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FACULTEIT GENEESKUNDE EN LEVENSWETENSCHAPPEN
master in de revalidatiewetenschappen en de kinesitherapie

Masterproef

Association between infants' looking behavior and visual short-term memory in a joint attention and color detection task: an eye-tracking study

Promotor :
Prof. dr. Marleen VANVUCHELEN

Copromotor :
Mevrouw Lise VAN SCHUERBEECK

Jana Van Hecke
Proefschrift ingediend tot het behalen van de graad van master in de revalidatiewetenschappen en de kinesitherapie

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The realization of a master's thesis is usually a long-time effort of not only the author, but also that of many other people in his or her surroundings. First of all, I would like to thank my promotor, Prof. Dr. Marleen Vanvuchelen, for believing in me and supporting me throughout the past 15 months. Without her help and creative solutions I wouldn't have been able to finish this thesis in a shorter than usual period. I would also like to thank her for carefully going through drafts I sent her, and providing the necessary feedback. Secondly, my appreciating goes to my co-promotor 'ad-interim' Dra. Lise Van Schuerbeeck, who helped my get a grip on the matter of this thesis, and helped me out with data at a time I reached a dead end alley. Furthermore, I want to thank my friends for their support in the final stressful weeks of writing. During the last couple of years we shared moments of laughter, irritation, joy and a fair share of stress, but as they say 'a sorrow shared, is a sorrow halved'. Last, but not least, I would like to thank my partner. Dries, thank you for the personal support, for putting up with me and encouraging me on nights and during weekends when I got fed up with the combined workload of internships, thesis and work.

Geetbets, January 2015 J.V.H

Context of the Research Project

Autism Spectrum Disorder (ASD), further also referred to as 'autism' is a pervasive developmental disorder with a prevalence of 62/10.000[1]. This makes autism one of the most prevalent developmental disorders in children. Typical characteristics for ASD are limitations in social communication and repetitive and/or stereotypical behavior and/or interests[2]. These characteristics should have an onset in (early) childhood before the age of three years[2], but diagnosis is often not prior to school-age. Earlier diagnosis can improve developmental outcome through the start of specific intervention at a younger age[3].

This present thesis is part of the doctoral project of L. Van Schuerbeeck, Through A Kid's Eyes: Is the association between action observation and imitation altered in young children with autism spectrum disorders? This project on ASD is realized at REVAL, the rehabilitation research center of Hasselt University (Prof. Dr. M. Vanvuchelen) in collaboration with the Leuven Autism Research Consortium (LAuRes). In the past the ASD research group at REVAL did work on imitation problems in autism which has advanced the diagnostic process to preschool age[1,3]. The estimated risk of recurrence for later-born siblings of children with autism is almost 20 percent[4]. For this reason, it is important to research indications of imitation problems in infants and toddlers at risk for ASD.

The doctoral project consist of an *explorative work package* and a *clinical work package*. In the explorative work package typically developing children are observed in an action-observation-action-execution model and during a change-detection task. During the clinical work package the same model and tasks are implemented on a group of infants and toddlers with autism or at risk for autism. The obtained information will be used to investigate whether the clinical group of children perform or react differently on these tasks than typically developing children, which could help in the earlier detection and diagnosis of ASD.

This thesis is part of the earlier mentioned explorative work package. The looking behavior in a three-shot change-detection task is investigated in a group of typically developing infants between the ages of 12 and 23 months with the use of eye-tracking technology. Change-detection tasks are used in both children and adults to study the visuospatial working memory. The change-detection task is a non-humane sequential comparison procedure with a brief exposure to a set of stimuli followed by an interval period and a subsequent test array.

The action-observation-action-execution model was studied by Sokol (2014)[5]. In the present study we use data acquired during the research of Sokol (2014)[5], which has a humane factor, and compare the looking behavior of the infants in this test to the looking behavior in the three-shot change-detection task.

This master thesis is written by a student Rehabilitation Sciences and Physical Therapy at Hasselt University (J.V.H.), under supervision of Prof. Dr. M. Vanvuchelen (promotor) and Dra. L. Van Schuerbeeck (co-promotor). The research question was developed together with the promotor and co-promotor. All data was collected earlier by the co-promoter, Dra. L. Van Schuerbeeck, Dr. M. Braeken, a student Rehabiliation Sciences and Physical Therapy (K.S.) and a student Biomedical Sciences (L.V.). Analysis of data, statistical analysis and combining these into clear results was executed by the student under supervision of the co-promotor and promotor. After receiving comments and feedback from Prof. Dr. M. Vanvuchelen and Dra. L. Van Schuerbeeck, the thesis was finished by the student.

