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Abstract

Through high-density electroencephalogram (EEG), the present study investigated brain responses and timing of prospective responses to a looming stimulus in preterm and full-term children at 6 years of age. A visual paradigm of a looming stimulus approaching at three different speeds was used, along with a response pad to estimate the time-to-collision with the loom. Additionally, motor performance was assessed through the Movement-ABC test. Looming-related visual evoked potentials (VEPs), button press (BPs) responses, and motor performance in the M-ABC test were further analyzed at the individual and group levels. Analyses performed on the VEPs showed that both groups displayed their brain responses at fixed times across speeds, indicating the use of an efficient strategy based on time to estimate the time-to-collision with the loom. However, full-terms displayed their VEPs significantly closer to time-to-collision than preterms, which is associated with a more efficient transmission of visual motion information. Two preterm children stood out in the individual VEP analysis, suggesting that these participants were using a less efficient strategy to estimate the time-to-collision with the loom. Analyses on BPs showed that both groups displayed larger deviations from time-to-collision with decreasing speed of the loom, which could suggest the use of a less efficient timing strategy in the motor domain to estimate the time-to-collision. No significant differences in BPs between groups were found. Further analyses performed on VEPs and BPs indicated that the preterm group showed significant differences in the deviation between their visual and motor responses, while full-terms showed similar deviation values between their two types of response. The similar deviation values amongst full-terms could be an indicator of a steadier visuo-motor development. Moreover, analyses of time windows between VEPs and BPs showed that the preterm group displayed larger time windows than full-terms, which could be associated with longer processing times required to prepare and emit a prospective response amongst the preterm participants. Finally, one participant from each group stood out in the M-ABC test with scores that indicated impairments in the motor domain. However, no significant differences were observed between groups in this test. Overall, results from the BP analyses and the M-ABC test suggest a similar performance in motor skills amongst all children, which could be explained by experience with self-locomotion and synaptic plasticity as a result of experience with the environment. Yet, the VEP and time window analyses point to significant differences in the transmission and processing of motion information between groups. Inefficient transmission of visual motion information along with longer processing times amongst preterms could be due to a dorsal stream vulnerability as a result of being born too soon. Considering these results, follow-up studies are required to determine if preterms keep presenting these response patterns at later stages in life, or if they manage to develop a response pattern similar to that of the full-term group, which could indicate that they have successfully caught-up with them.

1. INTRODUCTION

Preterm birth is a global problem that carries multiple burdens, both at the individual and social levels. At the individual level, even though it is possible to sustain the life of babies born preterm due to current advanced technology, they tend to develop multiple health complications that affect their lifespan. Some of these comorbidities can vary greatly from person to person, with some examples being cerebral palsy, cognitive impairment, motor difficulties, and underdevelopment of certain brain pathways (Bos, Van Braeckel, Hitzert, Tanis and Roze, 2013; Connors, 2003; Mayo Clinic, 2021; Menon, 2012; Moreira, Magalhães and Alves, 2014; Murphy and McLoughlin, 2015). On a social level, all the possible factors that could account for a preterm birth outcome are still not quite well understood and given the fact that risk factors might be different from country to country, prematurity is still difficult to prevent (Menon, 2012; Murphy and McLoughlin, 2015). In 2012 there was a worldwide increase of preterm birth (i.e., <37 weeks of gestational age) and prematurity caused by low birth weight (i.e., <2500 grams) in both developed and underdeveloped countries, causing 1 out of 10 babies to be born premature (Menon, 2012). This ratio translates to roughly 15 million premature babies being born every year, with complications that can lead to impairments amongst the survivors, such as learning disabilities and visuomotor problems (Menon, 2012; Moreira, Magalhães and Alves, 2014).

There is little information related to how long these difficulties last, whether they endure a lifetime, or whether preterm babies will eventually catch up with their full-term peers at later stages in life (Swamy, Ostbye and Skjaerven, 2008). An important reason for this information gap is the follow-up process of premature children ending usually around 2 years of age, and it is mainly concerned about detecting cerebral palsy or any other severe disability. However, only a small part of preterm children come to develop such severe sequelae, yet the majority of this population will come to experience multiple difficulties that can jeopardize their quality of life (Jarjour, 2015; Moreira, Magalhães and Alves, 2014). Thus, adequate longitudinal assessments become necessary in order to detect and study long-term morbidities within the preterm population, evaluate if they correct themselves at some point, and develop possible strategies to overcome them.

Europe also shows steadily increased rates of preterm birth amongst its different countries, with half a million babies born prematurely every year. In Norway, the rate of prematurity escalated from 6.4% in 1996 to 7.5% in 2021 (March of Dimes et al., 2012; Murphy and McLoughlin, 2015; Norsk Helseinformatikk, 2021). Furthermore, the Norwegian Institute of Public Health declared that 0.5% of all births in this country are extremely premature, meaning that the baby has not reached 28 weeks of gestational age (Tinderholt, Gundro, Hov, et al., 2017). The more premature a baby is born, the more likely it will be for him/her to have a second risk factor in the form of low birth weight (LBW). LBW can happen even in children born at term, but in premature children the most common cause of LBW is having underdeveloped organs, which can lead to medical complications in the long term (Jarjour, 2015; Nationwide Children's Hospital, 2021).

Hence, since there seem to be multiple known and unknown factors contributing to a prematurity outcome and it can take a significant amount of time before we reach a comprehensive explanation in order to improve the statistics worldwide, it is mandatory that in the meantime we assess the complications and consequences that this condition brings with it in the long-term, in order to develop interventions that help the increasing number of survivors catch-up with their full-term peers. Prematurity is a risk factor on itself, affecting the normal, comprehensive development process of children. As mentioned earlier, LBW is one risk factor associated with prematurity, and it is subcategorized into two types: *very low birth weight* (VLBW) equivalent to a weight lower than 1500 grams, and *extremely low birth weight* (ELBW) equivalent to a weight lower than 1000 grams. The smaller the gestational age and birth weight are at birth, the higher the chances of mortality and morbidity are for the child, since both variables affect the maturation process of several systems and functions in the body (Moreira, Magalhães and Alves, 2014; Pinheiro, Simões and Fontaine, 2014).

