Development of Stereo Vision in Young Infants

Martina Röthlisberger & Andrea Frick

University of Fribourg

A definitive version is published as:

Röthlisberger, M., & Frick, A. (in press). Development of stereo vision in young infants. *Infancy*.

DOI: 10.1111/infa.12359

Autor Note

This research was supported by a grant from the Swiss National Science Foundation #PP00P1_150486. Substantial support came from Dr. med. Thomas Lang and the LANG-STEREOTEST AG, who kindly provided us with the stereo test stimuli. We also wish to thank Kate Staehlin for her help with the data collection and coding.

The authors declare no conflicts of interest with regard to the funding source for this study.

Correspondence concerning this article should be addressed to Martina Röthlisberger, Department of Psychology, University of Fribourg, 1701 Fribourg, Switzerland.

E-mail: martinaroe@gmail

Abstract

In this study, infants' visual processing of depth-inducing stimuli was tested using a new method suitable for experimental settings. Stereograms of the Lang-Stereopad® were presented in a timed preferential-looking paradigm to determine infants' preference for a stereogram as compared to a stimulus not inducing an impression of depth. A total of 80 infants were tested at 7 months of age; of these, a sub-sample of 41 infants were tested longitudinally at 4 and 7 months to characterize the developmental trajectory of their preference. Infants were simultaneously presented with a card showing a random-dot stereogram (800" disparity) and a similar looking dummy card without stereogram. In the total sample, 7-month-olds showed a clear preference for the stereogram regardless of sex. In the longitudinal sample, 7-month-olds but not 4-month-olds looked significantly longer to the stereogram as compared to the dummy card. On individual level, 56% of the 4-month-olds, and 85% of the 7-month-olds predominantly looked at the stereogram. The findings yield evidence for a clear developmental progression, and show that the test cards of the Lang-Stereopad® prototype provide a viable instrument to determine the preference for depth-inducing stimuli in young infants when used in a controlled experimental setting.

Development of Stereo Vision in Young Infants

Depth perception and accurate distance estimation is fundamental in human daily life and relevant for basic activities such as locomotion in a three-dimensional environment, eye-hand coordination, and tool use. Monocular (pictorial) depth cues such as relative size, interposition, or linear perspective can provide some information about the three-dimensional environment. However, binocular depth perception, also known as *stereopsis*, yields largely superior information and is necessary for calculating exact size and distance information.

In spite of its important role in processing three-dimensional (3D) sensory input, binocular depth perception is rarely considered in developmental studies that present stimuli and events in a 3D context. However, the lack of binocular depth perception may affect infants' and young children's performance in such studies. Lacking binocular depth perception may also reduce infants' interest in 3D stimuli, and hence bias the results of studies that measure looking times. It is therefore crucial for developmental research to identify infants with impaired binocular depth perception. However, measuring binocular depth perception in young children poses a considerable challenge for clinicians and researchers, as tests are mainly designed for adults and older children (Fricke & Siderov, 1997).

In the present study, we presented test cards of the Lang-Stereopad® prototype to young infants in a timed preferential-looking paradigm and assessed their preference for a test card that evokes an impression of depth in an observer with functional stereopsis. By testing a large group of 7-month-olds, who had not been diagnosed with visual deficiencies, we first aimed to establish whether this method is suitable for testing infants in an experimental setting, and whether the results are comparable with findings of previous studies using different paradigms. By additionally testing a subgroup of infants longitudinally at 4 and again at 7 months of age, we investigated the development of this preference across an age range that is of major interest with respect to the development of visual perception, object recognition, and mental rotation. Major progression in the development of stereopsis could be expected in this age range based on previous research, as described in the following.

Development of Binocular Depth Perception

Binocular depth perception results from processing information from both eyes, comparing the slightly different retinal images that arise when a distal stimulus is projected onto each retina. This disparity between the two images is due to the horizontal distance of 50 to 75mm between the eyes in humans. If this disparity is small, the images are typically fused; if it is large, no fusion of the two images is possible and double "diplopic" images are seen. Nevertheless, diplopic images may still provide the observer with depth information (Wilcox & Allison, 2009). Disparities are measured in minutes (') and seconds (") of arc. The upper threshold for image fusion in adults is at about 3600" (Ogle, 1952a, 1952b). The term *stereopsis* refers to the ability to process depth information from both fused and non-fused images.

Stereopsis is not present at birth and typically emerges during the first year of life (Birch, Gwiazda, & Held, 1982; Birch & Petrig, 1996; Birch, Shimojo, & Held, 1985; Held, Birch, & Gwiazda, 1980; Norcia & Gerhard, 2015). Research using binocular visual evoked potentials has suggested that brain cells that are sensitive to differences in disparity may be present in different visual areas of the cortex as early as 2 months of age (Amigo, Fiorentini, Pirchio, & Spinelli, 1978). It has been hypothesized that younger infants have superimposed percepts from each eye (Shimojo, Bauer, O'Connell, & Held, 1986). However, Brown and Miracle (2003) found that infants as young as 6 weeks old preferred a fusible stimulus over a non-fusible one. In the same vein, at 8 weeks of age, infants have been found to prefer a fusible stereogram with horizontal disparity over a non-fusible stereogram with vertical disparity (Kavšek, 2013), and 9-week-olds have been shown to look longer to a stereogram compared to a stimulus evoking a blurred impression of depth (Wattam-Bell, 2003). This suggests that infants have some sensitivity to binocular depth information before 4 months of age. Binocular fusion still improves gradually up to 21 weeks of age with maturation of oculomotor control (Thorn, Gwiazda, Cruz, Bauer & Held, 1994) and with growing contrast sensitivity (Brown, Lindsey, Satgunam, & Miracle, 2007).

In a seminal study, Held et al. (1980) found evidence for coarse stereopsis from an average of 4 months on, which was confirmed in subsequent studies. For example, Birch et al. (1982) tested whether 2- to 12-month-olds looked longer at a pattern that provoked an illusion of depth – which can only be seen with functional stereo vision – as compared to a similar pattern that did not induce an impression of depth. At 4 months, 62% of the infants looked longer at a depth-inducing pattern at a very large disparity (58'). At 6 months, 100% of the infants looked longer at a depth-inducing pattern at disparities from 58' to 6'. Birch and Petrig (1996) used a similar preferential-looking paradigm and also found that 60% of the 4- to 5-month-olds looked longer at depth-inducing patterns of varying disparities. This percentage increased to 80% at 6 months, and reached 100% by 7 months of age. In a similar vein, Braun and Kavšek (2018) showed that the percentage of infants looking longer at a depth-inducing pattern showing a novel shape increased from 56% to 72% between 4 and 5 months.

Yonas, Arterberry, and Granrud (1987) tested 4-month-old infants for their recognition of objects, as well as their sensitivity to disparity. Infants were first habituated to moving, solid objects and tested for sensitivity to disparity with the same method as used by Held et al. (1980). Results indicated that, in the group of infants who showed a sensitivity to disparity, looked significantly more at the novel object, whereas infants without disparity sensitivity looked equally at the two objects. These findings suggested that 4-month-old infants who were sensitive to disparity in the displays were also able to extract object information from binocular cues and not only responded to disparity per se.