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Association between infants' looking behavior and visual short-term memory in a joint attention and color detection task: an eye-tracking study

Composed according to the guidelines of Developmental Psychology ®

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Abstract

In order to assess the association between infants' looking behavior and their visual short-term memory (VSTM), two tasks were presented on a monitor and eye movements were recorded by a Tobii eye-tracking device. On one hand, a novel instrument, the three-shot color change detection task was shown to twenty-four typically developing infants between the ages of 12 and 23 months old. On the other hand a joint attention task was presented. Results revealed that infants did have a significant preference for the inconsistent – changed – colored object in the first trial of the three-shot color change detection task, but not in the second trial of this task. For the joint attention task, no significant preference was found for either one of the colored objects. Furthermore, we investigated a possible correlation between the looking behavior in the three-shot color change detection task and the joint attention task, but no significant correlation was found. This means that we could not proof a underlying VSTM construct in the looking preference during a joint attention task, so no conclusions can be made in relation to object processing. Further research into the relationship between joint attention and VSTM using eye-tracking technology should be done first in a typically developing population, with the use of validated instruments, as a preliminary research, so in a later stage infants at risk of developmental disorders could be screened from an early age on.

Key Words: Visual Short-term Memory, Joint Attention, Looking Behavior, Infants, Eye-tracking

Introduction

Working memory is considered to be a neural network that provides in the temporarily storage of information and manipulates the necessary information to execute complex cognitive tasks (Baddeley, 1992). The 'Model of Working Memory' by Baddeley and Hitch (1974) assumes that the working memory is divided in one supervising component with three subordinate systems (Figure 1). The supervising component is the 'central executive', which controls what information is transferred to the subordinate systems - 'phonological loop', 'visuo-spatial sketchpad' en 'episodic buffer'. These systems work alongside each other constantly, with each system temporarily storing and processing its own kind of information (Baddeley, 1992 & 2010). The phonological loop stores auditive information such as sounds and spoken language. The visuo-spatial sketchpad covers information on images and human faces. The episodic buffer then forms an integrational system to keep the information comprehensible, and to ensure the possibility of our problem-solving skills (Baddeley, 2010). In literature these systems are also referred to as 'verbal working memory' or 'verbal short-term memory' and 'visuo-spatial working memory' or 'visual short-term memory' (Baddeley, 1974; Logie, 1995)

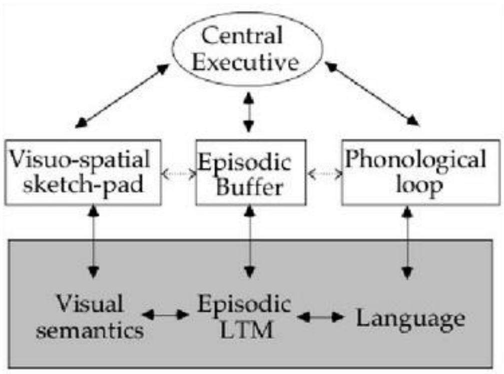


Figure 1 Schematic representation of the 'Model of Working Memory' (figure courtesy to Baddeley 2010)

Working memory is essential for optimal performance on task of daily life and in academics. Visual short-term memory (VSTM) enables a person to recall different locations and spatial connections between objects (Johnson, 2010). This makes it possible for a person to remember where an object is in relation to another object, which is important in daily activities such as navigation, team sports and academic tasks such as mathematics. The VSTM develops throughout childhood, adolescence and into adulthood. However, it is very difficult to test de VSTM in infants in a way that it is done in older children or adults, since their communication skills aren't yet enough developed. For this reason Oakes et al. (2013) developed an infant version of a change detection task using eye-tracking technology. Their modified one-shot change detection task had timing parameters similar to adult change detection tasks. The adults one-shot change detection task assesses memory by using a single stimulus cycle, which exist out of shortly presented encoding and retention periods (Luck and Vogel,1997). The following trial sequence is used: the sample array is presented for a very short time, followed by a short retention period (mostly 1000ms or less), after which a test array is presented that is either the same as the sample array of different. The participants then have to point out whether sample and test array were identical or not (Vogel et al., 2001), or indicate the location of the changed item (Hyun et al., 2009). The timing parameters are comparable to the natural visual cycle of fixation - retention (e.g. eye-blinking) – fixation. The modified version of the one-shot change detection test trials have the following sequence: the short presentation of a sample array with two colored squares (517ms), after which a short interval (317ms) is offered, followed by a test array in which one of the two squares has changed color is presented for 3000ms (Oakes, 2013). As a result of the short exposure and retention periods, the longer exposure to the test array will eliminate the possibility of the change detection being a reflection of iconic memory (Becker et al.,2000). Furthermore, the possible colors are limited to a small set, as to prevent interference of long term memory. To sum up, if infants fixate the changed color more than the unchanged color, then they must have created a VSTM representation of at least one item from the sample array (Oakes, 2013).

