably in their novelty to individuals with varying degrees in experience seeking in order to investigate further the aspect of novelty of humorous stimuli on the involvement of the hippocampus. Furthermore, as it is well-known, the hippocampus is involved in memory processes (Kandel et al., 2000). As, for example, Schmidt and Williams (2001) showed enhanced memory for humorous material in contrast to non-humorous materials, the hippocampus might be particularly involved in the mechanism that makes humorous stimuli easier to remember (our results suggest that the underlying mechanism might be the involvement of the hippocampus during processing of humorous, i.e., novel and surprising stimuli). This topic—the relationship between novelty, hippocampus and memory for humorous materials—provides material for interesting further studies.

Remarkably, experience seekers show more brain reactivity in response to nonsense humor than to incongruity-resolution humor which seems to be, at first glance, in contrast to the circumstance that it is a more complex process for the brain to integrate opposed scripts in incongruity-resolution humor in comparison to nonsense humor. It is assumed that in nonsense humor people laugh rather about the absurdities (about the incongruities that are not completely resolvable) than about a successful resolution of incongruities. However, experience seekers—known to prefer nonsense over incongruity-resolution humor (see, for example, Forabosco & Ruch, 1994)—process nonsense humor differently. It is possible that due to their tendency to explore stimuli more intensely they process nonsense humor even more deeply than incongruity-resolution humor as the latter might be a much “simpler” humor in relation to possible associations or interpretations.

The brain response towards humorous stimuli was also analyzed in relation to the 3 WD which measures the preference for incongruity-resolution over nonsense humor[7]. A structural preference index (SPI) was built since Forabosco and Ruch (1994) suggested it in order to determine whether nonsense humor is preferred over incongruity-resolution humor or vice versa. This SPI entered a second level analysis on humor processing in general and nonsense vs. incongruity-resolution humor, but no activation trespassed the threshold at $z > 2.58$ ($p < .005$, uncorrected). This might be due to the circumstance that there was not much variation in the data obtained with the 3 WD in the 17 subjects that participated in the fMRI study. In order to investigate whether the preference for incongruity-resolution or nonsense humor influence neural processes during humor processing in a similar way than experience seeking, a further study might select people with more extreme differences in the preference for incongruity-resolution and nonsense humor.

Among the 17 subjects that participated in the fMRI study there wasn’t any significant correlation between experience seeking and the preference for nonsense over incongruity-resolution humor as previous studies found (e.g., Forabosco & Ruch, 1994). This is possibly due to the limited number of participants which is far too little to show correlations between different personality questionnaires. However, other explanations shall be briefly considered, such as the stimuli themselves. Whereas the stimuli used in the present studies are cartoons by contemporary cartoonists, the stimuli of the 3 WD might be perceived to be less funny, only due to the circumstance that they are dated. Furthermore, as the 3 WD was administered after the scanning procedure and the post-scan funniness ratings of the same stimuli, the contrast between the up-to-date cartoons and the older stimuli of the 3 WD was perhaps too extreme. It might be useful to develop a new version of the 3 WD that measures both reliably and validly the preference for incongruity-resolution and nonsense (as well as sexual humor) beyond the present 3 WD test (Ruch, 1992). However, the risk is that in a couple of years the jokes and

[7] The 3 WD consists besides incongruity-resolution and nonsense humor also of sexual humor. However, as also discussed in the second paper (Samson, Hempelmann, Huber & Zysset, in press), sexual humor is not of interest here as it taps into content related and not structural related properties of humorous stimuli. Furthermore, the stimuli used in all of the present studies here, did not contain examples of sexual humor.

cartoons are again perceived to be less funny, just because of the rather old-fashioned drawing style. A further possibility for the non-correlation between the stimuli of the 3 WD and the stimuli used in the present study is the answer format: whereas the 3 WD asks for funniness and *aversiveness*, the query of the present study focused only on the perceived funniness of the cartoons. It is known that humorous stimuli are not only perceived one-dimensionally as more or less funny, but they can provoke responses to many dimensions (e.g., Ruch & Rath, 1993; Samson & Ruch, 2005). If it is not asked additionally to determine aversiveness, the funniness response perhaps has a more washed-out or blurred character. If someone has the possibility to indicate a positive attitude towards a stimulus and separately a negative response, for example aversion to a joke due to moral reasons, the picture receiving about humor appreciation is more adequate.