Visual perception and motor performance are some of these crucial functions affected by prematurity, being particularly important not just for their role in overall survival, but also because they have been shown to be indicators of underlying problems, as well as potential predictors of severe diagnoses (Pinheiro, Simões and Fontaine, 2014; Van der Meer, Van der Weel, Lee et al., 1995). Visuomotor integration involves both processes, comprising and coordinating visual perception and movement of the body, both at the gross and fine levels. Alarmingly, several follow-up studies show that visuospatial and visuomotor skills tend to be impaired amongst preterm children, and even at later stages in life as adolescents and adults (Aanondsen, Van der Meer, Brubakk et al., 2007; Agyei, Van der Weel and Van der Meer, 2016; Bos, Van Braeckel, Hitzert et al., 2013; Leung, Thompson, Black et al., 2017; Pinheiro, Simões and Fontaine, 2014; Van Braeckel and Taylor, 2013). When these abilities are impaired during early childhood, they become more evident when preterm children start school. Their perception, cognitive and motor drawbacks can differentiate them from the rest of their peers, making it more complicated not only to fulfill a successful educational process, but also to engage in play and social activities with their peers (Moreira, Magalhães and Alves, 2014; Pinheiro, Simões and Fontaine, 2014).

Presenting perceptual and/or motor impairments related to prematurity that make it difficult for these children to engage in activities with their full-term peers can become a vicious cycle that hinders progression of cognitive and motor development. This is because perception and motor performance feed information back to each other, or in Gibson’s words (1979): “We must perceive in order to move, but we must also move in order to perceive” (p. 223). Several studies following the line of the Gibsonian ecological theory of development (Agyei, Holth, Van der Weel and Van der Meer, 2015; Agyei, Van der Weel and Van der Meer, 2016; Van der Meer, Agyei, Vilhelmsen et al., 2015; Van der Meer, Fallet and Van der Weel, 2008) have demonstrated that visual perception develops hand in hand with motor experience, especially with self-produced locomotion. Visual perception and motor response feed and reciprocate one another, since the former provides information to act and navigate in the surroundings, but through that navigational motor response an optic flow is generated. This optic flow keeps affording visual information -such as location in space or direction of motion- that permits the continuous assessment of situations along with possibilities for action (Agyei, Van der Weel and Van der Meer, 2016).

Thus, if a child born prematurely already has visuomotor developmental problems and moreover, does not actively partake in activities, sports or games along with its peers, the sequelae progression can neither be hindered nor overcome, making these difficulties even more likely to persist throughout life. Because of this, relevant follow-up studies during the first years of school-age provide a rich ground for assessing and detecting neurodevelopmental lags between preterm and full-term children, since the academic and play activities proper of this stage put their visuo-motor skills to the test, while giving them the opportunity to improve them (Agyei, Van der Weel and Van der Meer, 2016; Astikasari, Amirullah, Festiawan et al., 2020). This type of research can further help develop intervention programs and functional strategies for the preterm population in order to catch-up with their full-term peers, allowing them to adapt to environmental demands and overcome them (Agyei, Van der Weel and Van der Meer, 2016; Bos, Van Braeckel, Hitzert et al., 2013; Leung, Thompson, Black et al., 2017; Moreira, Magalhães and Alves, 2014).

A particularly important ability within these environmental demands is to perceive and respond to a looming stimulus. By ‘looming’ we refer to the last part of a given optical event, in which an accelerating object approaches towards the observer (Kayed and Van der Meer, 2007). Depending on the context we find ourselves in, and the characteristics of the approaching loom, this will trigger different responses from our behavioral repertoire. Perceiving and responding to a loom is one of many forms of threat avoidance, and since this ability is present in multiple species like locusts (Santer, Rind and Simmons, 2012), rodents (Lischinsky and Lin, 2019; Yilmaz and Meister, 2013), cats (Liu, Wang and Li, 2011), monkeys (Cléry, Giupponi, Odouard, et al., 2017), and humans (Agyei, Van der Weel, and Van der Meer, 2016; Van der Meer, Svantesson and Van der Weel, 2012), this suggests its relevance for overall survival.

In order to keep ourselves alive, we need to be able to identify an object (‘*what’*), calculate its location in space (*‘where’*), determine whether it is moving (‘*motion’*) and, if so, how fast it is moving (‘*speed’*) and what trajectory it is following (‘*direction’*). This information is crucial to emit a response that helps us avoid a potential danger in the environment (Lischinsky and Lin, 2019; Santer, Rind and Simmons, 2012; Van der Weel and Van der Meer, 2009; Yilmaz and Meister, 2014). Whether it is an approaching ball in baseball or an approaching car on the street, we need to determine that an object is indeed moving rapidly towards us, and this assessment must be computed accurately and swiftly enough to respond equally fast and avoid a concussion by hitting the ball, or to avoid serious injury -or even death- by evading the trajectory of the car. All the different features of a loom are detected and processed by two different –yet interdependent- visual pathways known as the *ventral* and *dorsal* streams. The ventral stream is the one responsible for identifying an object based on characteristics like its shape, color, and size, and it runs from the primary visual cortex (V1) to other visual areas (V2, V3 and V4) and further regions located in the inferotemporal cortex of the brain (Van Polanen and Davare, 2015). However, the one that particularly concerns the scope of this paper is the dorsal visual processing stream. This pathway, known as the *‘where’* stream, also initiates in the primary visual cortex V1, running through visual areas V2, V3 and middle temporal complex (MT/V5+) to the medial superior temporal region (MST) and other regions in the parietal lobes and dorsal areas (Van Polanen and Davare, 2015).

The dorsal stream receives input from the two most ventral layers of the lateral geniculate nucleus (LGN), and then projects to the parietal lobe through the areas V1 and V5. Said layers are composed of magnocellular neurons, thought to be responsible for the integration, processing and analysis of motion, as well as guidance of motor actions (Felleman, 2001; Van Polanen and Davare, 2015). Motion integration in the dorsal stream occurs in a sequence, arising from motion detection caused by luminance changes or modifications in other components of the scene like depth, texture, or contrast (Leung, Thompson, Black et al., 2017). The integration of these visual components allows the dorsal pathway to recognize motion, and the middle temporal complex (MT/V5+) is thought to underlie the processing of radial motion in a looming stimulus (Greenlee, 2000). Therefore, the dorsal stream is associated with the perception and processing of the *'where'*, *'motion', 'speed'* and *'direction'* features of the loom, performing a detailed analysis on the nature of the movement. Besides these functions, the dorsal stream is also associated with visuomotor integration and guided control of actions. Together, these functions allow this pathway to accurately process moving stimuli in the environment, for us to properly interact with them (Agyei, Van der Weel, and Van der Meer, 2016; Galletti and Fattori, 2003; Mendes, Silva, Simões et al., 2005; Van Polanen and Davare, 2015).