The present study is part of a broader project which mainly aims to investigate action observation in young children with the use of eye-tracking technology. Action observation is the mechanism of 'knowing what others will do' including the executer's intentions behind the action. The direction of gaze, and with it joint attention, seems to play an important role in the understanding of the other person's intentions during actions (Tipper, 2010). Joint attention is the shared focus of two individuals on an object. It takes place when one person draws another person's attention to an object through eye-gazing, pointing or other verbal or non-verbal indications. In our study, data were used which were acquired during a previous joint attention study (Sokol, 2014). We will investigate the looking behavior of infants while observing an adult looking at a colored object and compare it to a three-shot change detection task with color information.

The first aim of the present study is to investigate whether the infants fixate more on the changed color than on the unchanged color in the three-shot detection task. If they prefer the inconsistent, or changed, colored square, this would indicate that they have formed a VSTM representation of the primed – consistent - color (Ross-Sheehy, 2003; Oakes, 2013). The second aim of this study is to investigate the infants' looking behavior in the joint attention task, in particular whether the infants will have a preference for the primed colored object or a novel different colored object. In analogy with the color change detection task, we then could hypothesize that if they prefer the novel colored object over the primed colored object, a VSTM representation is formed by the infant. The third aim is to check whether or not the infants that showed an inconsistent looking behavior in the non-human three-shot color change detection task, had a similar looking behavior in the human joint attention task.

Methods

Participants

As mentioned above, data were collected in a previous study**.** Twenty-four typically developing infants between the ages of 12 and 23 months old (15 female, 9 male) participated in this study. All infants were recruited in day-care center 'De Ukkies' in Hasselt. Only one inclusion criteria had to be fulfilled: at least one of the parents had to be Dutch-speaking. Infants were excluded in case of a diagnosed developmental disorder or abnormalities in the visual system (e.g. strabismus). This last exclusion criteria was needed to obtain reliable eye tracking data. Parents gave informed consent for their infants prior to the start of the study and after receiving an informational newsletter describing the study (Sokol, 2014)

This study was approved by the medical ethics committee of Hasselt University and the Catholic University of Leuven (B322201215699).

Eye-tracking devices

A Tobii T120 Eye Tracker (Tobii Technology, Stockholm, Sweden) was used to register eye movements. The test procedure was performed on a 17 inch monitor (1280 x 1024 pixels) with integrated eye tracking technology, user camera and speakers. Cameras underneath the monitor registered reflections of infrared light at a frequency of 120 Hz to assess the distance between the cornea and pupil of both eyes. The accuracy and precision of the measurement were in ideal conditions respectively 0.16° and 0.4° of the visual angle (Accuracy and precision test report: Tobii T120 Eye tracker, 2012). An extra camera recorded a frontal view of the face and upper body of the child.