As empathy and Theory of Mind are hypothesized to be essential for humor processing (e.g., Howe, 2002; Jung, 2003) and there is empirical evidence that empathy and Theory of Mind influence humor processing (e.g., Uekermann et al., 2006, 2007), the next two studies presented here investigated the perception of cartoons that differ in their LM dependent on empathizing and systemizing abilities. Empathizers (individuals with high empathizing and low systemizing scores) and systemizers (vice versa) rated PUNs, SEMs and TOMs for comprehensibility, funniness and explained why they thought a cartoon is funny, in order to reveal cognitive and emotional processes in more detail. The results of two samples not only provided repeated evidence that groups of LMs are perceived to be different, but also that empathizers tend to mentalize more often than systemizers (in giving more emotional/motivational and mentalistic explanations) and that TOM cartoons provoke more emotional/motivational as well as mentalistic explanations than PUNs and SEMs. This means that it depends on stimulus characteristics as well as interindividual differences whether mentalizing is applied or required in order to understand the punch line. Howe’s (2002) mind-reading hypothesis states that the ability to observe and understand thought processes in the mind of the subject of a joke are essential to understand humor. This might be true for Theory TOM cartoons and also for some of the SEM Cartoons. But empathizers—known to have better Theory of Mind abilities than systemizers—do not understand humor *better*, which would be the prediction of the mind-reading hypothesis, but *differently*: empathizers attribute mental states more often, even if the joke is abstract (as in visual puns) and mentalizing is actually not required in order to get the joke. The mind-reading hypothesis by Howe (2002) goes even so far as attempting to explain enjoyment of verbal puns: the real source of enjoyment of humor is the face of the person listening to the pun. Indeed, the reaction of a person to a joke might have an enhancing effect, but, according to the present results, it is most often not the source of humor in PUNs (particularly not in systemizers)—otherwise mentalizing areas had to be found to be activated in processing of puns as well (see the fMRI study). Of course, the perception of a (verbal) pun told in a social setting might be differently perceived (depending on the context or depending on the speaker) but the context does not create the core element of humor in PUNs. Therefore, I claim that Howe's theory has only limited impact/significance to explain the source of humor.

However, mentalizing or mind reading seems to be a funniness enhancing factor, which was shown in the present studies (i.e., Samson, Huber & Zysset, 2008; Samson, in press). As already mentioned in the introductory section, empathy and Theory of Mind might play a role in humor processing at several points: to understand that something (a remark, a joke) was meant to be funny, to understand the mental states of portrayed characters in a joke—especially in jokes that play with false beliefs of others. Furthermore, emotional aspects of empathy might alter the humorous response to put-down or hostile humor. However, the question is how Theory of Mind and humor are related to each other. Is the relationship between Theory of Mind and humor really that simple—in which Theory of Mind is a core element of humor processing? This hypothesis might explain some of the results found in previous studies (e.g., Uekermann et al., 2006, 2007). But on the basis of my results, I doubt that it is a simple relationship and would like to discuss another possible model. Is it possible that the incongruity-resolution process as well as mentalizing depend on the same cognitive processes which have something to do with drawing inferences, coherence building or shift of attention? If these processes are disturbed (for example through lesions in relevant brain areas) Theory of Mind tasks as well as jokes are difficult to process. The results of the meta-analysis by Decety and Lamm (2007)—that the TPJ is involved not only in Theory of Mind tasks but also in low-level computational processes that have something to do with shifts in attention—speak for the possibility that Theory of Mind as well as humor processing share the same core elements, i.e., inference drawing, as the TPJ is also a crucial area in the network that involves in humor processing. However, this hypothesis is yet to be tested in further studies.

As already mentioned, it can be concluded that it depends on stimulus characteristics whether mentalizing is required to understand the punch line. This has implications on further studies that attempt to investigate humor in relation to Theory of Mind—namely that it is necessary to control the stimuli carefully whether they might require mentalizing in order to be understood or not. This gain in knowledge can even lead to the reinterpretation of results from previous studies that focused on humor and Theory of Mind: if the humorous stimuli needed mental attribution to be understood or not. It is possible that the humorous stimuli, used in the studies which postulate a strong relationship between Theory of Mind and humor, required Theory of Mind to be understood. It would be interesting to analyze all the stimuli in those studies in more detail. However, this exceeds the limits of this thesis but encourages extended work in the future.