In a large-scale behavioral study, Birch and Salomao (1998) identified 80% of 95 tested 4-month-olds as showing stereopsis at a disparity of 1735" or less (with a mean of 2.75 log sec, which corresponds to 562"). From 6 months on, virtually all infants showed stereopsis at a disparity of 1584” or less. Moreover, Birch et al. (2005) found evidence for stereopsis in 4-month-old infants at a disparity of 600”, and in 6-month-old infants at a disparity of 200” when measured with random dot stereograms (see below). Thus, at 4 months of age, infants can typically process stereograms with a disparity of 600” or more.

Taken together, the above studies suggest, that stereo vision is typically acquired between 4 and 7 months of age. However, fine stereopsis or stereoacuity, i.e., the depth perception arising from very small disparities, develops continuously throughout the entire childhood (Ciner, Schanel-Klitsch, & Scheiman, 1991), and an adult level of stereoacuity is not achieved before adolescence (Giaschi, Narasimhan, Solski, Harrison, & Wilcox, 2013; for an overview see Norcia & Gerhard, 2015).

Yet, the development of stereopsis is disrupted in some children, which – if untreated – may result in visual deficits and restricted processing of spatial information in a three-dimensional context (Fawcett, Wang, & Birch, 2005; Simonsz, Kolling, & Unnebrink, 2005). Incomplete or lacking stereopsis may also have a negative influence on the development of eye-hand coordination (Fielder & Moseley, 1996). Critically, children with reduced stereopsis – particularly in connection with decreased near visual acuity – score significantly worse in visual-motor integration assessments and visual attention tasks (Kulp et al., 2017). Identifying infants with impaired binocular depth perception is therefore of central importance, as it may also affect developmental progression in other domains.

Measuring Depth Perception

Stereopsis is typically measured using stereograms (Fricke & Siderov, 1997; Westheimer, 2013). A stereogram is a two-dimensional image giving rise to an impression of depth in the observer. This is achieved by presenting two disparate images to the left and the right eye. For example, in random-dot stereograms, which were introduced by Julesz and Miller (1962), two almost identical images filled with randomly arranged dots are used. The difference of the images consists in a predefined region that has been displaced slightly against the background. Whereas the contour or shape of the displaced region is not discernable monocularly, the separate presentation of the two images to each eye results in perception of the displaced region as either closer to or further away from the observer with respect to the random-dot image. This evokes the simultaneous perception of depth and shape. The separation of the two images is usually achieved by either viewing black and white dots on a polarized surface through polarizing glasses, or by viewing red and green dots through red-green glasses.

Even though a multitude of random-dot stereo tests exist, few are suitable for young infants. In practice, two main types of random-dot stereograms are used for children and infants: contour stereo displays and plain random-dot stereograms. Contour stereo displays, such as the classical Titmus Fly Stereotest (Stereo Optical Co.), contain monocular contour cues – a feature that may bias the results in the sense that individuals without stereopsis may be able to distinguish the target from the distractor stimulus. Plain random-dot stereograms, such as the Randot Stereo Smile Test "Happy Face" (Ciner, Schanel-Klitsch, & Herzberg, 1996), the Random-Dot E (Stereo Optical Co.), the Lang Stereotest® (Lang & Lang, 2018), or the TNO Stereotest (Lameris Ootech) do not contain such monocular cues and require adequate binocular fusion. Therefore, these stereo tests are better suited for experimental and clinical use (Ciner et al., 1996; Fricke & Siderov, 1997).

Yet, most of the above random-dot stereo tests require the use of viewing devices such as polarizing or red-green glasses, which may be problematic when used with young infants. Calloway, Lloyd, and Henson (2001) for example, reported moderate goggle tolerance in the age groups from 2 to 4 months (66%) and from 8.5 months to 13 months (69%). Birch and Salomao (1998) reduced the problem by using polarized filters mounted in soft foam frames; yet, panographic stereograms, such as the versions I and II of the Lang-Stereotest® (Lang Stereotest AG, Küsnacht, Switzerland), completely avoid it.

The Lang-Stereotest consists of a set of random-dot stereograms (Lang & Lang, 2018). The two images of each stereogram have been sliced and intertwined into one image, which is covered by a transparent layer (known as lenticular sheet) with a three-dimensional surface structure in the form of parallel half-cylinders acting as prims. Under each half-cylinder lies a pair of image slices, of which one slice is projected to the left eye and one to the right eye, due to the prism effect of the cylinders. Observation of the test card from reading distance (35 to 40cm) evokes the impression of depth and the perception of a shape (e.g., a star) popping out from the image. Although the lenticular sheet may reduce the contrast of the black-and white random dot images, it has the advantage that the participants' eyes are clearly visible. Therefore, infants' looking direction can be observed more precisely than with viewing devices.

The Lang Stereotest has previously been applied successfully in infants and children from 6 to 72 months (Pai et al., 2012). Within the age group of 6- to 12-month-olds, 92% could be tested with the Lang Stereotest, but only 50% completed the Stereo Smile Test. In a study that compared different tests in 28 children under 2 years (Broadbent & Westall, 1990), only 2 children under the age of 12 months were willing to wear glasses, whereas 50% completed the Lang Stereotest. In the present study, we thus used one card of the Lang-Stereopad®, a newly developed prototype version using the same technology as the Lang-Stereotests I and II. Whereas the Lang Stereotests I and II show four stereograms of different disparities on the same card, the Lang Stereopad contains square cards, each presenting only one stereogram. It is thus particularly suitable for use in a preferential-looking paradigm. The Lang Stereopad has recently been tested on 217 children with suspected minimal esotropy between the ages of 3 and 10 years. It showed a high specificity and sensitivity, and higher predictive value as compared to the Lang Stereotest I (Piantanida, 2019).

Preferential-Looking Paradigm

In many of the stereopsis studies with infants, a two-alternative preferential-looking paradigm was applied. In the classic preferential-looking paradigm, infants are presented with pairs of stimuli that differ in one specific aspect such as shape or pattern (Fantz, 1961). Typically, a few trials of fixed duration are administered, and a naive observer measures the infant's looking time to both stimuli (Kavšek, 2013). The proportion of the looking time directed to the target in relation to the total looking time is calculated. This proportion is then averaged across a number of trials with counterbalanced target location, in order to obtain a preference score. Another widely used paradigm in infant vision research is the forced-choice preferential-looking paradigm or "FPL" (Birch et al., 1982; Birch et al., 1985; Birch & Petrig, 1996; Dobson, Teller, Lee, & Wade, 1978; Held et al., 1980; Teller, 1979). In FPL, multiple short trials are conducted, and trial durations are not fixed. The trials last until the observer judges which stimulus has been preferred by the infant. The preference score in this case is an average of the observer's binary judgements across the trials. Classic and FPL paradigms are widely used in infant research and in assessments of visual acuity. According to Kavšek (2013), both yield comparable results.

In the present study, we used a commercially available stereotest and presented it in a timed preferential-looking paradigm, which was based on looking-time measurement. A random-dot stereogram card from the prototype of the Lang-Stereopad® was presented along with a similarly looking dummy card without a stereogram. Infants' looking times were measured online during the experiment and also coded offline from video recordings by a second naïve rater in order to determine inter-rater reliability. We expected infants who are sensitive to binocular depth information to look longer at the stereogram, as this would be more informative than the dummy card and thus attract their attention. Based on previous literature, this could be expected for the majority of infants at the age of 7 months. By testing some of the infants longitudinally at 4 and 7 months of age, we aimed to characterize the developmental trajectory of infants' processing of binocular depth cues. Furthermore, by comparing the results with findings of previous studies using different paradigms should yield valuable information on the usefulness of this method for testing infants in an experimental setting.

