Longitudinal looming study in infants using high-density EEG

by

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Summary

A rapidly approaching object provides information about the object's approach and how imminent a collision is. Prospective control when responding to a looming object approaching on a direct collision course was studied longitudinally in infants 3/4 and 11/12 months of age. Different characteristics of peak VEP activity from infants' brain electrical recordings (EEG) were compared between the infants at these two different ages. The aim of this study was to find evidence for infant brain electrical responses coherent with a looming stimulus approaching the infant under three different accelerations. The results showed that there were differences in peak VEP activation with age. At the age of 3/4 months, infants showed peak VEP activation significantly later after the end of the looming sequence and VEP peaks with longer duration compared to when they were 11/12 months old.

One of the underlying causes of the developmental trend found in our study could be due to an increase in locomotor experience as infants grow older and become more mobile. More follow-up research is needed to investigate the relation between behavioral development and changes in brain activity associated with infants' perception of looming motion.

1. Introduction

How we are able to get about in our daily lives and avoid collisions with our surroundings all comes down to how well we interact with our environment. Interacting with the environment requires an individual to have highly efficient systems of integration of visual information around which adaptive behavior develops (Wilkie and Wann, 2003). Perception, action and cognition are tightly connected in a complex system that requires prospective control that is needed for navigation and interaction with events in the environment (von Hofsten, 2004, 2007; Lee, 1998).

Looming stimuli allow one to investigate defensive responses in animals and people. The term looming refers to the motion in which an object, on a direct collision course, projects an expanding image with a rapid symmetrical growth on the retina. The vital information provided by looming is how imminent the collision is (Schiff, Caviness and Gibson, 1962). The collision avoidance behaviors elicited by looming stimuli have been investigated in a very wide range of species, for instance in the fruit fly (Tammero and Dickinson, 2002; Hammond and O'Shea, 2007), the fly (Holmqvist and Srinivasan, 1991; Jabłoński and Strausfeld, 2001), the locust (Robertson and Johnson, 1993; Hastopoulos, Gabbiani and Laurent, 1995; Simmons et al., 2010), the crab (Hemmi, 2005), the frog (Yamamoto et al., 2003), the monkey (Schiff et al., 1962; Maier et al., 2004) and humans (Ball and Tronick, 1971; Poljac et al., 2006). In addition, looming-sensitive visual neurons have been reported to exist in the moth (Wicklein and Strausfeld, 2000), the mantis (Yamawaki and Toh, 2009), the locust (Rind and Simmons, 1992; Hastopoulos, Gabbiani and Laurent, 1995; Rind and Simmons 1997; Gray et al., 2010; Rogers et al., 2010), the crab (Medan et al., 2007), fish (Gallagher and Northmore, 2006), the frog (Nakagawa and Hongjian, 2010), the monkey (Schiff et al., 1962; Maier et al., 2004), the pigeon (Sun and Frost, 1998), the cat (Liu, Wang and Li, 2011) and in humans (Poljac et al., 2006).

In humans the dorsal stream and the ventral stream are parallel interconnected pathways that make up the primary visual cortex. The information taken in by the primary visual cortex either goes through the dorsal stream, which carries the information to the parietal lobe, or through the ventral stream, which carries the information to the temporal lobe. The processing of movement is thought to be performed by the dorsal stream and the processing of object recognition by the ventral stream (Morrone, Tosetti, Montanaro, Fiorentini, Cioni and Burr, 2000; Dougherty, Koch, Brewer, Ficher, Modersitzki and Wandell, 2003; Shirai and Yamaguchi, 2004; Holliday and Meese, 2005; Proverbio, Del Zotto and Zani, 2007). Studies show that the dorsal stream and its incorporated areas in the adult cortex have neurons that are selectively activated by motion stimuli (Cheng, Fujita, Kanno, Miura and Tanaka, 1995; Braddick, Birtles, Wattam-Bell and Atkinson, 2005; Rosander, Nystrøm, Gredebäck and von Hofsten, 2007). In infants, the function and development of these areas are still under investigation.

In early infancy, it is established that blinking is the most reliable form of awareness to visual stimuli on a collision course. This defensive blink needs to be precise, if the blink takes place too late or too early the eyes risk getting hurt. The time remaining to when an object is about to hit, is referred to as the time-to-collision. Picking up this time requires precise prospective control, in which the collision has to be perceived ahead of time to allow time for the body to respond appropriately, e.g. by blinking, ducking, or moving the hands in front of the face (von Hofsten, 2004, 2007).

Blinking in infants as young as 3-6 weeks of age has been tested at the behavioral level with both loom and zoom trials. The most important factor in determining whether an infant of this age will be able to perceive the display as a potential dangerous optical event is based on the rate of expansion in the display. The results obtained showed that the infants responded with significantly more blinking on the loom than zoom trials. It was also shown that the increased blinking tended to occur at the end of the loom trials, this is where the information for collision was maximal (Bower, Broughton and Moore, 1970).