This visual architecture, however, can suffer several degrees of damage as a result of being born prematurely. Preterm children are more likely to present visual problems either by optical deficits and/or by cortical processing impairments. When the problem resides in the brain, assessing the underlying cause of the visual impairment becomes more challenging (Leung, Thompson, Black et al., 2017). Even though there are multiple cortical structures that could be affected, impairment in the dorsal stream usually accounts for visual difficulties amongst preterm children (Agyei, Van der Weel and Van der Meer, 2016; Leung, Thompson, Black et al., 2017; Santos, Duret, Mancini and Gire, 2009). This is because myelination of the visual system begins during the last trimester of pregnancy, which is the time at which preterm babies are born. Although the myelination process continues, conditions out of the womb during this critical period might not be as suitable for an adequate development to take place (Agyei, Van der Weel and Van der Meer, 2016; Van der Meer, Fallet and Van der Weel, 2008; Shoykhet and Clark, 2011).

Being born during critical weeks makes neuronal tissue more susceptible to injury, particularly in the periventricular area (Connors, 2003). Preoligodendrocytes are the cells responsible for initiating the myelination process, and their function can easily be disrupted by factors like insufficient levels of oxygen, abnormal blood flow, or inflammatory processes, all of which are associated with prematurity. When this happens, the myelination process is jeopardized, leading to white-matter injuries which preterms are at greater risk of developing (Back, 2017; Connors, 2003; Shoykhet and Clark, 2011). An inadequate myelination translates into a lack of efficiency in the transfer of information from one nerve cell to another, or from the nervous system to the muscle tissue, causing processing or reaction delays in sensory or motor areas, respectively (Agyei, Van der Weel and Van der Meer, 2016; National Institute of Neurological Disorders and Stroke, 2019; Shoykhet and Clark, 2011). Besides the impaired development of white matter, other neurological complications associated with prematurity are abnormalities both in cerebral morphology and microstructure of brain tissue, as well as atypical glucose metabolic rates in posterior and temporal lobes related to inefficient neuronal processing and transmission. Regardless of the reason, atypical development of the dorsal stream in the preterm brain imposes a serious threat, making it difficult to accurately process looming danger, and therefore decreasing the ability to time and emit a protective motor response (Chugani, Müller and Chugani, 1996; Vilhelmsen, Agyei, Van der Weel and Van der Meer, 2019).

This brings us to another important variable in this process: *timing*. Since we need to interact with an external environment, we need to adjust our behavior and movements in relation to the environmental properties, which can either be stationary or changing (Von Hofsten, 1993). To determine whether these properties are steady or not, our brain makes use of optic flow information coming from the retina, being constantly updated as we move. This establishes the visuo-motor feedback cycle mentioned above, which states that self-produced movement and a more accurate and detailed visual perception develop side by side (Agyei, Van der Weel and Van der Meer, 2016; Gibson, 1979; Van der Meer, Fallet and Van der Weel, 2008). Specificity of perceived environmental factors is a key aspect for obtaining accurate visual information and thus, a precisely timed motor response. Said specificity is obtained through multiple variables within a visuo-motor task. One of these variables is *tau*, which is the time it takes for motion gap between two points to close (Lee, 1998). When perceiving a collision trajectory, *tau* is responsible for estimating the time-to-collision with the object, so that a precisely timed interceptive response can be produced (Agyei, Van der Weel and Van der Meer, 2016; Lee, 1976). However, other variables can also be used as a source of visual information to estimate time-to-collision, and they are influenced by changes in the environment, like the speed at which a loom is approaching, or the loom's growth projected on the retina (Van der Meer, Svantesson and Van der Weel, 2012). Examples of these variables are *visual angle*, *velocity*, and *time-to-collision*, all of which can be used as possible strategies to estimate when the virtual collision with the loom will take place (Kayed and Van der Meer, 2000, 2007; Van der Meer, Svantesson and Van der Weel, 2012).

However, not all strategies are equally effective to predict the collision accurately. A strategy based on *velocity* of the loom will depend on this information variable being held constant, meaning that the brain will only respond to a loom when this has reached a specific velocity. When the strategy used is based on *visual angle*, the information variable that is held constant is the angle created by the edges of a loom when it is being observed from a specific point of view. Thus, the loom needs to reach a certain size for the observer to respond to it. Finally, a strategy based on *time-to-collision* is that in which the information variable being held constant by the brain is the time before a loom collides with the observer, consequently showing a response a certain time before the impact (Kayed and Van der Meer, 2000, 2007; Van der Meer, Svantesson and Van der Weel, 2012).

A problem that arises with both *velocity* and *visual angle* strategies is that, by the time the loom has reached the key velocity or size required to trigger a brain response, it might be too early or late to respond adequately in order to protect us, increasing our chances of getting hurt (Kayed and Van der Meer, 2000; Van der Meer, Svantesson and Van der Weel, 2012). On the other hand, the strategy based on *time-to-collision* has been proven to be less prone to error, since it does not rely on changes in speed or size of the loom. Hence, the brain response is always triggered a certain time before the impact regardless of the duration of the looming sequence and so, an accurate protective response takes place (Kayed and Van der Meer, 2000, 2007; Van der Meer, Svantesson and Van der Weel, 2012).

Research has shown that full-term infants between 4 and 7 months of age tend to use strategies to estimate time-to-collision either based on velocity (Stople, 2018; Van der Meer, Svantesson and Van der Weel, 2012) or visual angle (Kayed and van der Meer, 2000, 2007), switching to the more efficient strategy based on time at some point between 6 and 12 months of age (Kayed and Van der Meer, 2000, 2007; Van der Meer, Svantesson and Van der Weel, 2012; Van der Weel and Van der Meer, 2009), or even as soon as 22 weeks of age (Kayed and Van der Meer, 2007). Preterms, however, tend to show a more variable developmental pattern compared with their full-term peers, being more prone to shift from visual angle or velocity strategies to a time strategy relatively later, at around the year of age (Kayed, Farstad and Van der Meer, 2008; Stople, 2018). Yet, several longitudinal studies show that some preterms kept using a strategy based on visual angle across all testing sessions during the first year of life (Kayed, Farstad and Van der Meer, 2008), while other studies suggest that the shifting to a more efficient strategy occurred at some point between 11/12 months and 6 years of age, or did not occur at all (Van der Meer, Agyei, Vilhelmsen et al., 2015; Stople, 2018).