Test Environment and procedure

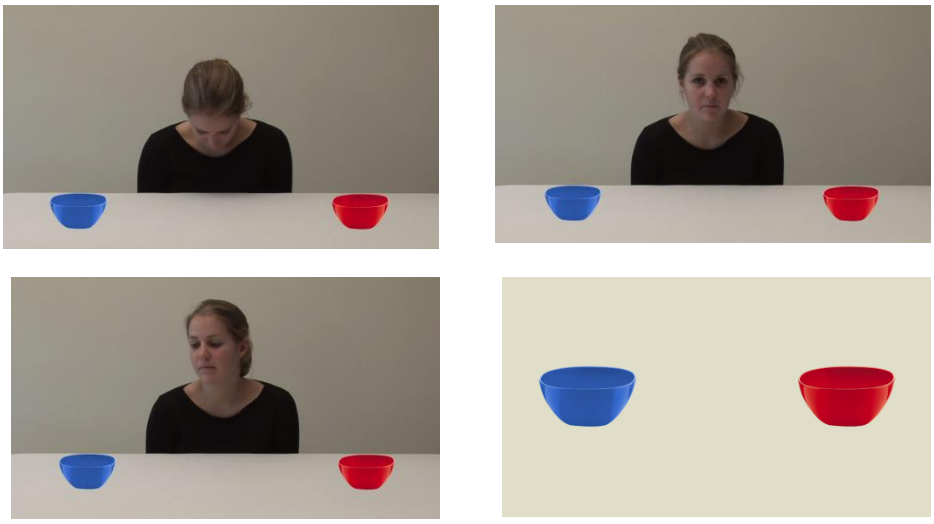
The eye-tracking technology was placed in a separate silent space in the day-care center, where the children were individually tested (Figure 2). The Tobii 120 monitor was installed against a stimuli-free white wall. Computers, equipment, and the researchers were enclosed by a white curtain on the left side of the room and invisible for the child. The infants were seated in a car seat at - approximately - 65cm from the monitor. A small seat was provided next to the car seat for the caregiver of the child

Figure 2 Test environment at daycare center 'De Ukkies': Tobii T120 monitor and car seat (left), Tobii T120 monitor, car seat and small seat for the caregiver (middle), and computers for data registration invisible to the child (right). (Sokol, 2014)

The moment the infant arrived in the silent room, he or she was placed in the car seat by the caregiver, who then took place on the small seat. The caregiver was present during the entire session. A popular toddler movie 'Bumba' was shown to pull the infant's attention to the screen and to make him/her feel at ease. If the infant had the intent of leaning forward or crawling out of the car seat, seatbelts could be used to prevent this. After a period of watching 'Bumba', the movie was interrupted and a 5-point calibration was made. When the calibration was successful (looking at 4 out of 5 cued locations), video clips were presented on the screen. First, the joint attention task was offered. Next, the children saw the Three-shot Color Detection task. Between different stimuli an attention-pulling animation – spinning toys and figures – were presented.

Tasks

Joint Attention Task. The following stimuli were presented (figure 3). In the video clip, a female model sat in front of a table against a neutral background. The model was wearing a black shirt and her hair was tied back. One blue and one red colored bowl were placed on equal distance left and right in front of the model. At the beginning of the task, the eyes of the female model were fixated on the table in front of her (1s). The model looked into the camera (1s) and turned her head towards one of the two colored bowls (3s). In the next phase of the task, the test array, the model disappeared and only the two bowls are presented against a neutral background (3s). The infants were presented with eight trials in a randomized order, with attention-pulling animations between each trial. . For the test to be valid and the data to be included, the infants had to look at the priming color in the gaze direction or priming phase for at least 0.200s to ensure that there was a real fixation on the area. The AOI around the models face measured 7.38° and 5.76° of vertical and horizontal angles. The rectangular AOIs around the colored bowl measured 5.76° and 7.38° of vertical and horizontal angles.



A) B) C) D)

Figure 3 Snapshots of the joint attention task with color differentiation A) model's eyes fixate to table (1s); B) model looks into camera (1s); C) model looks at one of the colored bowls (3s); D) test array – blue and red bowl. A, B and C are the gaze direction or priming phase, D is the test phase.

Three-Shot Color Detection Task. The video clip started with a figure pulling attention to the screen. Subsequently, in the priming phase, the infants were either primed with blue or red squares. The colored square was shown three successive times for 1 second, with a 1 second interval in between them. After the three shots of priming, in the test phase, a test screen was shown with one square in blue and a second square in red, for 3 seconds. Immediately following this first trial was a second trial, in which the priming color was changed. The rest of the second trial was analogous to the first trial (Figure 4) For the test to be valid and the data to be included, the infants had to look at the priming color for at least 0.200s to ensure that there was a real fixation on the AOI and not just a saccadic movement of the eyes. The area of interest around the colored squares in this task measured 8.24° of vertical angle and 8.24° of horizontal angle.