Methods

Participants

A total of 80 full-term healthy infants (38 girls, 42 boys) were tested. Two additional infants (2.4%) had to be excluded for fussiness. All infants were tested at 7 months of age (mean age = 7 months, 19 days, *SD* = 8 days, range: 7 months, 1 days – 8 months, 7 days). A sub-sample consisting of 41 infants (19 girls, 22 boys) were tested longitudinally, at 4 months (T1, mean age = 4 months, 19 days, *SD* = 7 days, range: 4 months, 5 days – 4 months, 30 days) and at 7 months of age (T2, mean age = 7 months, 20 days, *SD* = 8 days, range: 7 months, 7 days – 8 months, 7 days). The two samples did not differ significantly with regards to sex, $\chi^2(1, N = 121) = 0.02$ $p = .904$, nor mean age at T2, $t(119) = 1.16$, $p = .25$. Four additional infants were tested at T1 but were not available at T2.

The infants were recruited via maternities of local hospitals, nurseries, baby workshops, and an office for family planning. The families were predominantly from middle-class background and lived near or in a small city in Switzerland. All infants were accompanied by their mother or father. Infants were rewarded with a small toy and a diploma. The present study was conducted according to guidelines laid down in the Declaration of Helsinki, with written informed consent obtained from a parent or guardian for each child before any assessment or data collection. All procedures in this study were approved by the Internal Review Board of the University of Fribourg (reference # 154).

Stimuli and Apparatus

Test cards of the prototype of the new Lang Stereopad® (Lang Stereotest AG, Küsnacht, Switzerland) were used as stimuli. One of the cards displayed a random-dot stereogram of a 5-pointed star with an outer diameter of 2 cm. This stereogram was presented at a disparity of 800". This disparity was chosen based on reports of Birch et al. (2005), showing a mean stereoacuity of 600"as measured by randot stereograms in a large sample of 4-month-olds. The stereogram (target) card was always presented together with a dummy (distractor) card. This dummy card was created by the manufacturer of the Lang Stereopad, had the same physical characteristics and showed a dot pattern similar to the stereo card, except that it did not contain a stereogram. (The dummy card can now be purchased for a small production fee.) Both the stereo and the dummy card measured 6.4cm x 6.4cm, were printed with 600 points per inch, and were covered by a lenticular sheet with 60 half-cylinders per inch. These half-cylinders acted as lenses, each of which was 0.432 mm wide, resulting in a dot size of 0.432 mm. Viewing distance was about 30 cm, resulting in a visual angle of 297" per dot. The illuminance on the stimuli was 60 lux on average, which corresponds to a luminous intensity of about 587 candelas at a distance of 30 cm. The cards were presented with lenticular half cylinders running in the vertical direction, which is necessary for 3D perception. To ensure that the cards are viewed from the same horizontal angle (which should not exceed 27°), the cards were arranged one above the other, on a vertical panel (40.5 x 40.5 cm). The top card was located at 7 cm from the top of the panel, the bottom card at 7.5 cm from the bottom of the panel. The distance between the lower edge of the top card and the upper edge of the bottom card was 11.5 cm. A hole of 4 cm diameter for the camera was situated exactly in the center between the cards. There were vertical slits of 2 cm height and 1 cm width in the panel, 2 cm to the left and right of the cards. These openings were covered with a black, semi-transparent fabric, through which a blinking colored LED could be seen during attention getting. These LED lights were mounted on a background panel, which was placed behind the panel with the cards. Panels were coated with black self-adhesive felt. For an illustration, see Figure 1.

The panels were mounted inside a puppet stage of 41 cm height, 59 cm width, and 41 cm depth. All visible parts of the puppet stage were covered with black felt. The front opening of 28 x 32 cm could be closed by a sideways sliding screen, in order to exchange the panels out of the infant's view. A black curtain hung from the ceiling and fully enclosed the front of the puppet stage and the seat with the caregiver and the infant, thus hiding the experimenter who exchanged the panels through the ceiling of the puppet stage.

Infants were seated on their parents' lap at about 30 cm distance from the stereograms in front of the puppet stage. A white high-density LED chain illuminated the inside of the puppet stage. It was placed behind and around the front opening, so that it would not blind the infant but evenly illuminate the stimuli. A standard lamp was directed towards the ceiling of the experimental room.

Video recording was done with a Sony DCR-AX33 camcorder capturing the infant's face through the 4-cm hole in the center of the panels. The night-shot function of the camera was turned on allowing for clearer observation of the infant's looking direction. The experiment was controlled by a MATLAB® script (MATLAB and Statistics Toolbox Release 2014b, The MathWorks, Inc., Natick, Massachusetts, United States). Puppet stage light onset and offset was controlled by an Arduino UNO R3® board with the Arduino IDE 1.8.5 Software (https://www.arduino.cc/en/Main/Software) by way of MATLAB® Support Package for Arduino® Hardware. The colored LEDs on the background panel were activated manually.

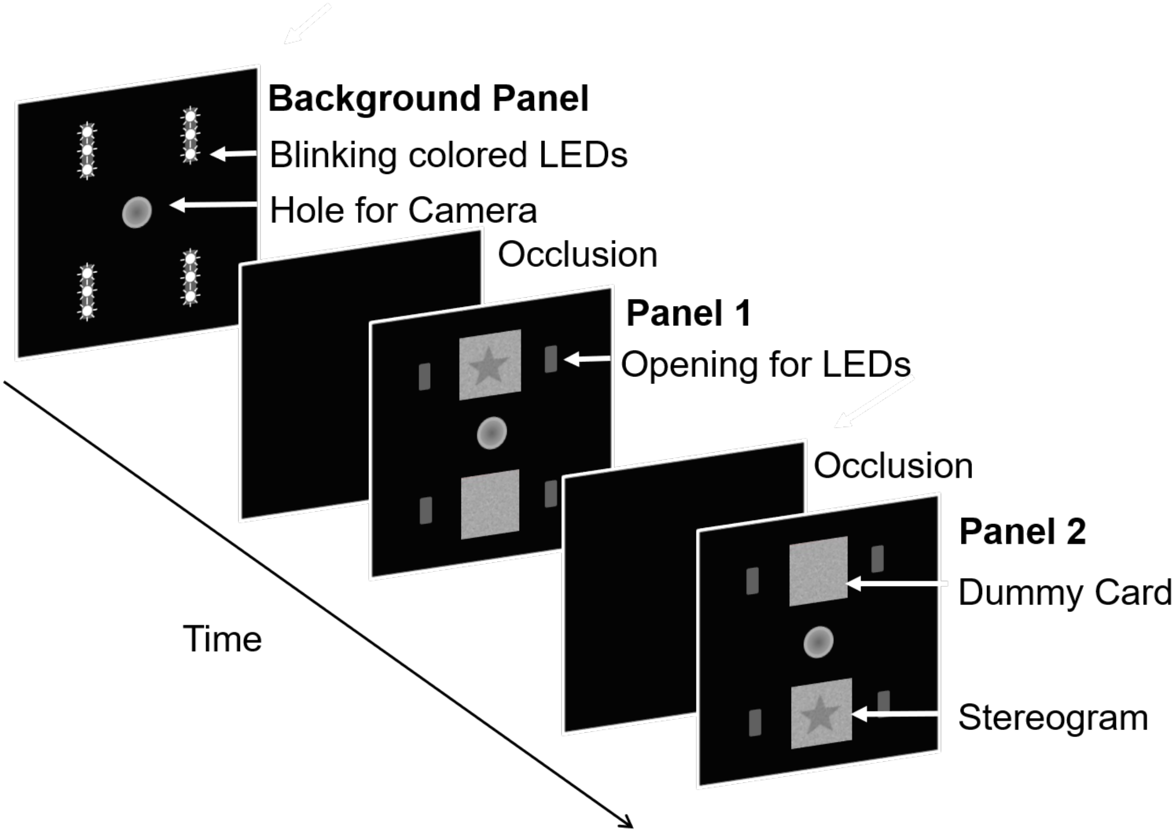

Figure 1. Schematic depiction of the experiment flow (showing one out of two possible orders). The white arrows were not visible for the infants.