Agyei, Van der Weel and Van der Meer (2016) argue that besides increasing age, a second variable that seemed to boost the shift to an efficient time strategy was self-produced locomotion. Right before this shift took place, participants had begun moving in an active and purposeful way, mainly through crawling. It is theorized that as soon as an infant starts crawling, an increasing and enriched optic flow experience starts taking place (James and Swain, 2011; Rasulo, Vilhelmsen, Van der Weel and Van der Meer, 2021; Van der Meer, Fallet and Van der Weel, 2008). Among other assets, one of the main experiences the infant gets through crawling is the ability to start discriminating directional changes in the optic flow, which simultaneously provides information of its own action in space. Basically, when infants move forward, the point in front of them expands, generating a flow that emanates from the center of this point. After sufficient exposure, the infant’s brain associates this type of optic flow with the body moving forward and will eventually use this information to adjust the body’s movement according to a desired goal (Rasulo, 2020; Rasulo, Vilhelmsen, Van der Weel and Van der Meer, 2021). Forward optic flow also provides the necessary information for perception of looming danger, since it tells the observer that whatever he is facing is expanding, and thus getting closer. Therefore, forward optic flow happening as a result of the onset of crawling is thought to promote the maturation of specialized neural networks that process information regarding an imminent collision along with our own movement in space, which eventually allows us to modify our own body movement in order to perform a controlled, purposeful action depending on the goal we want to achieve (Agyei, Van der Weel and Van der Meer, 2016; Rasulo, Vilhelmsen, Van der Weel and Van der Meer, 2021; Van der Weel and Van der Meer, 2009).

Regardless of our goal, we require to prepare ourselves accordingly for our motor response to be properly controlled and executed. In a looming context, this controlled action needs to occur in a future-oriented manner through our best guess of what is about to happen considering the available information in the environment, in order to have sufficient time to acknowledge the imminent collision, estimate the time-to-contact, and perform a protective response before the impact (Agyei, Van der Weel and Van der Meer, 2016; Griffiths, Kemp and Tenenbaum, n.d.; Von Hofsten, 1993). This future-oriented response resulting from an accurate coupling between visual information, cognitive processing and motor skills is known as *prospective control* (Agyei, Van der Weel and Van der Meer, 2016; Lee, 1976, 1998; Von Hofsten, 1993). A prospective response can take multiple forms -, and its main function is to execute a movement within the range of all possibilities of action in such a way that we end up adapting to the environmental demands (Agyei, Van der Weel and Van der Meer, 2016; Fajen, 2007; Lee, 1998; Von Hofsten, 1993).

In previous research conducted on infants born at term, prospective responses have been assessed through blinking before a virtual collision (Kayed and Van der Meer, 2000, 2007) and catching a toy in movement after being hidden behind an occluding screen (Van der Meer, Van der Weel and Lee, 1994). Results show a developmental trend in prospective control, were gaze-fixing helps predicting where the object is going to move and how fast in order to time their response (Agyei, Van der Weel and Van der Meer, 2016; Van der Meer, Van der Weel and Lee, 1994). At very early stages (3-6 weeks of age), infants are already capable of blinking or moving their head as a protective mechanism when perceiving a loom (Náñez, 1988), and later in their development, between 6 and 11 months of age they start displaying more complex movements that require prospective control, like attempting to reach for a moving object in a future position rather than the current position of the toy (Agyei, Van der Weel and Van der Meer, 2016; Van der Meer, Van der Weel and Lee, 1994). In these studies, the visuo-motor integration of an anticipatory gaze movement always preceded an accurate hand-reaching movement, which seems to imply that this ocular motion might be a requirement to start developing a prospective response (Agyei, Van der Weel and Van der Meer, 2016; Van der Meer, Van der Weel and Lee, 1994). The role of visuo-motor skills in prospective control development is only accentuated over time, as increasingly challenging environmental demands also arise with increasing age and thus, performing more complex movements like keeping the balance, walking, running, or jumping becomes necessary in order to survive (Agyei, Van der Weel and Van der Meer, 2016; Von Hofsten, 1993).

Since it is extremely dependent on visuo-motor integration, prospective control amongst preterm children might follow a different developmental trend over time compared to children born at term. There are studies supporting this idea (Kayed, Farstad and Van der Meer, 2008; Van der Meer, Van der Weel, Lee et al., 1995), since they have reported significant differences in prospective responses from infants born prematurely and infants born at term. Whether it is in terms of blinking (Kayed, Farstad and Van der Meer, 2008) or catching a moving toy (Van der Meer, Van der Weel, Lee et al., 1995), their prospective response seems to be impaired mainly because premature participants still use a velocity or visual angle strategy at ages where their full-term peers (and some preterms as well) are already using a strategy based on time. In some cases, half of the total sample is still relying on less efficient strategies at 26 weeks of age, and some participants do not manage to improve their prospective control in any of the testing sessions at 22, 26, and 30 weeks even when corrected for prematurity (Kayed, Farstad and Van der Meer, 2008). Findings from a longitudinal study gathered between 20 and 48 weeks of age amongst preterm and full-term participants, reported that even though both groups were able to direct their gaze waiting for a moving toy to reappear after being occluded, a significant difference in the onset of hand-reaching and coupling of gaze-hand was seen between groups. Moreover, several preterms emitted their reaching response towards the toy based on a distance strategy instead of a time strategy, which proved to be inefficient once the speed of the toy increased (Van der Meer, Van der Weel, Lee et al., 1995).

Besides an impaired visual perception secondary to a dorsal stream vulnerability, another factor that could account for the differences observed between groups is an atypical development of fine and gross motor skills, to which premature babies are at higher risk of suffering as well (Bos, Van Braeckel, Hitzert et al., 2013; Connors, 2003; Moreira, Magalhães and Alves, 2014). Even though most of the early motor difficulties will improve or disappear in the course of the first year after birth, a significant part of premature or VLBW infants will present long-lasting motor impairments or even be diagnosed with cerebral palsy (Connors, 2003). Nevertheless, determining in a precise manner the type of complications a child can exhibit based on his/her specific gestational background is not a simple task, and thus, a constant follow-up is required to detect early signs of motor impairment, assess how they progress over time, and intervene to correct them as much as possible (Leung, Thompson, Black et al., 2017). Based on the reasons exposed earlier related to the academic, motor, and social development that takes place at school, preterm children that have reached school-age are at an optimal stage to do so.

Fine and gross motor skills within this population can easily be studied through the Movement Assessment Battery for Children (M-ABC), which is the most widespread motor test amongst children at school-age (Bos, Van Braeckel, Hitzert et al., 2013). The M-ABC has also been successfully used to detect atypical performance in preterm children as soon as 3 years of age, with significant differences being reported between preterm and full-term children (De Rose et al., 2013; Foulder-Hughes and Cooke, 2003a), and scores indicating a slight degree of motor impairment amongst VLBW children have been significantly correlated with problems in school performance (Foulder-Hughes and Cooke, 2003b). By using this test, motor performance can be assessed within this population to detect possible impairments in fine and gross motor skills (Bos, Van Braeckel, Hitzert et al., 2013).