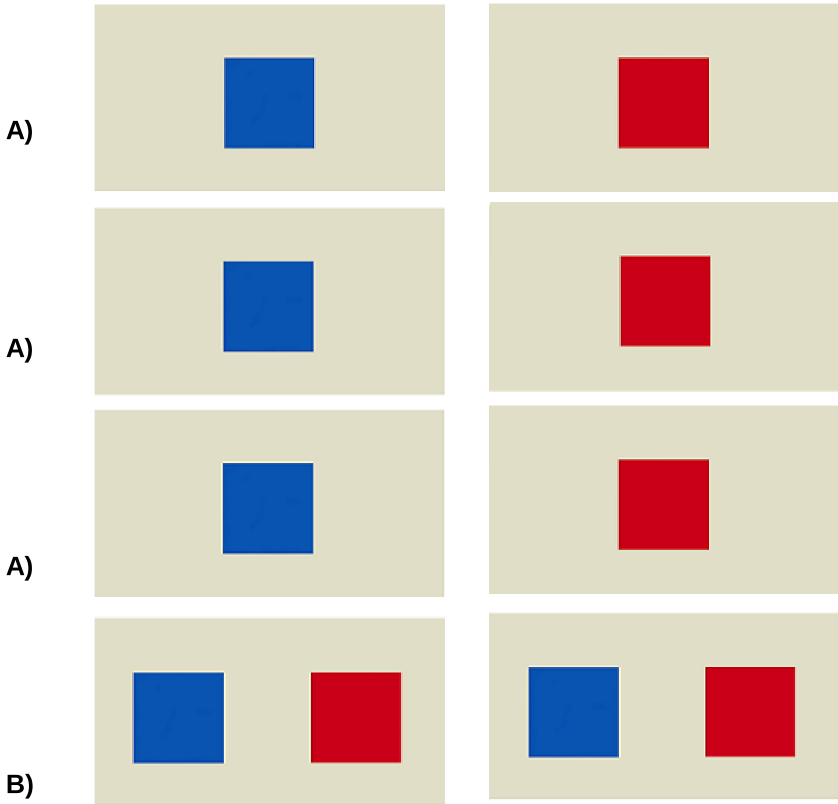


Figure 4 Snapshots of the three-shot color change detection task. A) priming phase; B) Test phase

Scoring system of eye-tracking data

Before statistical analysis could be commenced, the eye tracking data had to be sorted out. To distinguish between the different trials and different colors, we had to determine which stimuli was presented in which trial. Therefore the frontal camera recordings of the infants were viewed together with the simultaneously running video clip with the stimuli. This way it was possible to manually determine what color stimuli was first presented. The scoring of the looking behavior and first look was already done by another researcher (L.V.S.) using the software program TimeStudio (Time Studio Project). TimeStudio is a framework which works on MATLAB (The MathWorks, Inc.) and uses the raw eye tracking data and compares it to the AOI on any given time. In the present study we only had to sort the data between trials and colors.

We obtained three different sorts of timing data from the eye tracking technology. The first sort of data was the total amount of time the infants were looking within both AOI. Secondly and thirdly, we obtained data about the amount of time the infants looked at the inconsistent - or changed - colored object and the time they looked at the consistent – or unchanged – colored object.

The location of the first fixation – the first look - during both the joint attention task and the three-shot color detection task, was determined. This procedure was performed by researchers and based on the scoring of the TimeStudio framework in MATLAB. The scoring was as followed: a score of 1 for the first fixated color and a score of 0 for the other colored object. The number of valid trials was determined by looking whether the infant had a fixation on the correct AOI during the priming phase of the tests. When an infant fixated on the correct AOI, that trial was considered valid, and was awarded a score of 1. If the infant failed to fixate on the priming color, the score was 0 and the trial was not included in the calculation of the difference score.

To be able to compare the data of the joint attention task which existed out of 8 trials and the three-shot color change detection task which had 2 trials, a difference score for every child was calculated using following equations:

$$Difference\ score\ Looking\ Time = \frac{\text{time looking consistent } - \text{time looking inconsistent}}{\text{total time looking at both AOI}}$$

$$Difference\ score\ First\ Look = \frac{\text{first look consistent} - \text{first look inconsistent}}{\text{total number of valid trials}}$$

Statistical Analysis As the sample size was less than n = 30, non-parametric statistics were used. A Wilcoxon Signed Rank Test (Z) was used to compare data of two related samples. We compared the looking times between trials, with and without regard of which trial was presented first, with the use of a Wilcoxon Signed Rank Test (Z). Furthermore we compared the first look over the different trials with the use of a Wilcoxon Singed Rank Test. The same statistical analysis was performed on the data of the joint attention task. At the end we also compared the calculated difference score between the joint attention task and the three-shot color change detection task. At last we also checked for a correlation between the infants' looking behavior on the two different tasks with the use of a Spearman Rho correlation coefficient (r_s).