Although blinking is the easiest way of noting a response to looming stimuli it may not be the most reliable. It is difficult to determine whether or not blinking is really an indication of the infants understanding and processing of the looming stimuli, or merely a reflex reaction or even a coincidence to the stimuli. By pairing VEP activity in the brain areas which have been found to respond to looming in adults with the looming stimuli it is possible to establish whether the infant brain is able to process the looming stimuli (Morrone et al. 2000; Ptito et al. 2001; Shirai and Yamaguchi, 2004; Holliday and Meese, 2005). Even without a blinking response, it is still possible to detect VEP activity that directly corresponds to the looming stimuli (van der Weel and van der Meer, 2009).

The use of high-density electroencephalography (EEG) permits a non-evasive investigation of how the human brain processes looming information from our surroundings. In a cross-sectional study where EEG was used to record VEP activity in infants in response to looming stimuli it was shown that the infant nervous system extracts and processes information for impending collision. The findings indicated that looming-related brain activity in infants 5-11 months of age was characterized by theta oscillations, and source analyses were able to reveal that this activity was located in the visual cortex. There was a clear age-dependent development where the youngest infants at 5-7 months used almost twice as long to process the looming information and could not differentiate between the three different accelerations of the loom, whereas the older infants at 10-11 months had short and distinct brain waves clearly showing that they differentiated between the different looms (van der Weel and van der Meer, 2009).

As infants become increasingly mobile with age, they are faced with more obstacles and therefore danger, thus requiring the need for perceptual and neural structures that allow them to judge impending collisions more adequately. A study by Kayed and van der Meer (2007) investigated blinking to visual stimuli on collision course and showed that before infants are fully mobile they have problems timing the blink and are less sensitive to optical collisions. Another study carried out by Fielder, Harper, Higgins, Clarke and Corrigan (1983) found that VEP latencies decrease with age and that the amplitudes decrease significantly during the first year of life. A study by Kræmer, Abrahamsson and Sjøstrøm (1999) found VEP maturation within the first three months of normal postnatal development where there was a long latency at term only after which the VEP developed dramatically giving short-latency potentials.

The present thesis focused on finding evidence for infant brain electrical responses coherent with a looming stimulus approaching the infant under three different accelerations using a longitudinal design. It investigated differences in how infants time their electrical brain activity in response to looming at 3-4 months and again at 11-12 months, and tried to explain any possible developmental changes.

2. Methods

2.1 Participants

A total of 15 babies were recruited from the local newspaper's birth announcement section. Three of the babies were later excluded from the analyses due to not being able to return for the second testing around their first birthday. For the final sample twelve infants (3 boys) provided the data. They were first tested at an age of 13-17 weeks, that is 3-4 months, giving a mean age of 16 weeks (SD= 1.7). The second test session took place when the infants were 47–52 weeks old, or 11-12 months, with a mean age of 49 weeks (SD= 1.8). Eleven of the babies were healthy and full-term infants, whereas one infant was slightly preterm (5 weeks). It was determined from parental report that there were no birth complications and that all infants showed typical development. It was also confirmed that the infants had minimal if any locomotor experience for the first testing session and that for the second session the same infants had gained substantial locomotor experience in the form of crawling. The age the infants started crawling was from 27 to 41 weeks, the mean age at crawling onset was 36 weeks (SD= 4.8). The number of weeks each infant had of crawling experience varied from 9 to 22 weeks before the second testing, the mean number of weeks of crawling experience was 14 weeks (SD= 3.8).

2.2 Testing apparatus

The testing took place in a secluded room with a projection screen, 180 cm wide and 80 cm high, hanging down from the ceiling. Infants sat facing the projection screen at a distance of 80 cm (see Figure 1A). For the first testing session the infants sat on the parent's lap, for the second testing session they were placed in a baby car seat for support throughout the testing session. The computers for stimulus generation and data acquisition were placed in an adjacent room which was divided from the experimental room by a glass partition.

We recorded electroencephalogram (EEG) activity using a high density 126 channel Geodesic Sensory Net 200 (GSN) (Tucker, 1993), with 12g Ag/AgC1 sponge sensors evenly distributed across the infant's scalp. Using a sampling rate of 500 Hz amplified EEG signals were recorded with Net Station software on a Macintosh computer. During the entire experiment, corneal reflection (Tobii x50) was used to record the gaze of both eyes (50 Hz), and trials where the infants did not look for the entire stimulus duration were disregarded from further analyses.