We were interested in investigating visual perception and prospective control with a looming stimulus in preterm and full-term children that had reached school-age, and high-density electroencephalography (EEG) is a useful non-invasive tool to do so. This technique can also be helpful to overcome –at least in part- the difficulties that assessing visual impairments at the cortical level can impose, as mentioned before (Leung, Thompson, Black et al., 2017). EEG detects event-related potentials (ERPs), which are brain waves that arise in response to a given stimulus in the environment. These neuronal responses happen as a result of the accumulation of dendritic postsynaptic potentials firing in a synchronous manner (Luck, 2005). In the occipital lobe, ERPs are known as visual evoked potentials (VEPs), and they arise when a visual stimulus is being perceived (Agyei, Van der Weel and Van der Meer, 2016; Brecelj, 2003). A motion-sensitive negativity (N2) dominates VEPs, which is thought to arise from the MT/V5 area. Based on previous longitudinal studies (Stople, 2018; Van der Meer, Svantesson and Van der Weel, 2012; Zotcheva, 2015), looming-related VEPs at 4-5 months, 11-12 months, and 6 years of age tend to arise on average at –1.01 s, -1.03 s and –0.41 s amongst preterms, and at -0.89 s, -0.55 s, and -0.21 s amongst full-terms, respectively. This suggests that preterms elicit a visual response earlier in the looming sequence, compared to full-terms who respond closer to time-to-contact. By projecting a looming stimulus with different approaching speeds on a screen and measuring looming-related VEPs arising on the scalp as it has been done in previous studies (Stople, 2018; Van der Meer, Svantesson and Van der Weel, 2012; Van der Weel and Van der Meer, 2009; Zotcheva, 2015), we can efficiently and harmlessly detect the times at which the brain detects and processes the imminent collision, in order to compare the visual processing speed between preterm and full-term children. In addition, by including a button to register the time at which the children consider the loom is going to make contact with them, we can compare the prospective responses between groups as well. Finally, as a supplementary tool to evaluate and compare motor performance between groups, the Movement Assessment Battery for Children (M-ABC) can also be used, given its sensitivity to detect differences between preterm and full-term children at school-age (Bos, Van Braeckel, Hitzert et al., 2013).

Thus, the aim of this study was to investigate visual perception and prospective motor responses amongst preterm and full-term children at school-age through a virtual looming task simulating a collision with the observer. The data in the present study correspond to the third and final session of a longitudinal study assessing visuo-motor development amongst moderate to very preterm children, as well as children born at term, at 6 years of age. High-density EEG along with a manual response pad were used, in order to collect looming-related VEPs and prospective motor responses timing the collision, respectively. main hypothesis was that we would observe less efficient visual processing of the virtual collision amongst the preterm children, understood as VEPs arising earlier in the looming sequence and farther away from the time-to-collision, whilst the full-terms were expected to show VEPs closer to time-to-contact, suggesting a more efficient visual processing. Also, since full-terms and most preterms already tend to use a strategy based on time before collision by 12 months of age according to the literature, we expected all our full-term participants and most of the preterm participants in our sample to use this efficient strategy based on time to estimate the time-to-collision as well. The preterm group was also expected to show less accuracy when timing the collision with the loom, understood in terms of higher deviation from the mean in their button press responses compared to the full-term group. Since preterms tend to show their brain responses earlier in the looming sequence, larger time windows between VEPs and button responses were expected amongst these children. Finally, due to the intimate relationship between visual perception and motor performance, and since prematurity makes the development of visuomotor problems more likely, we also expected the preterm group to show a less accurate performance than the full-term group in the M-ABC test.

2. METHODS

2.1 Participants

Fourteen children partook in this experiment, from which 7 were born full-term and 7 were born prematurely. All participants were healthy, and none of the preterm children had any significant neurological deficits associated with prematurity (e.g., cerebral palsy, retinopathy of prematurity, etc.). The mean birth weight for the full-term children was 3703 grams (SD= 686, range= 3085-5120), and their mean gestational age was 40 weeks (SD= 1.1, range= 39-42). For the preterm children (born moderate to very prematurely), the mean birth weight was 1657 grams (SD= 516, range= 1000-2670) and the mean gestational age was 31 weeks (SD= 1.7, range= 28-33). Both groups were matched for age and sex (4 boys and 3 girls), and in order to have a valid comparison between groups' performance, the age of the preterm children was corrected for prematurity. The mean age for the full-term group at the time of assessment was 6 years and 7 months (SD=6, range= 73-88 months), while the mean age for the preterm group was 6 years and 9 months (SD=1, range 81-85 months). The results in this paper correspond to the third and last session of a longitudinal study; by the time this session took place, all participants had already started primary school.

2.2 Stimulus

On a soft white background, a black 2D circle with four smaller color circles inside (blue, yellow, red, and green, all of which had 1/3 of the black circle's diameter) was presented, rotating with a constant angular velocity of 300 degrees per second. This looming stimulus also had auditory cues (not considered for the analysis of the present study), which in addition to the rotating movement gave the illusion of a virtual collision with the observer. The loom approached with three different speeds, and depending on the speed, the loom would virtually "collide" with the participant 2, 3, or 4 seconds after the loom's onset. The acceleration for each of these conditions was $–21.1\ m/s^2$, $-9.4\ m/s^2$ and $–5.3\ m/s^2$, respectively. Regardless of the condition presented, the loom always kept a constant angle, size, and virtual distance at the beginning (visual angle= 5°, diameter= 6.5 cm, virtual distance= 43.1 m) and at the end (visual angle= 131°, diameter= 350 cm, virtual distance= 0.8 m) of the trial. To avoid sensory adaptation, a one-second lasting interval consisting of a white screen without any sound was presented after each trial, and the order of the speeds presented in the looming sequence was random.

2.3 Apparatus

2.3.1 Visual loom presentation

The looms were presented using E-Prime software (Psychological Software Tools) on a screen (80 cm x 108 cm) that was placed 80 cm in front of the participant. An Ask M2 projector was used to display the looms on the screen.

2.3.2 EEG recording and amplification

To record brain activity, a Geodesic Sensor Net (GSN) 200 with either 128 or 256 sensors was used, depending on the size of the children's head (Tucker, 1993; Tucker, Liotti, Potts, Russell, & Posner, 1994). A high-input EGI amplifier for an optimal signal-to-noise ratio with maximum impedance of 50KΩ was connected to the net, ensuring a sufficient signal detection and amplification (Budai, Contento, Locatelli and Comi, 1995; Ferree, Luu, Russell, & Tucker, 2001; Picton, Bentin, Berg, et al., 2000). The amplified EEG signals were recorded using Net Station software on a Macintosh computer, with a sampling rate of 500 Hz. Net Station also received the triggers for the onset and offset of the looming stimuli from E-Prime.