The statistical analyses were performed using the statistical software SPSS version 22.0. P-values smaller than .05 were considered to be significant.

Results

Three-shot change detection task

Preference in looking time (test phase). First of all the looking times were assessed according to the priming color. When analyzed with a Wilcoxon Signed Rank Test, no significant difference in looking behavior was found between the blue- and red primed trials (Table 1). The p-values were respectively .338 for the blue primed trial, and .106 for the red primed trial. When we sorted the data into a trial 1 and trial 2, according to what trial was first presented to the infant but regardless of the priming color, we found a significant difference (p = .015) in looking behavior with a preference for the inconsistent or changed square. In the trial that was presented as second, no significant difference in looking behavior was found (Table 1).

Table 1 Results from the Wilcoxon Signed Rank test for the Looking Time during the three-shot color change detection task

	Z-score	p-value
Looking Time Blue	-.957	.338
Looking Time Red	-1.614	.106
Looking Time Trial 1	-2.443	**.015 ***
Looking Time Trial 2	-0.57	.954

Furthermore, a difference score was calculated to determine whether the infants showed a preference for the changed or the unchanged colored square during the test array of the three-shot change detection task, and to be able to compare these results to the results of the joint attention task. This difference score was calculated by subtracting the time the infant looked at the inconsistent square from the time looking at the consistent colored square and then dividing this by the total time the infant was looking within both areas of interest. If the infants had a preference for the changed object, this difference score would be a negative value between -1 and 0. On the other hand, if the infants preferred the unchanged object, the score would be between 0 and +1. The further away the difference score was situated from 0, the bigger the infants preference. This difference score was then statistically analyzed using a one sample Wilcoxon Signed Rank Test and compared to 0. The results of this analysis were the same as the results in table 1.

Preference in first look When analyzing the first fixation or first look of the three-shot color change detection task, we find results that are comparable to the results of the looking time (Table 2). Only when analyzing the trials separately, irrespectively of the primed color, a significant difference ($p = .014$) in looking behavior is found for Trial 1, with a preference for the inconsistent changed colored square.

Table 2 Results from the Wilcoxon Signed Rank test for the First Look data during the three-shot color change detection task

	Z-score	p-value
First Look Blue	-1.225	.221
First Look Red	-1.335	.221
First Look Trial 1	-2.449	**.014 ***
First Look Trial 2	.000	1.000

Joint Attention Task

Correct looking behavior during gaze direction phase (priming phase). First we investigated whether the infants followed the gaze direction of the model in the video clip. A Wilcoxon Signed Rank Test was used, and a significant difference ($Z = 3.20$; $p = .001$) between incorrect and correct gaze following was found in favor of a correct gaze direction following.

Preference in looking time (test phase). Using a Wilcoxon Signed Rank Test the preference in looking time during the test phase of the joint attention task was analyzed for the first trial. No significant difference in looking behavior was found in looking time during this task ($Z = .00$; $p = 1.0$), so no preference was found in looking time during this task.

Preference in first look (test phase). The preference in first fixation during the first trial was investigated using a Wilcoxon Signed Rank Test. No significant difference ($Z = .25$; $p = .79$) was found between first look at the changed or unchanged colored object.

Comparing Three-shot color detection and Joint Attention Task

The last analysis we performed was a correlation between the infants' looking behavior on the two different tasks with the use of a Spearman Rho correlation coefficient. We found no significant correlation ($r_s = .18$; $p = .41$) between the looking behavior in the three-shot color change detection task and the joint attention task when taking all trials together. When isolating the first trial of both tasks, no significant correlation ($r_s = .26$; $p = .334$) was found either.