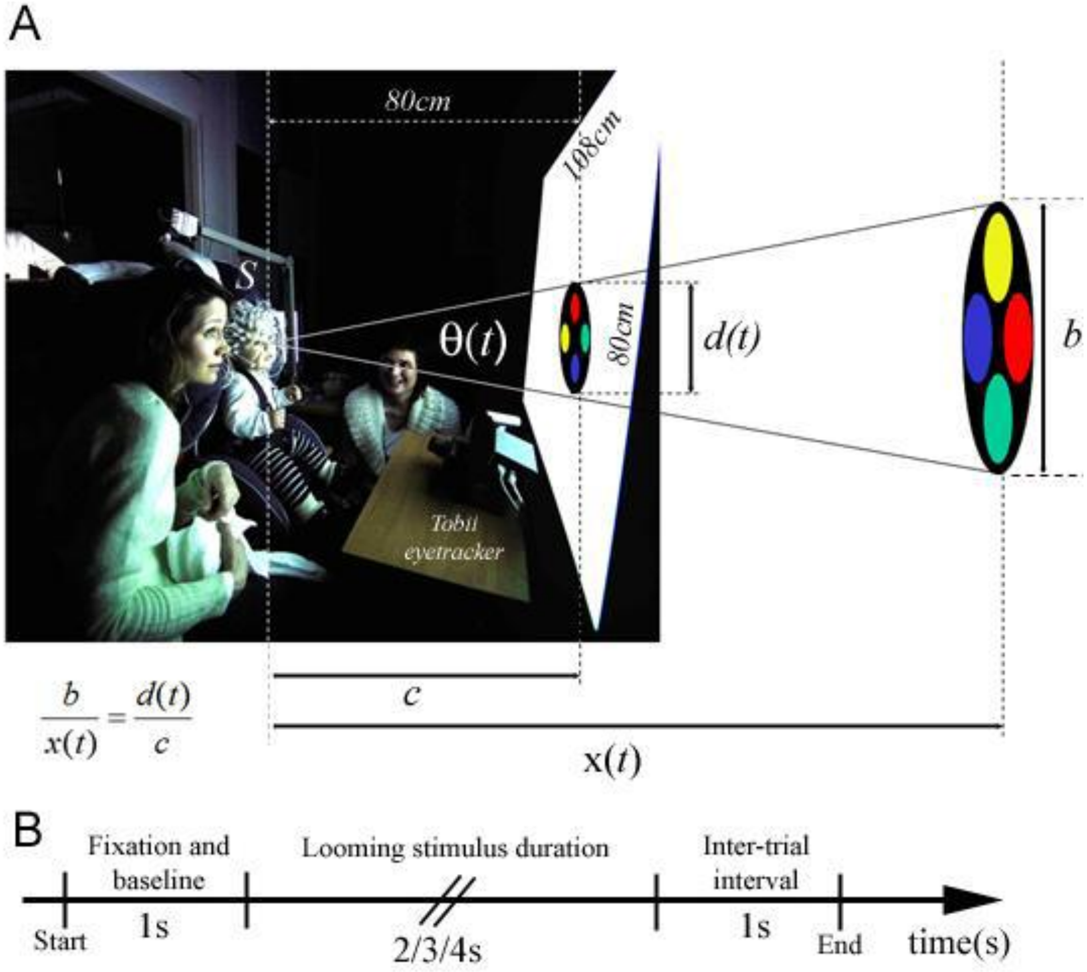


Figure 1: **A** shows how the experimental setup was during the testing sessions, except for when the infants were 3-4 months when they sat on the parent's lap instead of in the baby car seat. **B** shows a timeline of the looming stimuli sequence. Each infant was shown a virtual object of a flat circle approaching them on a direct collision course. The looming stimulus simulated an object coming from a distance and approaching for 2, 3 or 4 seconds under three different accelerations (21.1, 9.4 and 5.3 m/s^2, respectively). As the stimulus approached the infants the image on the screen grew exponentially. The loom stopped when the image filled the entire screen leaving a blank screen.

2.3 Stimuli

The stimulus consisted of a flat, black circle with four smaller circles with different colors (red, green, blue, and yellow) each of equal size, rotating within it (see Figure 1A). The entire stimulus object rotated with a constant angular velocity of 300 degrees per second and was shown on a cream white background. The inner circles' radius was 1/3 of that of the radius of the outer circle. The looming stimuli were programmed to loom towards the infant, and by coming up to the infant's face would make the infant experience a visual collision. The image of the virtual object appeared on the screen and stayed at its smallest size for 1 second, at a virtual distance of 43.1 m, before it expanded during a looming phase and finally reaching its full size, only to disappear leaving a blank screen for 1 second. The initial visual angle of the virtual object was 5˚ (diameter of 6.5 cm), and grew to a maximum visual angle of 131˚ (diameter of 350 cm).

The looming stimulus approached the infants on a direct collision course under three different constant accelerations over a period of 2 seconds (21.1 m/s^2), 3 seconds (9.4 m/s^2), and 4 seconds (5.3 m/s^2). The image of the virtual object had the same visual angle both at the beginning and at the end of the approach, independent of the virtual object's approach time. The virtual object would move over the same virtual distance, 43.1m – 0.80m in all three conditions (see Figure 1B).

2.4 Procedure

The baby and its parent(s) were greeted by the experimenters upon arrival. They were briefed on how we were going to go about the experiment and were informed about the procedures involved in collecting the data. It was important for the experimenters to get better acquainted with both parent(s) and baby to gain trust from both parties. When the bond had been made between baby and experimenter the head circumference was measured to determine which net would be used on the infant. While one of the experimenters was getting the net ready, soaking it in a lukewarm saline solution for 10 minutes, the main experimenter asked the parent(s) details around the infant's birth and locomotor experience.

The main experimenter, that had gotten to know the infant best, fitted the electrode net on the infant's head while the infant was distracted with toys by the other experimenter, and an assistant took a picture of the baby wearing the net as a souvenir for the parents. During the whole process of fitting the net on the infant's head, the infant sat on the parent's lap, where it would feel safest. After the fitting was completed the baby, parent and main experimenter went into the testing room, where the net was plugged into an amplifier and the impendence of the electrodes was checked. Any electrodes that did not have sufficient contact with the scalp were repositioned to improve contact. The parent sat with the baby through the entire experiment to avoid any stress that a missing parent may cause. The parent was instructed not to interfere unnecessarily. The main experimenter sat slightly to the side of the infant to monitor the experiment and to help the baby keep focusing on the screen.