2.3.3 Behaviour recording

Two cameras were situated at different angles in front of the participant to keep a record of his/her behavior while performing the task. This information would then be used in the offline analysis, if necessary, to check for movements that could explain artifacts in the EEG raw data during the visual inspection process.

2.3.4 Recording of collision-related motor response

A response pad with four large buttons –like piano keys- was placed in the child's lap, in order to record the prospective motor response. When the child considered that the loom was about to make virtual contact, s/he would push any button, and the signal was then sent to the Net Station software. If the child pressed the button more than once per trial, the software would only store the last response, which could take place before or after the loom had collided.

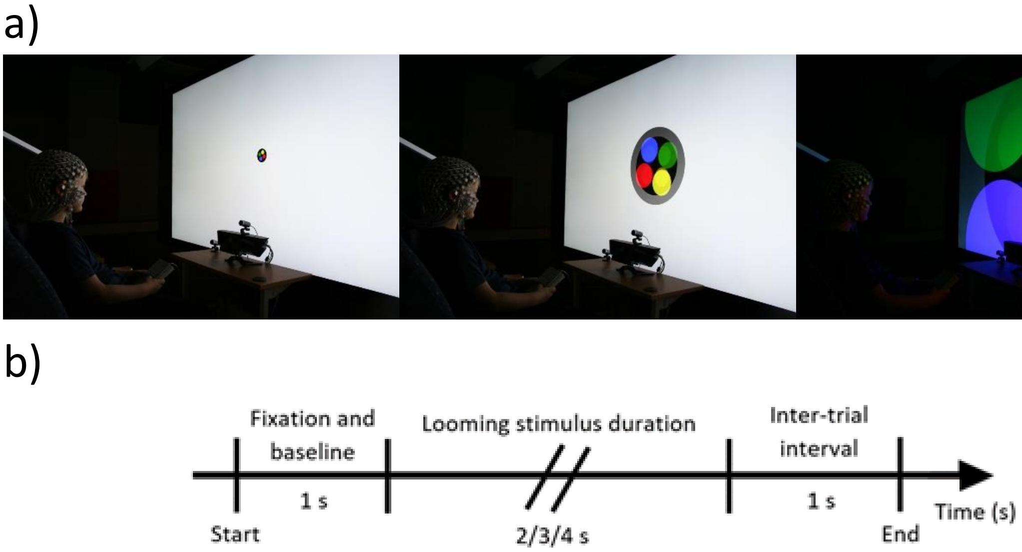

Figure 1. *a) Experimental set-up, showing the loom's approaching sequence leading to the virtual collision. b) Timeline of the stimulus.*

2.4 Instrument to assess motor skills

The instrument used to assess the children's motor dexterity was the *Movement Assessment Battery for Children* (M-ABC) (Henderson & Sugden, 1992). This battery consists of eight standardized tasks divided into three categories: *Manual Dexterity*, *Ball Skills*, and *Static and Dynamic Balance*. An assistant explained to each participant how to perform the tasks, while a second assistant assessed and rated the accuracy of the child's performance. With previously signed informed consent from the parent(s), the session was videorecorded in order to have access to it afterwards whenever there was a doubt about the child's performance. The total administration time was between 20 and 40 minutes, with a possible score between 0 and 40 points. A total score of 13.5 points or higher indicated delay in motor development. All participants performed the motor tasks corresponding to the test version for children 4-6 years of age, except for full-term participant VE. This girl had already reached 7 years of age at the time of testing, and she was therefore assessed with the test version for 7- to 8-year-old children.

2.5 Procedure

All the procedures and recordings were conducted at the Developmental Neuroscience Laboratory at NTNU Dragvoll campus, in Trondheim. The present data corresponds to the third session of a longitudinal study.

The child came to the laboratory accompanied by one or both parents, and while the experimenter talked with them, the child would have time to play and get used to the lab environment. The experimenter then informed the parent(s) about the aim of the study, and that they could withdraw their child from the experiment at any given time. After getting a signed informed written consent, the child's head was measured to select the appropriate size of EEG net, which was soaked in a lukewarm saline solution to boost conductivity. After the net was mounted on the head, the child was led to the experimental room and seated in a chair in front of the screen, and the net would then be connected to an amplifier. In the control room (separated from the experimental room by a wall with a window), one or two assistants checked the quality and strength of the signal captured by the EEG net after being connected to the amplifier. If the assistant(s) saw that there was impedance still preventing the electrical signal from being picked up by the net, necessary adjustments were made, either by adjusting the electrodes or by adding electrolyte solution to the sensors with a pipette. The child was then instructed to press the button on the response pad held in its lap when she thought the loom on the screen was about to collide with her face.

Then, the session started. Four experiments were recorded in one block, the third one corresponding to looming which lasted 4-6 minutes on average. The average of looming trials recorded was 60 (SD= 14, range= 44-97) on this session. At any given point, if the child showed tiredness or irritability the experiment was paused in order to play or talk a little so that he/she could draw its attention back to the screen. If this was not achieved, the session was suspended. After a short break with some refreshments, the Movement-ABC was carried out in order to assess the motor skills of the children and analyze those results along with the ones obtained through the EEG data.

High-density EEG is a safe, painless, and non-invasive physiological procedure. Nevertheless, if the children did not want to wear the EEG equipment or cooperate in any other way, the session was terminated. The original sample consisted of 10 preterm (2 of them twins) and 10 full-term children, but on the third session one preterm child refused to wear the net, and the twins' parents did not want to bring them in for the follow-up session at school-age. Thus, only 7 preterms remained, and the full-term sample was matched in size and gender in order to compare results. The study was approved by the Norwegian Data Services for the Social Sciences and the Norwegian Regional Ethics Committee.

2.6 Data Analysis

All EEG data processing and analyses were performed using BESA (Brain Electrical Source Analysis) Software, version 7.0. Through the Net Station software, the recordings were first segmented and then exported as raw files. In order to eliminate mainline noise interference in the recorded EEG data, notch filter was set at 50 Hz, the low cut-off filter (high band pass) was set at 1.6 Hz for removing slow drift in the data, and the high cut-off filter (low band pass) was set at 80 Hz. Next, a visual inspection and manual artifact correction trial by trial took place, in order to mark artifacts and detect noisy channels. Depending on the magnitude and prolongation of the noise, such channels would either be defined as 'bad channels' or be interpolated. If the amplitudes were excessively high at first sight and persisted that way throughout the entire session, the channel would be defined as 'bad' and thus eliminated from the final analysis. The percentage of bad channels could not exceed 10% in order to keep sufficient data to perform a valid analysis. To do so, channels that seemed noisy only on certain parts of the recorded data were first interpolated to assess how much the noise was diminished, and if the result was satisfactory, they would be kept and further analyzed. However, if the channel proved to still be noisy even after the interpolation, it would then be defined as 'bad' and discarded.