Design

Infants saw two trials: In one trial, the stereogram was at the top and the dummy card at the bottom; in the other trial, the stereogram was at the bottom and the dummy card at the top. The order of these two trials was counterbalanced between participants, so that about half of the infants in each sample saw the stereogram at the top in the first trial and at the bottom in the second trial, and half of the them saw the inverse order.

Procedure

Throughout the experiment, two experimenters were present: a desktop operator coding the infants' looking times online, and a stage operator presenting the stimuli. While the participants were being seated, only the background panel with the blinking colored LEDs was visible and a cheerful music was playing. The desktop operator ensured that the infant was ready, dimmed the ceiling light and closed the curtain. Then, the stage operator closed the screen, slid in the first panel, and opened the screen again. The desktop operator observed the live camera feed of the infant's face on a monitor and started the trial as soon as the infant looked steadily at the panel. At the trial start, the music stopped, and the stage operator turned off the blinking LEDs. The stage light turned on, rendering the two stimulus cards visible. While being unaware of the stereogram position, the desktop operator registered the infant's looking to the top card, to the bottom card, and away. Maximal trial duration was 30 seconds, in order to allow infants plenty of time to recognize the stereogram. However, trials were terminated if infants lost interest in both of the cards and looked away for 2 consecutive seconds after the first 6 seconds of a trial had elapsed. After the first trial, the stage operator closed the screen and replaced the panel with the one presenting the cards in the opposite locations, which took an average of 8.25 s (*SD* = 1.85 s). Then, the second trial was presented analogously. Trials were not repeated.

Results

Reliability

Trained but naïve second coders analyzed 95% of the videos of infants' looking behavior offline using Datavyu (Datavyu Team, 2014). They coded the times infants looked (a) toward the stereogram, (b) toward the dummy card, or (c) anywhere else. One-way random intraclass correlation (ICC) analyses were used to assess inter-rater agreement, because several second coders were involved (Landers, 2015). The average ICC of (a) and (b) was excellent both at T1, ICC(36, 35) = .96, $p < .001$, and at T2, ICC(73, 74) = .96, $p < .001$ (Cronbach's alpha = .96 at both timepoints).

Total Sample

The infants in the total sample on average looked at the stimuli for 6.58 s (*SE* = 0.41) in the first test trial, and 5.62 s (*SE* = 0.39) in the second test trial, which did not differ significantly, $t(79) = 1.76$ $p = .082$, Cohen's $d = 0.27$. To assess the 7-month-olds' individual looking preferences, their looking times toward the stereogram and the dummy card was analyzed. Infants' looking times were averaged across the two test trials, in order to account for a possible bias to preferentially look at the top or bottom card. In addition, a relative preference score was calculated as the percentage of looking towards the stereogram in relation to the total looking time (i.e., the sum of the looking time to the stereogram and the dummy cards).

Out of 80 infants, 58 (28 girls, 30 boys) looked longer to the stereogram than to the dummy card (i.e., had a relative preference score > 50%), which is significantly different from an equal distribution (binomial test, $p < .001$; Figure 2). Boys and girls did not differ significantly in their preference for the stereogram or the dummy card, χ^2 (1, $N = 80$) = 0.051, $p = .821$.

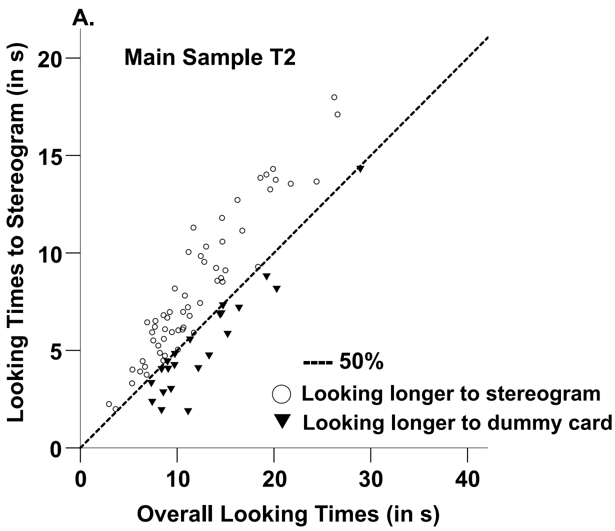

Figure 2. Looking times to the stereogram as a function of total looking times in 7-month-olds ($N = 80$). The dotted line indicates equal looking times to both cards.

Next, we analyzed whether the infants as a group looked significantly longer at the stereogram compared to the dummy card. Using IBM® SPSS® Statistics 25.0, a repeated-measures ANOVA was performed, with mean looking times as the dependent variable. The position of the stereogram (top vs. bottom) and card (stereogram vs. dummy) were entered as within-participant variables, sex and order (card with stereogram at top first vs. card with stereogram at bottom first) as between-participant variables. In addition, permutation tests were performed using R (R Core Team, 2014) as looking time data deviated from a normal distribution. The *p* values resulting from permutation tests are reported in square brackets. The ANOVA revealed a significant main effect of card, $F(1, 76) = 36.75$, $p < .001$ [permuted $p < .001$], $\eta^2 = 0.33$, indicating that infants looked significantly longer at the stereogram (M = 3.70 s, SE = 0.2) than at the dummy card (M = 2.42 s, SE = 0.2). A significant effect of the position of the stereogram, $F(1, 76) = 6.02$, $p = .016$ [permuted $p = .025$], $\eta^2 = 0.07$, indicated that looking times were longer when the stereogram was at the bottom position (M = 3.47 s, SE = 0.3) as compared to the top position (M = 2.65 s, SE = 0.2). Furthermore, the analysis yielded an interaction of card and order, $F(1, 76) = 5.99$, $p = .017$ [permuted $p = .015$], $\eta^2 = 0.07$. Post hoc comparisons with Sidak corrections showed that infants in the condition that presented the stereogram at the top position first and at the bottom position second looked significantly longer to the stereogram (M = 4.07 s, SE = 0.3) compared to the dummy card (M = 2.26 s, SE = 0.2, $p < .001$). Likewise, infants who saw the stereogram at the bottom position first also looked longer to the stereogram (M = 3.34 s, SE = 0.3) than to the dummy card (M = 2.57 s, SE = 0.2, $p = .01$), but the looking time difference was not as large. No other main effect or interaction was found (all *F*s < 2.95, all *p*s > .08 [all permuted *p*s > .08], all $\eta^2 < 0.04$).[1]