The stimulus was generated with E-Prime (Psychology Software Tools, Inc), and the three different looms (lasting for 2, 3 and 4 s) were presented in a random order. If the infant had temporarily lost interest in the stimulus short pauses were introduced, even though data acquisition was performed in one block. Interest was tried to be regained by playing with the infant. However, if no further interest could be obtained or if the infant showed signs of agitation or discontent the experiment was aborted.

The looming experiment was performed together with an optic flow experiment and an occlusion experiment. The looming experiment was usually conducted after the optic flow experiment. Each experiment would take approximately 3-5 minutes depending on the infant's interest and patience.

2.5 Data analysis

Brain Electrical Source Analysis (BESA) 5.3 was the software program used to carry out all data analyses. Before exporting data from Net Station to BESA it was made sure that none of the participants had more than 10 % of the channels defined as bad during testing. In order to remove slow drift in the data, notch filter was set to 50 Hz and low cut-off filter (high band pass) was set to 1.6 Hz. High cut-off filter (low band pass) was set to 30 Hz.

In order to be included in the analyses, an infant would have to have VEP peaks in at least two trials for each of the three looming stimuli. This criterion was set low mainly for when the infants were tested for the second time at 11-12 months of age. Analysis was performed on 581 trials. On average, each infant contributed with 29 trials (SD= 6.0) at the first session and 18 trials (SD= 7.2) at the second session more or less evenly distributed over the three looms.

The electrical changes in the infant's brain caused by groups of neurons firing within the cerebral cortex were measured by EEG recordings. This allowed us to understand the spatial distribution of the brain activity evoked by visual looming and the time course of the brain activity. Each infant's raw EEG recording was used for the trial-by-trial investigation, by looking at the reference free channel distribution. Based on earlier studies investigating VEP (Di Russo, Martinez, Sereno, Pitzalis and Hillyard, 2001), prominent VEP peaks were marked at electrode sites Oz, O1 and O2. These VEP peaks provided information about the activity at the specific selected brain regions as a direct measure of amplitude. A 3D mapping of the activity of a build-up and a decline of voltage activity in the visual cortex over time could also be used to make sure that there was brain activity in the right area for the selected peak. This 3D mapping, trial-by-trial visual inspection, and knowledge of prior studies of anticipated peak location according to age were criteria used to determine which VEP peak to choose (see Figure 2).