To summarize, this dissertation has a multidisciplinary character as it investigates behavioral and neural correlates of visual humor stimuli which are characterized according to parameters derived from cognitive-linguistic (GTVH, Attardo & Raskin, 1991) and psychological humor models (e.g., Suls, 1972; Ruch, 1992, 1995; Ruch & Hehl, 2007). The network which is involved in incongruity-resolution only, without referring to pre-processing steps, showed that the humor response alterates dependent on LMs and the resolvability of the incongruity. It also demonstrated that Theory of Mind is not always involved in humor processing as not all humorous stimuli require mental state attribution and some individuals tend to mentalize spontaneously more or less often in relation to their empathizing and systemizing skills. Furthermore, experience seeking seems to be a personality characteristic that moderates not only the humor response on pure behavioral variables but also the neural correlates of humor processing. This multidisciplinary approach seems to be helpful in elucidating complex cognitive as well as affective processes, such as humor processing, which play a crucial role in daily social interactions. The present studies also show that it is important not to rely on rating scales only if someone is interested in subtle cognitive and affective processes involved in humor appreciation. Not only is it rewarding to take into account neural mechanisms during humor processing as neural data can reveal important information about processes that don't lead directly to differences in overt behavior, but also to consider explanations on why individuals think a certain humorous stimuli is funny, as the analysis of the explanations revealed information that are overlooked if one only uses rating scales.

Moreover, many new questions can be raised on the basis of the present studies. I would like to enumerate some of them—in case they have not already been mentioned before—in the following. For example, how do people recognize that a joke or cartoon is nonsense humor? It is possible that it has something to do with the third stage of humor processing, i.e. to recognize that something is just pleasant nonsense (Ruch, 1999). Might this realization even be more intense in nonsense humor? Presumably, in processing nonsense humor, at a certain point people stop searching for a meaningful interpretation of the incongruity—what leads to the realization that there is no meaningful interpretation and could it be that the almost irresolvable incongruity is the funny element? Furthermore, what is the difference between resolution of incongruity that leads to exhilaration and resolution of incongruity that doesn’t? Is it really only the script overlap (e.g., Attardo & Raskin, 1991) and the realization that someone got fooled, that the resolution is only a pseudo-fit (e.g., Ruch, 2007)? As already mentioned above, how do the LMs relate to the resolvability of the incongruity? Is it possible that certain LMs belong more than others to incongruity-resolution or nonsense humor? One first attempt to resolve these questions was done by Hempelmann and Ruch (2005)—this approach definitively has potential to be continued. Furthermore, how are the three groups of LMs processed by individuals with limited mind-reading skills, such as individuals with Asperger syndrome, or by individuals with Williams syndrome with a marked sense for emotions and feelings of others (Tager-Flusberg & Sullivan, 2000)? These are only some of the possible further studies that are worthwhile to be conducted in order to comprehend, in more detail, the complex processes that are necessary to understand and appreciate humorous stimuli.

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List of Abbreviations

3 WD	3 "Witz Dimensionen" Humor Test
amPFC	anterior medial prefrontal cortex
AS	Asperger Syndrome
ASD	Autism spectrum disorders
BOLD	Blood oxygen level dependent
BOLD	blood oxygen level dependent
EEG	Electroencephalography
EPI	Echo-Planar-Imaging
EQ	Empathizing Quotient
FID	free induction decay
fMRI	functional magnetic resonance imaging
FWHM	Full-width half-maximum
G	Gauss
GTVH	General Theory of Verbal Humor
HFA	high functioning autism
HRF	hemodynamic response function
IFG	inferior frontal gyrus
INC	Incongruity
INCRES	Incongruity-resolution
IPL	inferior parietal lobule
KR	Knowledge Ressources
LFP	local synaptic voltage
LIPSIA	Leipzig Image Processing and Statistical Inference Algorithm
LM	Logical Mechanisms
M F G	medial frontal gyrus
MEG	Magnetencephalography
MUA	multiple-unit spiking activity
mvPFC	medio ventral prefrontal cortex
NIRS	Natrium-Infrarotspektographie
NON	Nonsense

PET	Positron emission tomography
PFC	prefrontal cortex
pMTG	posterior medial temporal gyrus
psc	percent signal change
pSTS	posterior superior temporal sulcus
PUN	visual pun
rCBF	regional cerebral blood flow
rCBV	regional cerebral blood volume
RF	radio-frequency
rINC	residual incongruity
SEM	semantic cartoons
SFG	superior frontal gyrus
SHQr	Revised Sense of Humor questionnaire
SHRQ	Situational Humor Response Questionnaire
SOp	Script opposition
SPECT	Single Photon Emission Computer Tomography
SPM	statistical parametric map
SQ	Systemizing Quotient
SSS-V	Sensation Seeking Scale V
SSTH	Semantic Script Theory of Humor
T	Tesla
TOM	Theory of Mind cartoon
TPJ	Temporo-parietal junction

List of Figures

Part I

Part II

Chapter 10:

Chapter 11:

Chapter 12:

List of Tables