Similar analyses were conducted with preference scores as dependent variables. First, it was analyzed whether the overall preference score was significantly different from 50%, which would indicate an unequal distribution of looking times across the two cards. A *t*

[1] An analogous ANOVA that excluded infants whose looking time per trial did not exceed 2s (remaining $n = 75$) yielded the same significant effects. Most crucially, the main effect of card was still significant, $F(1, 71) = 31.47$, $p < .001$ [permuted $p < .001$], $\eta^2 = 0.31$.

test indicated that the average preference score of 61% (*SD* = 16%) was significantly different from 50%, $t(79) = 5.99$, $p < .001$, Cohen's $d = 0.67$. Then preference scores were analyzed by means of an ANOVA with the same independent variables as above, except for the variable card which was now obsolete due to the use of the preference scores. The ANOVA yielded a significant interaction of stereogram position and order, $F(1, 76) = 4.41$, $p = .04$ [permuted $p = .04$], $\eta^2 = 0.06$, which was due to a higher preference for the stereogram in the top position for infants who saw the stereogram at the top first (*M* = 0.68, *SE* = 0.05) compared to those who saw the stereogram at the bottom first (*M* = 0.5, *SE* = 0.05, $p = .011$); yet, preference scores did not differ for the stereograms in the bottom position ($p = .848$). No other main effect or interaction was found, all *F*s < 3.46, all *p*s > .07 [all permuted *p*s > .07], all $\eta^2 < 0.04$.

Longitudinal sub-Sample

The longitudinal sub-sample included 41 infants from the total sample, who were tested twice, a first time at 4 months (T1) and a second time at 7 months (T2) of age. This sub-sample did not differ in their preference for the stereogram at T2 from the sub-sample of 39 infants who were only tested cross-sectionally, $t(58.46) = 1.64$, $p = .106$, Cohen's $d = 0.37$. Again, there was no significant difference between the looking times in the first trial (*M* = 5.66 s, *SE* = 0.67), and the second trial (*M* = 4.59 s, *SE* = 0.44) at T1, $t(40) = 1.52$, $p = .137$, Cohen's $d = 0.29$, nor at T2 (first trial: *M* = 6.81 s, *SE* = 0.66; second trial: *M* = 6.17, *SE* = 0.57), $t(40) = 0.72$, $p = .479$, Cohen's $d = 0.16$.

Table 1 and Figure 3 show the number of infants who predominantly (> 50% of the total time) looked to the stereogram or the dummy card at T1 and T2. The looking preference of boys and girls did not differ at T1, $\chi^2 (1, N = 41) = 0.17$, $p = .678$, nor at T2, $\chi^2 (1, N = 41) = 0.04$, $p = .846$. A significantly larger number of infants showed a preference for the stereogram at T2 than at T1 (McNemar test: $p =$

.004). Table 1 also shows the changes in the preference for the stereogram from T1 to T2. Whereas 51% of the infants showed a preference for the stereogram both at 4 and 7 months (column labeled s/s), 34% apparently developed a preference for the stereogram between 4 and 7 months (column d/s). However, 10% of the infants looked longer at the dummy card at both time points (d/d), and 5% showed a preference for the stereogram at 4 but not at 7 months of age (s/d).

Table 1

Number (and percentage) of infants looking longer to the stereogram (s) or the dummy card (d) and changes from 4 months (T1) to 7 months of age (T2) in the longitudinal sub-sample.

	T1		T2		Changes from T1 to T2				
Sex	d	s	d	s	d/d	d/s	s/s	s/d	Total
female	9 (22)	10 (24)	3 (7.5)	16 (39)	2 (5)	7 (18)	9 (22)	1 (2.5)	19 (46)
male	9 (22)	13 (32)	3 (7.5)	19 (46)	2 (5)	7 (18)	12 (29)	1 (2.5)	22 (54)
Total	18 (44)	23 (56)	6 (15)	35 (85)	4 (10)	14 (34)	21 (51)	2 (5)	41 (100)

Note: n = 41

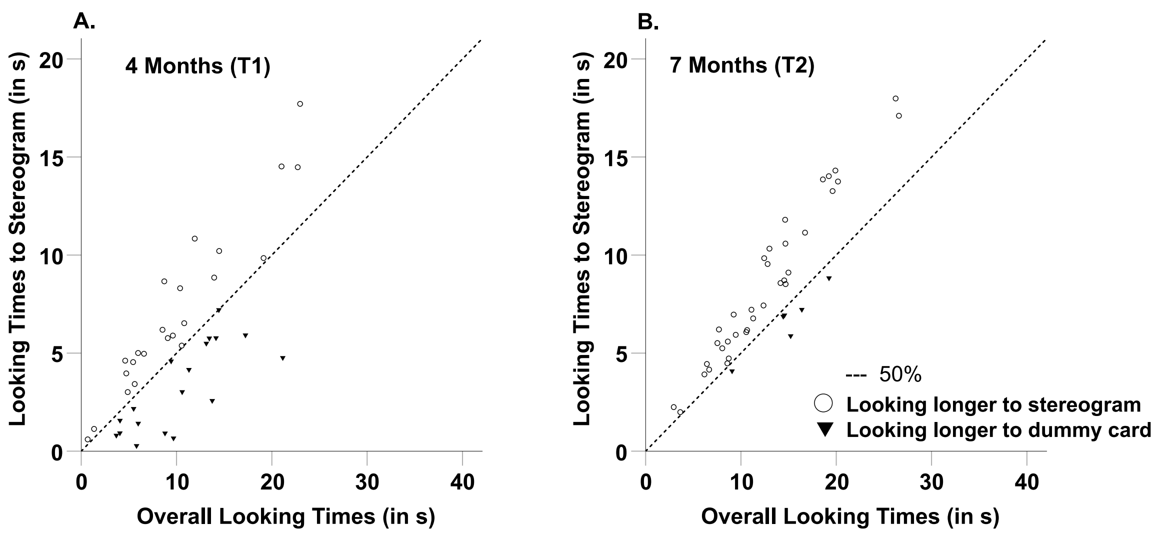

Figure 3. Average looking times to the stereogram as a function of total looking times in the longitudinal sub-sample (n = 41) at 4 months (A) and at 7 months (B) of age. The dotted line indicates equal looking times to both cards.

To investigate the developmental progression of infant's stereogram preference at group level, a repeated-measures ANOVA was performed, with timepoint (T1 vs. T2), stereogram position (top vs. bottom), and card (stereogram vs. dummy) as within-subject variables, and sex and order (card with stereogram at top first vs. card with stereogram at bottom first) as between-subject variables. Again, permutation tests were performed, and the resulting p-values are reported in squared brackets. A first analysis showed no effects or interactions with sex or order (all Fs < 2.19, all ps > .14 [all permuted ps > .18], all $\eta^2 < 0.06$), nor with stereogram position (all Fs < 3.42, all ps > .07 [all permuted ps > .06], all $\eta^2 < 0.09$); therefore, these variables were not considered in the following analysis.