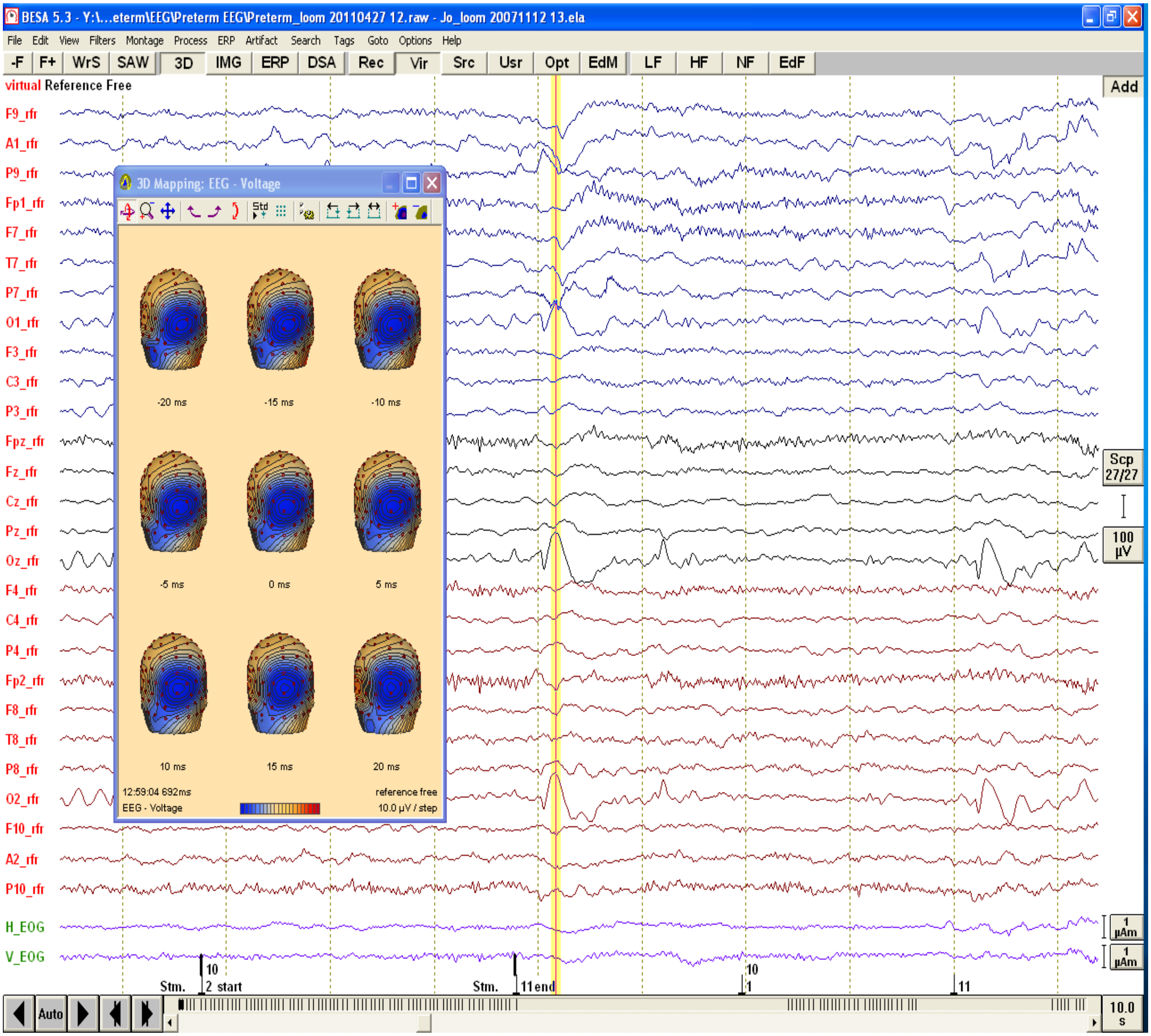


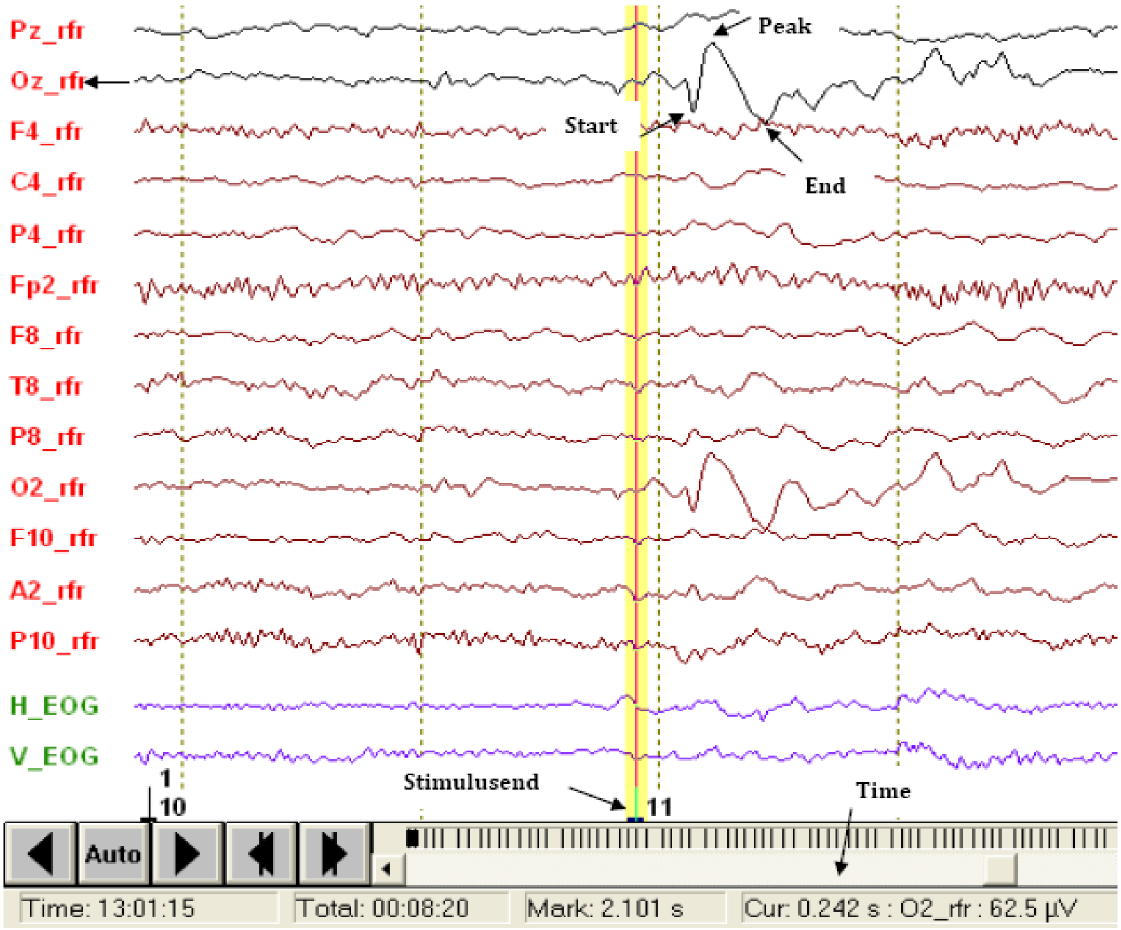
Figure 2: Raw data of EEG recordings from a 4-month-old baby boy displayed in BESA using standard 10-20 reference free sites. Increased electrical brain activity is marked with the yellow vertical line. Prominent VEP peak activity at sites O1, Oz and O2 about 300 ms after the end of a 3 s looming trial is seen as a direct response to the virtual collision of the looming stimulus. To the right, similar VEP peak activity in the same channels can be seen with similar latency after the end of the next 2 s looming trial. An EEG voltage build-up and a decline over time in blue can be seen in the 3D mapping window on the left.