2.6.1 VEP Selection

Once bad channels were removed or interpolated, VEPs were selected through visual inspection for further analysis. For the VEP selection, high cut-off filter was changed to 8 Hz for an easier VEP detection. The criteria considered for the VEP identification in this study are based on previous research on VEPs (Di Russo, Martinez, Sereno, et al., 2002; Van der Meer, Svantesson, & Van der Weel, 2012). In order to choose relevant VEPs, they should arise in the Oz or Pz electrodes in the reference-free channel distribution of 27 standard electrodes, since these electrodes are thought to pick up brain signals related to visual perception of the loom. To aid in the selection process, a 3-D head model was used to identify changes in voltage in areas of interest (see Figures 2 and 3). Whenever two or more peaks were found in one trial, the one with the highest amplitude and/or closest to the stimulus offset would be the chosen one, since it was considered more functionally related to the visual perception of the loom's imminent collision. Trials in which the button pressing occurred too soon (i.e., 1 second before collision or even earlier), or where there was no button pressing at all, were discarded.

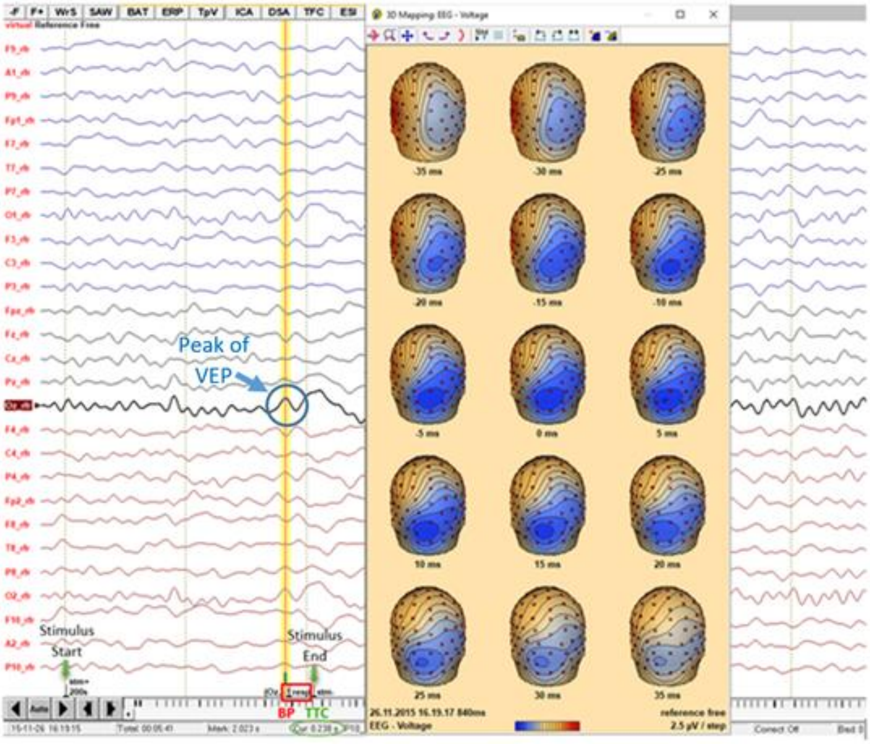

Figure 2. *Example of raw EEG data in the reference-free configuration of 27 electrodes in BESA. On the left, the yellow line is marking a VEP arising in electrode Oz, and on the right, the 3-D head model is showing increased activity in visual cortex occurring during the perception of the loom. The time-to-collision (marked in green) is understood as the time window between the highest value or peak of the VEP (blue) and the stimulus offset, which in this example is –0.238 s (horizontal axis). Button pressing response (BP) is marked in red.*

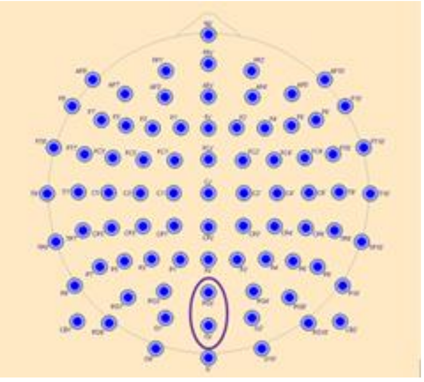

Figure 3. *Distribution of EEG electrodes according to the reference-free configuration (nose up), where the main electrodes of interest (Oz on bottom, Pz on top) are marked.*

Initially, 805 trials were obtained, of which 424 were from preterms and 381 from full-terms. In order to obtain the final trials that would be analyzed, both mean and standard deviations were calculated for all the time values at which the button pressing took place per condition per child. Then, we calculated the value corresponding to the *mean minus one standard deviation (Mean – 1 SD)*, and the result was the first threshold that would help include or exclude trials per condition per child based on button press values. Any button press value that was higher than the obtained *mean - 1 SD* value, would be excluded along with the whole trial it pertained. Once this was done, attention was directed to the VEP values for the remaining trials. Once again, mean and standard deviation of VEP timings were obtained per condition per child, and the exclusion criteria were: a) to have a low amplitude value smaller than 2 µV, b) to occur in a particularly noisy trial where the amplitude of the VEP was significantly higher than in other trials within-subject for that condition, and/or c) to be a significant outlier in terms of timing, compared to other VEPs within-subject. After identifying the VEP values that met one or more of these criteria, they were eliminated along with the trials they belonged to, leading to our final trial set to be analyzed. A total of 639 trials were considered for the final analyses, of which 336 were from preterms and 303 from full-terms. On average, each preterm participant contributed with 48 trials (SD= 9.67, range= 39-63), and each full-term participant contributed with 43 trials (SD= 12.55, range= 34-69). The VEPs were evenly distributed amongst speed conditions and groups.