An ANOVA with timepoint (T1 vs. T2) and card (stereogram vs. dummy) as within-subject variables yielded significant main effects of card, $F(1, 40) = 13.42$, $p = .001$ [permuted $p < .001$], $\eta^2 = 0.25$, and timepoint, $F(1, 40) = 5.63$, $p = .023$ [permuted $p = .024$], $\eta^2 = 0.12$, as well as an interaction of card and timepoint, $F(1, 40) = 13.73$, $p = .001$ [permuted $p = .001$], $\eta^2 = 0.26$ (Figure 4). Post hoc comparisons with Sidak correction showed that at T1, infants looked equally long to the stereogram (M = 5.43 s, SE = 0.6) and the dummy card (M = 4.81 s, SE = 0.6, p = .450). In contrast, at T2 infants looked significantly longer to the stereogram (M = 8.23 s, SE = 0.6) than to the dummy card (M = 4.74 s, SE = 0.4, p < .001). Moreover, post hoc tests showed that looking times to the stereogram increased significantly between T1 and T2 (*p* = .001), whereas looking times to the dummy card did not (*p* = .902)[2].

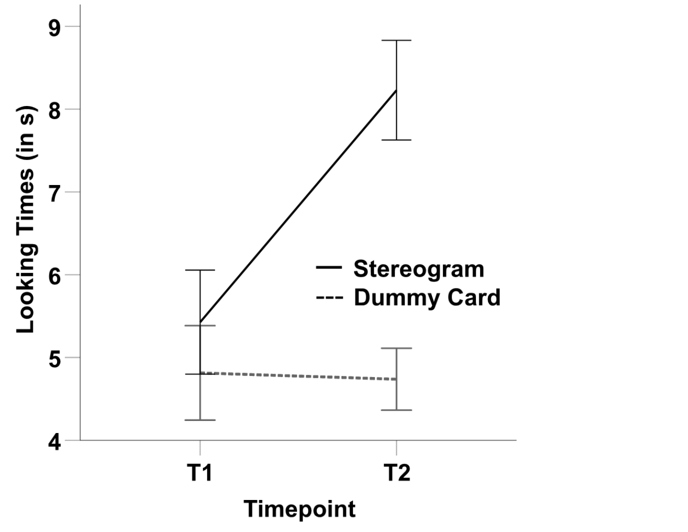

Figure 4. Means of cumulated looking times across the two trials at T1 and T2. Error bars indicate +/- 1 standard error.

Again, a preference scores was calculated for both timepoints. At T1, infants on average looked to the stereogram 54% (*SD* = 26) of the time, which was not significantly different from an equal distribution, $t(40) = 1.08$, $p = .287$, Cohen's $d = 0.17$. In contrast at T2, infants looked at the stereogram 64% (*SD* = 11) of the time, which differed significantly from 50%, $t(40) = 8.00$, $p < .001$, Cohen's $d = 1.25$. An ANOVA was carried out with preference scores as a dependent variable and timepoint and stereogram position as within-participant variables (sex and order again showed no significant effects or interactions and were therefore omitted). The

[2]An analogous ANOVA that excluded infants whose looking time in each trial did not exceed 2s (remaining *n* = 29) yielded similar results, except that the main effect of timepoint was no longer significant ($F < 1$). Crucially, the interaction of timepoint and card was still significant, $F(1,28) = 9.34$, $p = .005$, $\eta^2 = 0.25$. Thus, it is unlikely that the developmental increase in looking longer to the stereogram between T1 and T2 was merely caused by a few infants with very short looking times or due to an age difference in attention span.

analysis resulted in a significant main effect of timepoint, $F(1, 40) = 4.85$, $p = .034$ [permuted $p = .037$], $\eta^2 = 0.11$, and an interaction between timepoint and stereogram position, $F(1, 40) = 5.9$, $p = .020$ [permuted $p = .018$], $\eta^2 = 0.13$. Yet, the main effect for the stereogram position was not significant, $F(1, 40) = 0.004$, $p = .949$ [permuted $p = .953$], $\eta^2 < 0.001$. Pairwise comparisons (Sidak corrected) showed that especially when the stereogram was at the top position, the preference scores at T1 ($M = 0.45$, $SE = 0.05$) were significantly lower than at T2 ($M = 0.65$, $SE = 0.04$, $p = .002$). When the stereogram was at the bottom position, preference scores were also lower at T1 ($M = 0.55$, $SE = 0.04$) than at T2 ($M = 0.56$, $SE = 0.04$), but this was not statistically significant ($p = .872$).

Discussion

The development of infants' visual processing of depth-inducing stimuli was investigated by presenting infants with stereograms of the Lang Stereopad® prototype, in a timed preferential-looking paradigm. Of the 80 infants tested at 7 months of age, 58 (72.5%) looked longer to the stereogram as compared to a dummy card devoid of depth cues. Our findings thus indicate that at the age of 7 months, a majority of infants prefer to look at a stimulus giving an impression of depth.

Previous studies found that 100% of 7- to 8-month-olds could be classified as having stereopsis at various disparities from 58' to 1' (Birch et al., 1982; Birch et al., 1985; Held et al., 1980). Compared to these studies, the percentage of infants in our total sample who looked predominantly at the stereogram was considerably lower, which may have several reasons. First, we did not test the infants for oculomotor status or refractive errors beforehand, whereas these former studies only included infants within the normal range regarding refractive errors such as myopia (nearsightedness), hyperopia (farsightedness), or astigmatism (irregularity of the cornea or the lens). Large scale vision screenings show that in a healthy population, about 5-6% of infants between 7 and 9 months have refractive errors, which may impair the development of stereopsis (Atkinson et al., 1996). It is therefore possible that our sample included infants with atypical or delayed development.

A second reason may lie in the stimulus presentation, as Birch et al. (1982; 1985), and Held et al. (1980) did not use random-dot stereograms. They rear-projected black-and-white bar stereograms on a screen, and disparity was achieved through polarizing filters on the stereo-projector and glasses worn by the infants. It is conceivable that their high contrast stimuli might have attracted the infants' gaze more than the stereo cards used in the present study.

A third reason for the lower percentage of stereo-sensitive infants in our sample may lie in the low dropout rate (2.4%). Whereas in the present study, infants were presented with only two trials, some of the previous studies presented a much larger number of trials. Unfortunately, most of them did not report their dropout rates. In the studies that did report dropout rates, twice to ten times as many infants did not complete all trials and were excluded from analyses (Birch et al., 1985; Braun & Kavšek, 2018). It is possible that these infants had no impression of depth and got bored earlier. Such a selective dropout of infants not perceiving the stereograms could have resulted in a disproportionately large percentage of infants showing a preference for the stereogram in the analyzed sample.

A further methodological difference may lie in the use of a forced-choice preferential-looking procedure in the cited studies (Birch et al., 1982; Birch et al., 1985; Held et al., 1980; Thorn et al., 1994), whereas the present study applied a preferential-looking method that was based on looking time measurement. The excellent inter-rater agreement in the present study suggests that this measure was highly reliable and objective.

Results from the longitudinal sample further showed that 56% of the infants exhibited a preference for the stereogram over the dummy card at 4 months of age and 85% at 7 months of age. The proportion of infants developing a preference for a stereogram between 4 and 7 months of age is roughly consistent with the developmental trajectory outlined by Birch et al. (1982) and Held et al. (1980; Birch et al., 1982; Held et al., 1980). Their results showed a steep increase in the preference for a stereogram, as compared to a stimulus without disparity, from about 40% of the infants at 4 months, to 100% at 8 months of age. In our sample, about half of the infants who showed a preference for the stereogram at 7 months did so already at 4 months, and a third of them seemed to have develop a preference for the stereogram between 4 and 7 months. However, four infants did not show a preference for the stereogram at either timepoint, and two showed a preference for the stereogram at 4 but not at 7 months of age. It is conceivable that these infants may have had problems with binocular vision or shown false positive results.