The following criteria were adopted in case of multiple waves, different wave patterns, or other variations. The first prominent looming-related response was selected when a number of consecutive responses were seen just after stimulus end. Trials where the looming responses were not prominent, occurring too early before the end of the loom or too late (more than one second after the end of the loom) were discarded. Such variable responses were regarded as indecisive behavior when responding to a looming object.

2.6 Timing of VEP response

Examination of EEG data and recoding of VEP by the naked eye, showed that the timing of the looming response was rather variable both from the end of loom in different trials and between infants. The timing data for start, peak and end of each VEP from the end of stimulus were recorded manually in O1, Oz and O2 (see Figure 3). The data were recorded separately for all three looms for both testing sessions of the infants.

In order to compare whether there were any age-related timing differences as well as differences in responses to the three different looming conditions, the following two parameters were explored in depth from area Oz as this was the area that all the infants had the most prominent and consistent waves. 1) VEP latency, i.e. timing of VEP activation after the end of the looming stimulus. 2) VEP duration, i.e. duration time from start to end of each VEP.



Time: 13:01:15

Total: 00:08:20

Mark: 2.101 s

Cur: 0.242 s : O2_rfr : 62.5 µV

Figure 3: Marking and timing of individual VEP in raw EEG data, showing how the start, peak and end of the looming-related VEP were marked manually in Oz and O2 in a single trial, from the end of the stimulus which is indicated by the vertical yellow line. Corresponding timing data were recorded from the lower tab.

3. Results

3.1 Activity areas

The three occipital electrodes O1, Oz, and O2 showed prominent and similar looming-related brain electrical activity in all the trials. Compared to the activity in the occipital electrodes, parietal electrodes Pz and P3 representing a visual processing area higher up the dorsal stream showed much less looming-related VEP activity. About 80% of infants showed either no or very little activity in these parietal electrodes, so it was not further explored.

3.2 VEP responses

The analyses were performed on a total of 362 trials from the first testing session and a total of 219 trials from the second testing session. Infants contributed on average 30 trials (SD = 6.570, Range 22-44) and 19 trials (SD = 6.410, Range 8-30) to the first and the second session, respectively.

A 2 (age: 3-4 months and 11-12 months) x 3 (loom: 2 s, 3 s and 4 s) repeated measures ANOVA was performed on VEP latency at Oz. A main effect of age was found, $F(1,11) = 32.667$, $P<0.05$, indicating that the average peak VEP activation occurred significantly closer to after the end of the virtual collision when the infants were 11-12 months, 0.238 s (SD = 0.08), than when they were 3-4 months, 0.401 s (SD = 0.04) (see Figure 4). No main effect of loom was found, nor a significant interaction.

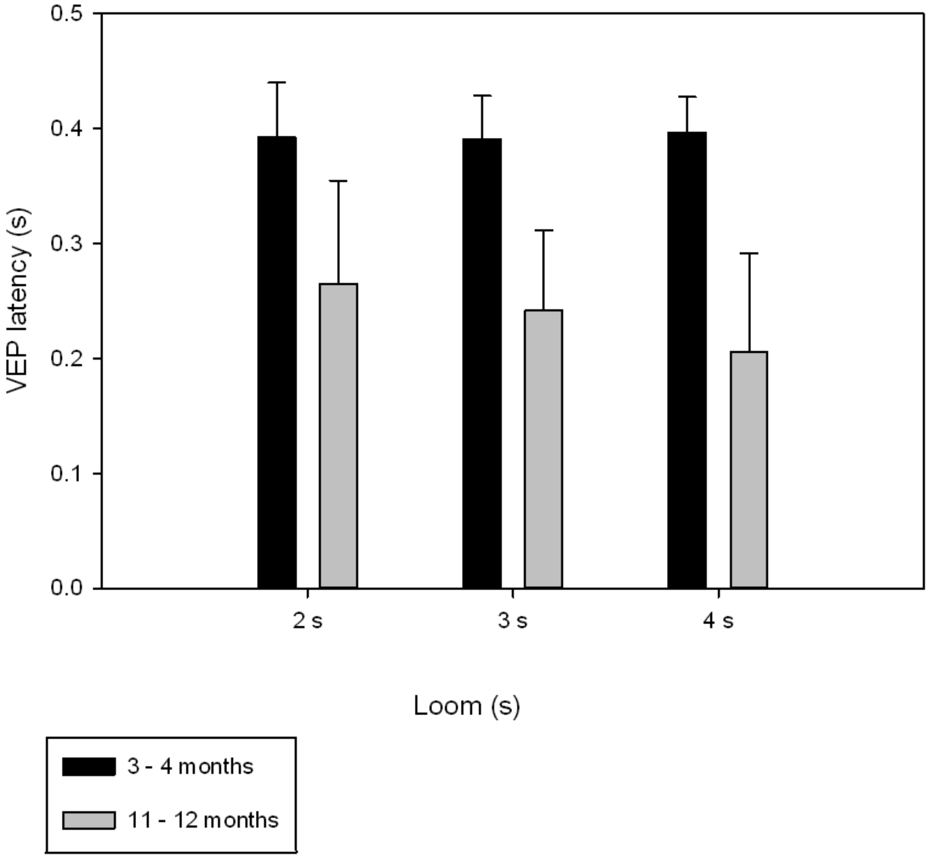


Figure 4: Averaged VEP latencies (in s), including SD bars, for the three looming conditions are significantly longer at 3-4 months than at 11-12 months.