Discussion

Studies on social cognition (e.g. action observation, joint attention) in infants make use of eye-tracking technology and stimuli that appeal on short-term memory or working memory (Oakes, 2012; Navab, 2011; Swanson, 2013). The relation between the responses on such stimuli and the short-term memory has been insufficiently investigated. This is the first study to investigate if there is an association between the looking behavior in a working memory task and a joint attention task. The present study examines whether there is a relation between the looking behavior in a working memory task, using a three-shot color change detection task and a joint attention task. At the beginning of this study, we assumed that infants who had a preference for the changed or inconsistent colored subject made a representation of the primed – consistent- color in the visual short term memory (VSTM) similar to the conclusions other studies drew (Ross-Sheehy, 2003; Oakes, 2013). In our three-shot color change detection task, we found a significant preference for the square that changed color. However, this preference was only found for the first trial of the task. Within the second trial of the task absolutely no difference in looking behavior was found. This could mean that the infants habituated to the task, through the process of 'synaptic depression', which states that repeating the stimulus after a short delay leads to a decreased neuronal response as compared to the first presentation (Huber and O'Reilly, 2003; Davelaar, 2011). The risk of habituation could be prevented by presenting the trials in a different way, for instance by providing a longer time in between trials.

Our second aim was to investigate the looking behavior of the infants in a joint attention task. In the joint attention task no significant preference was found for the changed or unchanged colored object. However, during this task, not all infants had a correct gaze following during the gaze direction or priming phase, which resulted in smaller dataset of fifteen infants for the data of the looking time. Also, unlike the three-shot color change detection task, the joint attention task did not have the same test setting during priming and test phase. During the priming phase, a model sat behind a table with 2 colored bowls, while in the test phase, the model disappeared and the colored bowls were presented against a neutral background. This could have caused the infants to experience the test phase as a new element instead of a continuation of the task, which could have resulted in lacking a significant effect in this task. In future research it might be better to leave the model in the background during the test phase of the joint attention task.

Another aim of this study was to check whether or not the infants that showed an inconsistent looking behavior in the non-human three-shot color change detection task, had a similar looking behavior in the human joint attention task. We investigated this research question by performing a correlation analysis between the looking behavior of both tasks. No significant correlation was found when performing a correlation analysis over all trials of both tasks. Since only the first trial of the three-shot color change detection task found a significant preference, we then compared this first trial to the first trial of the joint attention task to rule out possible habituation effects. However, we didn't find a correlation between the results on the first trials either.

The three-shot color change detection task that was used in the present study was not found in other literature. The limited literature that did discuss VSTM in infants using a change detection task, used a one-shot version and even younger infants (Oakes, 2013). The advantage of a one-shot detection task above a three-shot detection task in infants can be that the one-shot detection task is shorter and needs a smaller attention span than the three-shot change detection task. Furthermore, the one-shot change detection task has been validated for measurement of working memory in adults (Luck and Vogel, 1997).

We could not proof a underlying VSTM construct in the preference during a joint attention task, and so no conclusions can be made in relation to object processing. However, it is important to find a way to investigate the VSTM in young infants. When VSTM can be accurately measured in typically developing infants, it would be possible to do this as well in children with suspicion for developmental disorder such as autism spectrum disorder (ASD).

Most studies agree that people with ASD have a problem with VSTM, which is demonstrated with various visuospatial tasks such as the Wechsler Memory Scale – III (WMS-II) (Barnard e.a., 2008; Williams e.a., 2005a; Williams e.a., 2005b) or the Cambridge Neuropsychological Test Automated Battery (CANTAB) (Sachse e.a., 2013; Steele e.a., 2007). Another point on which most studies agree, is that the problems in VSTM are a secondary problem to ASD. Therefore it is important to be able to investigate the VSTM from an early age on, so intervention can be started as well as soon as the problems protrude. As testing the VSTM in infants is not possible with the conventional tasks that are used in adults, an eye-tracking task could be a solution.

As in all research, the present study must be considered within the strengths and limitations of its design. A limitation of our investigation is the use of a novel version of a change detection task, - the three-shot color change detection task - which is an instrument that has not been validated yet, so the results found in this study are not inconclusive, since with a not-validated instrument we are not entirely sure that the instrument measured what we wanted to measure. Another limitation is that the tasks and trials in our research were part of a larger video fragment, which consisted out of several different social cognition tasks. As a result, the demands of the other tasks could have influenced the infant's looking behavior or the longer duration of the total testing time could have affected the attention of the infant. However, a strength of this study is the use of eye-tracking technology, which allows for highly precise and accurate spatial and temporal gaze following recordings, and is increasingly been used in the research of development in perceptual, cognitive, and social abilities throughout infancy.

Further research into the relationship between joint attention and VSTM using eye-tracking technology should be done first in a typically developing population, with the use of validated instruments, so in a later stage infants at risk of ASD could be screened from an early age on.

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