Given the young starting age of our longitudinal sample, it should also be considered whether some of the younger infants may not have had the necessary visual acuity to recognize the stereogram. In a longitudinal study, Sokol (1978) presented 27 infants between 2 and 7 months of age with checkerboard patterns with check sizes from 7.5 to 90' at the retina. Visual evoked potentials were measured to determine visual acuity. As a group, the infants showed a rapid improvement in acuity from about 9' at 2 months, to 4' at 4 months, and 1' at 7 months. Thus, because the dot size of 4.95' (297") in the Lang stereograms is larger than 4', the stereogram should be discernible for 4- and 7-month-old infants.

Analyses of looking times on group level further confirmed that 7-month-olds in the total sample looked significantly longer at the stereogram than at the dummy card. Group analyses also confirmed that the preference for the stereogram increased significantly from 4 to 7 months of age in the longitudinal sample, as reflected in an interaction of card and timepoint in the analyses of looking times, and in a main effect of timepoint in the analyses of preference scores.. In fact, infants looked significantly longer to the stereogram than the dummy card at 7 months of age, but there was no significant looking time difference at 4 months of age (Figure 4). Total looking time also increased from T1 to T2, however this increase was solely due to an increase in looking to the stereogram, whereas looking time to the dummy card stayed the same across the two timepoints. In light of the specificity of this increase, it is rather unlikely that a general increase in visual attention span was responsible for the present results. This interpretation is further supported by the fact that the results did not change if infants with very short looking times were excluded from the analyses. The preference for the stereogram was distributed equally among girls and boys both at 4 and 7 months of age, and we found no sex differences on group level. Findings of earlier studies have indicated a slightly earlier onset of stereopsis for girls than for boys (i.e., at 9.1 and 12.1 weeks, respectively, in Gwiazda, Bauer, and Held, 1989, and at 11.6 and 13.5 weeks in Thorn et al., 1994). Yet, the earlier onset of stereopsis in girls does not appear to influence the ability to extract depth information from stereograms at a later age, as none of the studies by Held et al. (1980), Birch et al. (1982; 1985), Gwiazda et al. (1989), and Thorn et al. (1994) yielded a sex difference at 18 weeks or older. The absence of an effect of sex in the present study is thus in line with these findings.

Group analyses further showed that looking times were generally longer when the stereogram was presented at the bottom position, and they also yielded significant interactions with stereogram position or order. These variables were likely to affect looking times in an infant study due to effects of postural control and familiarization. However, as we fully counterbalanced these variables across participants, and the effects went in the same direction and were just smaller in one condition, they were not pertinent to our interpretations.

Finally, it should be considered that infants may have been sensitive to the disparity of the stereogram per se, rather than reacting to a perceived shape. Although this possibility cannot be ruled out complete based on the present design, there is evidence from previous studies suggesting that even young infants are able to recognize the shape of an object based on 3D cues. For example, in a study by Yonas et al. (1987), 4-month-old infants who were sensitive to disparity also recognized an object shape based on binocular depth cues, but not infants who did not display a sensitivity for disparity. On the same subject, Braun and Kavšek (2018) reported that at 5 months, infants preferentially looked at a novel shape as compared to a familiar shape on a stereogram. If the infants had only reacted to the disparity per se, they would not have shown any preference for the novel object, since both the known and the novel object had the same disparity. These results suggest that, at least by the age of 5 months, infants are able to process 3D cues provided in stereograms in order to recognize an object shape. They thus support the assumption that the 7-month-old infants in the present study showed a preference for the object shape on the stereogram and were not only attracted by the disparity.

Conclusion

In the present study, stereo cards of the Lang-Stereopad® were presented in a timed preferential-looking paradigm to 80 infants at the age of 7 months, and roughly half of the infants were also tested at 4 months of age. To our knowledge, the present study is the first to investigate the usability of a commercially available stereo test in a standardized experimental setting and with a large sample of young infants. The number of infants showing a preference for the stereogram increased significantly from 4 to 7 months of age, and this increase was also reflected in group analyses, showing a significant interaction of timepoint of testing and looking to the stereo card. As no children were excluded and the drop-out rate was very low, the present findings may be considered as representative. Moreover, the excellent inter-rater agreement indicated that this new method allows for reliable and objective measurement, even though it is highly efficient and can easily be combined with other assessments. Thus, the test cards of the Lang-Stereopad® are well suited for application in an experimental setting and provide an easily available instrument for assessing very young infants' sensitivity to depth-inducing stimuli in future research.

References

Amigo, G., Fiorentini, A., Pirchio, M., & Spinelli, D. (1978). Binocular vision tested with visual evoked potentials in children and infants. *Investigative Ophthalmology & Visual Science*, *17*(9), 910–915.

Birch, E. E., & Salomao, S. (1998). Infant random dot stereoacuity cards. *Journal of Pediatric Ophthalmology & Strabismus*, *35*(2), 86–90.

Birch, E. E., Shimojo, S., & Held, R. (1985). Preferential-looking assessment of fusion and stereopsis in infants aged 1-6 months. *Investigative Ophthalmology & Visual Science*, *26*(3), 366–370.

Birch, E., & Petrig, B. (1996). FPL and VEP measures of fusion, stereopsis and stereoacuity in normal infants. *Vision Research*, *36*(9), 1321–1327. https://doi.org/10.1016/0042-6989(95)00183-2

Birch, E., Gwiazda, J., & Held, R. (1982). Stereoacuity development for crossed and uncrossed disparities in human infants. *Vision Research*, *22*(5), 507–513. https://doi.org/10.1016/0042-6989(82)90108-0

Birch, E., Morale, S., Jeffrey, B., O'Connor, A., & Fawcett, S. (2005). Measurement of stereoacuity outcomes at ages 1 to 24 months: Randot® Stereocards. *Journal of American Association for Pediatric Ophthalmology and Strabismus*, *9*(1), 31-36. https://doi.org/10.1016/j.jaapos.2004.11.013

Braun, S., & Kavšek, M. (2018). Infants perceive two-dimensional shape from horizontal disparity. *Infant Behavior & Development*, *52*, 140–145. https://doi.org/10.1016/j.infbeh.2018.07.003

Broadbent, H., & Westall, C. (1990). An evaluation of techniques for measuring stereopsis in infants and young children. *Ophthalmic and Physiological Optics*, *10*(1), 3–7. https://doi.org/10.1111/j.1475-1313.1990.tb01097.x

Brown, A. M., Lindsey, D. T., Satgunam, P., & Miracle, J. A. (2007). Critical immaturities limiting infant binocular stereopsis. *Investigative Ophthalmology & Visual Science*, *48*(3), 1424–1434. https://doi.org/10.1167/iovs.06-0718

Brown, A. M., & Miracle, J. A. (2003). Early binocular vision in human infants: Limitations on the generality of the Superposition Hypothesis. *Vision Research*, *43*(14), 1563–1574. https://doi.org/10.1016/S0042-6989(03)00177-9

Calloway, S. L., Lloyd, I. C., & Henson, D. B. (2001). A clinical evaluation of random dot stereoacuity cards in infants. *Eye*, *15*(5), 629–634. https://doi.org/10.1038/eye.2001.198

Ciner, E. B., Schanel-Klitsch, E., & Scheiman, M. (1991). Stereoacuity development in young children. *Optometry and vision science: official publication of the American Academy of Optometry, 68*(7), 533-536. https://doi.org/10.1097/00006324-199107000-00004

Ciner, E. B., Schanel-Klitsch, E., & Herzberg, C. (1996). Stereoacuity development: 6 months to 5 years. A new tool for testing and screening. *Optometry and Vision Science*, *73*(1), 43–48. https://doi.org/10.1097/00006324-199601000-00007

Dobson, V., Teller, D. Y., Lee, C. P., & Wade, B. (1978). A behavioral method for efficient screening of visual acuity in young infants. I. Preliminary laboratory development. *Investigative Ophthalmology & Visual Science*, *17*(12), 1142–1150.