Another repeated measures ANOVA, 2 (age: 3-4 months and 11-12 months) x 3 (loom: 2 s, 3 s and 4 s) was performed on averaged VEP duration ($VEP_{end} – VEP_{start}$). A main effect of age was found on VEP duration, $F(1,11) = 14.207$, $P<0.05$, indicating that averaged VEP duration at 11-12 months, 0.211 s (SD = 0.053) was significantly shorter than averaged VEP duration at 3-4 months, 0.301 s (SD = 0.056) (see Figure 5). Again, there was no significant main effect of loom, or a significant interaction.

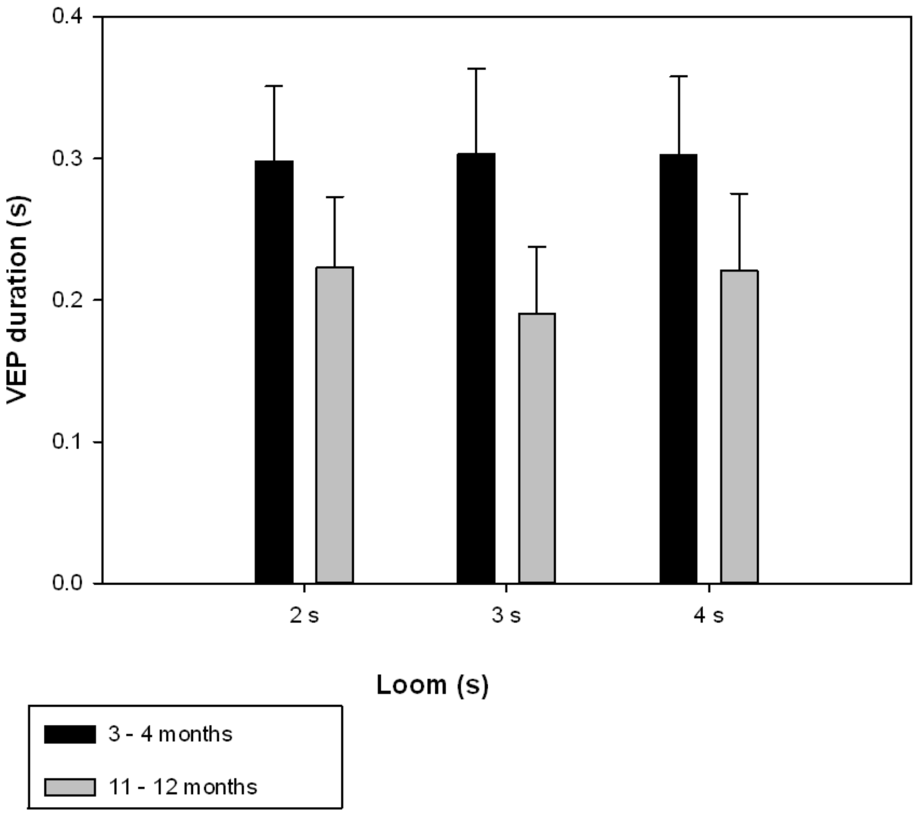


Figure 5: Averaged VEP durations (in s), including SD bars, for the three loom conditions are significantly shorter at 11-12 months than at 3-4 months.

Findings from the two ANOVA's indicate that the averaged peak VEP activation appeared significantly later after the end of the looming sequence and that the VEP response had a longer duration at the first testing session when the infants were 3-4 months of age, as opposed to at the second session when they were 11-12 months of age. With age, infants thus showed a significant improvement in VEP response where VEP activation was closer to stimulus end and was of a shorter duration.

4. Discussion

During the course of this longitudinal study we observed the development of motion processing of a looming object approaching on a direct collision course under three different accelerations, in infants that were 3-4 months of age and then when the same infants were 11-12 months of age. During the first year of life the infant visual system goes through a drastic growth and development. The infant requires a high degree of prospective and visuo-cognitive ability in order to be able to extract and process information for an impending collision (Lee, 1998; Wilkie & Wann, 2003; von Hofsten, 2004, 2007). Both the primary and secondary visual processing areas in the brain are represented by occipital electrodes and have shown significant activity to looming stimuli in both infants (van der Weel & van der Meer, 2009) and adults (Dougherty et al., 2003).

4.1 VEP latencies and VEP durations

The results from this study showed that infants at 3-4 months of age showed an average looming-related VEP peak 0.401 s after the virtual collision, compared to 0.238 s after virtual collision when they were 11-12 months of age. This indicates an improvement in the infants' timing of the looming-related VEP with age. The results also showed that infants at 3-4 months of age showed an average VEP duration of 0.301 s compared to 0.211 s at 11-12 months. Thus, irrespective of the three different loom speeds infants at the age of 3-4 months showed an average peak VEP more than 150 ms later and an average VEP duration of almost 100 ms longer compared to when they were 11-12 months of age.

Findings from this study showed that the average peak VEP duration was almost twice as long and with a VEP peak further from looming end after virtual collision for infants at 3-4 months compared to when they were 11-12 months of age. Results from the first testing session when the infants were of 3-4 months of age, corresponded to findings of early maturation of sensory and motor cortices (Casey et al., 2005) and the ability to perceive directed motion and tracking with the eyes that is developed already around 12 – 16 weeks of age (Grönqvist, Brodd, & Rosander, 2011). Results from the second testing session showed a developmental trend in infants of 11-12 months in the direction of shorter peak VEP duration and peak VEP closer to virtual collision, which could be an indication of a more efficient way to process visual motion information (Fielder, Harper, Higgins, Clarke & Corrigan, 1983; Kræmer, Abrahamsson & Sjøstrøm, 1999; Coch et al., 2005; Dubois et al., 2008; Johnson, 2000; Webb et al., 2005; Picton & Tylor, 2007; van der Weel & van der Meer, 2009; van der Meer, Svantesson & van der Weel, 2012). Although the infants' looming-related VEP responses took place after the end of the looming stimulus at both 3-4 months and 11-12 months, we see shorter latencies with age.

It is known that in the course of the first year the infant brain more than doubles in weight and undergoes many changes (Johnson, 2000; Picton & Tylor. 2007), such as an increase in white matter due to myelination of axons (Dubois et al., 2008; Grieve et al., 2003; Webb et al., 2005). The late activation of the peak VEP long after virtual collision in the infants when they were 3-4 months of age might be due to the fact that at this age the infants did not have fully developed networks for processing visual information. The slow processing of motion information in infants compared to adults (Langrova, Kuba, Kremlacek, Kubova, & Vit, 2006) and in our case in early infancy vs. late infancy is in correspondence with Webb et al. (2005) and can be attributed to a lesser degree of neuronal myelination in the white matter leading to much slower conduction rates. In order to increasing the processing speed of visual information in the cortical pathways the myelination of axons is needed (Picton & Taylor, 2007).

Maturation of the infant brain during the course of development might be an outcome of synaptic maturation through neural selection and competition between the different neural pathways. As stabilization of connections between pathways that are closer to one another are easier to establish than those separated further apart, close-by pathways are more likely to outdistance other pathways. There is strengthening of some connections and pruning of other connections. This strengthening and pruning of neural pathways might be a developmental change that affects processing speed and efficiency as a more restricted brain area gets activated due to neural pathway specialization (Jacobs, 1999; Johnson, 2000).

As mentioned earlier, crawling experience may also play a part in our findings. For the first testing session the infants had little to no experience when they were 13 to 17weeks but they at least had some crawling experience for the second testing session when they were 47 to 52 weeks. The main difference between the two testing sessions thus was locomotion experience. Motor activity has been associated with psychological development by several investigators (Anderson et al., 2001; Campos et al., 2000; Gilmore, Baker & Grobman, 2004). The argument made by these studies is that experience in locomotion can influence whether or not available information about a specific stimulus will be noticed and used by the one perceiving the stimulus. Thus, experience in locomotion might let the infants convert effective information variables available in the optic flow field into useful information in regards to prospective control (Gibson, 1979). Thinking of the relationship between brain and behavior as an interdependent one will allow us to argue that as infants gain more experience in locomotion, their ability to be more accurate with processing visual information based on impending virtual collision will therefore improve (van der Weel & van der Meer, 2009).

4.2 Activity areas

The three occipital electrodes O1, Oz, and O2 showed prominent and similar looming-related brain electrical activity in all trials, as opposed to the activity in the parietal electrodes, Pz and P3, representing a visual processing area higher up the dorsal stream, which showed much less looming-related VEP activity. About 80% of infants showed either no or very little activity in these parietal electrodes, so it was not further explored. All the results gathered from this study was based on area Oz as all the infants had the most prominent and consistent waves in this area.

The occipito-parietal areas in the right and left visual cortices is where processing of motion in early infancy is mainly localized (van der Meer et al., 2008; van der Weel & van der Meer, 2009) which at the age of 4 months goes through a rapid cortical activation (Rosander, Nystrom, Gredeback, & von Hofsten, 2007). Having such a dominant response to looming in occipital areas but not in parietal areas is in accordance with the structural development pattern as the occipital areas are less specific and less refined than the parietal areas (Casey et al., 2005). Another reason for the lack of significant P3 and

Pz activity could be due to the presence of an alternative sub-cortical pathway for motion perception (Johnson, 2000). It is hard to pick up EEG activity from such deep sub-cortical pathways and structures.

4.3 Conclusion

In conclusion, the findings from this study provide an indication that visual pathways are generally less specialized at the age of 3-4 months than at 11-12 months and through normal development the infant visual system matures. The results showed age-related differences in VEP activity, shown by a decrease in processing time and peak VEP activation closer to the loom's end after the virtual collision. The observed differences can reflect both a less mature anatomy as well as less specialization of brain pathways in the infant brain compared to amount of crawling experience and compared to adults.

It is also possible to argue that changes in behavioral development together with changes in the developing brain could be the underlying causes of this trend. Our study of the development of prospectively judging when a looming object will collide by using EEG recordings may contribute to a deeper understanding of the neural functions underlying the development of this process. Further work should address these and possibly other underlying causes in order to enhance our understanding of the development of infant prospective control. Observing infants over a longer period of time and as well as observing larger groups of infants, would give even more profound understanding on how the normal infant brain develops over time.

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