Fantz, R. L. (1961). The origin of form perception. *Scientific American*, *204*(5), 66–73.

Fawcett, S. L., Wang, Y.-Z., & Birch, E. E. (2005). The critical period for susceptibility of human stereopsis. *Investigative Ophthalmology & Visual Science*, *46*(2), 521–525. https://doi.org/10.1167/iovs.04-0175

Fielder, A. R., & Moseley, M. J. (1996). Does stereopsis matter in humans? *Eye*, *10*(2), 233–238. https://doi.org/10.1038/eye.1996.51

Fricke, T. R., & Siderov, J. (1997). Stereopsis, stereotests, and their relation to vision screening and clinical practice. *Clinical and Experimental Optometry*, *80*(5), 165–172. https://doi.org/10.1111/j.1444-0938.1997.tb04876.x

Giaschi, D., Narasimhan, S., Solski, A., Harrison, E., & Wilcox, L. M. (2013). On the typical development of stereopsis: fine and coarse processing. *Vision Research*, *89*, 65-71. https://doi.org/10.1016/j.visres.2013.07.011

Gwiazda, J., Bauer, J., & Held, R. (1989). Binocular function in human infants: Correlation of stereoptic and fusion-rivalry discriminations. *Journal of Pediatric Ophthalmology and Strabismus*, *26*(3), 128–132. https://doi.org/10.3928/0191-3913-19890501-08

Held, R., Birch, E., & Gwiazda, J. (1980). Stereoacuity of human infants. *Proceedings of the National Academy of Sciences*, *77*(9), 5572–5574. https://doi.org/10.1073/pnas.77.9.5572

Julesz, B., & Miller, J. E. (1962). Automatic stereoscopic presentation of functions of two variables. *Bell System Technical Journal*, *41*(2), 663–676. https://doi.org/10.1002/j.1538-7305.1962.tb02424.x

Kavšek, M. (2013). The onset of sensitivity to horizontal disparity in infancy: A short-term longitudinal study. *Infant Behavior & Development*, *36*(3), 329–343. https://doi.org/10.1016/j.infbeh.2013.02.002

Kulp, M. T., Ciner, E., Maguire, M., Pistilli, M., Candy, T. R., Ying, G.-S., . . . Moore, B. (2017). Attention and visual motor integration in young children with uncorrected hyperopia. *Optometry and Vision Science: Official Publication of the American Academy of Optometry*, *94*(10), 965–970. https://doi.org/10.1097/OPX.0000000000001123

Landers, R. (2015). Computing intraclass correlations (ICC) as estimates of interrater reliability in SPSS. *The Winnower*, *2:e143518.81744*, 1–4. https://doi.org/10.15200/winn.143518.81744

Lang, J. I., & Lang, T. J. (2018). Eye screening with the Lang Stereotest. *American Orthoptic Journal*, *38*(1), 48–50. https://doi.org/10.1080/0065955X.1988.11981769

Norcia, A. M., & Gerhard, H. E. (2015). Development of three-dimensional perception in human infants. *Annual Review of Vision Science*, *1*, 569–594. https://doi.org/10.1146/annurev-vision-082114-035835

Ogle, K. N. (1952a). Disparity limits of stereopsis. *Archives of Ophthalmology*, *48*(1), 50–60. https://doi.org/10.1001/archopht.1952.00920010053008

Ogle, K. N. (1952b). On the limits of stereoscopic vision. *Journal of Experimental Psychology*, *44*(4), 253–259. https://doi.org/10.1037/h0057643

Pai, A. S.-I., Rose, K. A., Samarawickrama, C., Fotedar, R., Burlutsky, G., Varma, R., & Mitchell, P. (2012). Testability of refraction, stereopsis, and other ocular measures in preschool children: The Sydney Paediatric Eye Disease Study. *Journal of AAPOS: The Official Publication of the American Association for Pediatric Ophthalmology and Strabismus*, *16*(2), 185–192. https://doi.org/10.1016/j.jaapos.2011.09.017

Piantanida, A. (2019, June). *Statistical evaluation in pediatric patients of the new Lang Stereopad test: A preliminary report.* Manuscript submitted for publication.

R Core Team. (2014). R: A language and environment for statistical computing: R Foundation for Statistical Computing. Retrieved from http://www.R-project.org/

Shimojo, S., Bauer, J., O'Connell, K. M., & Held, R. (1986). Pre-stereoptic binocular vision in infants. *Vision Research*, *26*(3), 501–510. https://doi.org/10.1016/0042-6989(86)90193-8

Simonsz, H. J., Kolling, G. H., & Unnebrink, K. (2005). Final report of the early vs. late infantile strabismus surgery study (ELISS), a controlled, prospective, multicenter study. *Strabismus 13*(4), 169–199. https://doi.org/10.1080/09273970500416594

Sokol, S. (1978). Measurement of infant visual acuity from pattern reversal evoked potentials. *Vision research*, *18*(1), 33-39. https://doi.org/10.1016/0042-6989(78)90074-3

Teller, D. Y. (1979). The forced-choice preferential looking procedure: A psychophysical technique for use with human infants. *Infant Behavior and Development*, *2*, 135–153. https://doi.org/10.1016/S0163-6383(79)80016-8

Thorn, F., Gwiazda, J., Cruz, A. A., Bauer, J. A., & Held, R. (1994). The development of eye alignment, convergence, and sensory binocularity in young infants. *Investigative Ophthalmology & Visual Science*, *35*(2), 544–553.

Wattam-Bell, J. (2003). Motion processing asymmetries and stereopsis in infants. *Vision Research*, *43*(18), 1961-1968. https://doi.org/10.1016/S0042-6989(03)00282-7

Westheimer, G. (2013). Clinical evaluation of stereopsis. *Vision Research*, *90*, 38–42. https://doi.org/10.1016/j.visres.2012.10.005

Wilcox, L. M., & Allison, R. S. (2009). Coarse-fine dichotomies in human stereopsis. *Vision Research*, *49*(22), 2653–2665. https://doi.org/10.1016/j.visres.2009.06.004

Yonas, A., Arterberry, M. E., & Granrud, C. E. (1987). Four-month-old infants' sensitivity to binocular and kinetic information for three-dimensional-object shape. *Child Development*, *58*(4), 910-917. https://doi.org/ 10.2307/1130531