2.6.2 VEP analyses

Group averages for VEPs were used in order to detect which timing strategy preterms and full-terms were using to time their brain responses. Values for VEPs were averaged per speed condition and across speeds in order to compare the results between groups. However, even though these averages can suggest that a whole group is using an efficient strategy, there can still be individual cases within the group that are relying on a less efficient strategy. Thus, an individual VEP analysis was conducted in order to detect such cases. These children can be identified through outlier values in their SDs across speeds, since an efficient strategy based on time to estimate time-to-collision is characterized by a low value in the SD across speeds. This means that the brain is responding to the imminent collision at approximately the same time regardless of the speed of the loom. According to Field (2009), an outlier is defined as a value that is above or below a numeric threshold equivalent to *Mean ± (SD*2.5).* Thus, *Mean ± (SD*2.5)* was calculated for the SDs of VEPs across speeds in the full-term group, and then individual SDs across speeds for each preterm child were compared to the threshold value.

2.6.3 Button Press Analysis

Since this study is, to the best of our knowledge, one of the first ones attempting to analyze simultaneously visual perception through VEPs and prospective control through button press responses (BPs), finding an appropriate way to analyze the latter proved to be challenging. Ideally, a BP should occur at the exact time of collision (TTC= 0), which would mean that the timing error would be equal to 0. However, unlike VEPs that always occurred before the virtual collision, BPs happened either before or after the virtual collision, which means that they acquired values that could either be negative (i.e., too early) or positive (i.e., too late). To solve this challenge, we decided to analyze our BP data using Root Mean Square (RMS) to calculate how much the responses deviated from their mean.

To obtain RMS values, the timings at which BP happened were squared, then a mean was obtained, and finally the square root of the mean was calculated, per speed condition as well as across speeds. Under the scope of RMS applied to BPs, a BP is assumed to be an error whether it happens before or after TTC, promoting a homogenization of the errors (responses) in order to analyze them. By squaring the times at which BPs happened, we eliminated the problem of the signs (- or + if the BP occurred before or after TTC, respectively), allowing us to determine the amount of deviation of the motor response per condition and across speeds, both individually and per group. Children were assumed to keep timing their motor response using a strategy based on the same features of the loom described previously (time-to-collision, velocity or visual angle). Thus, the RMS value was also helpful to determine the amount of variation per condition and across speeds for children in both groups, so as to determine if they were using a more efficient or less efficient timing strategy to emit their prospective responses. And so, having smaller deviations of BP responses across speeds would be indicative of the use of an efficient strategy that was less prone to error, contrary to higher deviations suggesting the use of a less efficient timing strategy.

2.6.4 Joint analyses of VEP and BP responses

Given our interest in studying VEPs and BPs jointly, we also calculated the RMS values for VEPs, so as to have both visual and motor responses on the same scale for further analyses. Since a delay between a brain response and a motor response was naturally expected, time windows between them were used for analysis as well. However, children from both groups displayed BP responses that could happen either before or after the looming-related VEP regardless of the speed condition. In pursuance of keeping and analyzing as much data as possible, it was decided to consider the absolute value of time windows between VEP and BP regardless of the order in which they appeared, so as to average them per condition as well as across speeds.

3. Results

Looming-related VEPs were observed in the occipital and parietal lobes during the looming sequence before the virtual collision. Since VEPs arose in both the Oz and Pz channels amongst all children, data collected from both channels was further analyzed.

3.1 VEP analysis at the group level

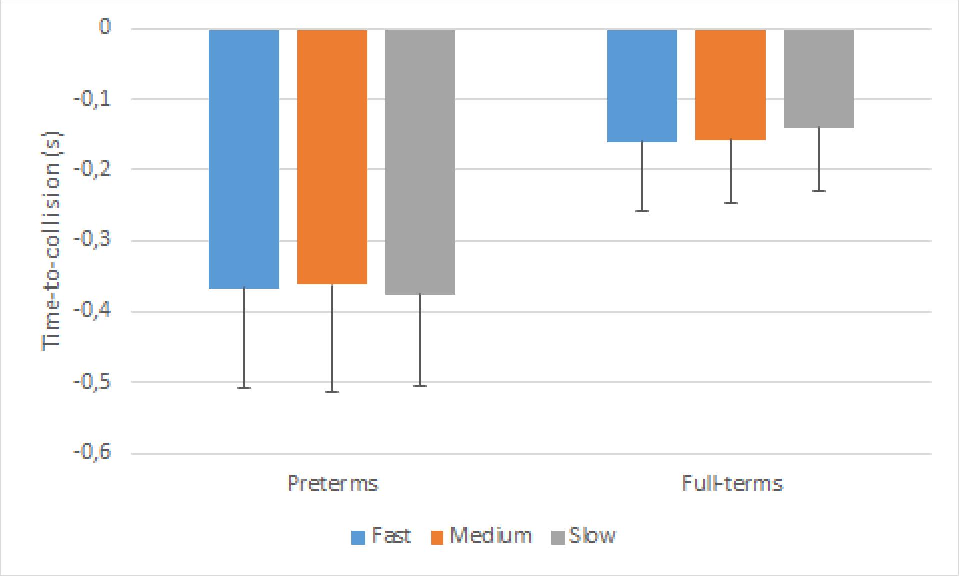

Figure 4. *Averaged looming-related VEP responses with SDs for the three looming speeds in the Oz and Pz electrodes for preterm and full-term children at 6 years of age. Both groups showed their VEP peaks at a relatively fixed time-to-collision, irrespective of the loom's speed. These results are consistent with a strategy based on time, which both groups seem to be using in order to estimate the time-to-collision with the loom. Full-terms' VEPs were significantly closer to time-to-collision than those from the preterm group (p<.001).*

Analysis showed that at 6 years of age, full-terms' looming-related brain responses across speeds occurred on average at a time-to-collision of -0.15 s (SD= 0.09), whilst preterms' brain responses happened much earlier in the looming sequence at a time-to-collision of -0.37 s (SD= 0.14). The small values of the standard deviations (SDs) indicate that both groups responded at a relatively fixed time-to-collision irrespective of the loom's approaching speed. On average, full-terms showed their looming-related VEPs at -0.16 s (SD= 0.10), -0.16 s (SD= 0.09), and -0.14 s (SD= 0.09) for fast (2 s), medium (3 s), and slow (4 s) looms, respectively, while preterms showed their looming-related VEPs at larger values of time-to-collision, namely at -0.37 s (SD= 0.14), -0.36 s (SD= 0.15), and -0.38 s (SD= 0.13).

A 2 (group: preterms/full-terms) x 3 (loom speed: fast/medium/slow) repeated measures ANOVA was conducted to test for possible differences between groups in their averaged VEP responses, where group was set as between-subjects factor and speed of loom as within-subjects factor. To adjust for multiple comparisons, a Bonferroni correction was performed. Results showed a significant effect of group, F (1,12)=41.9, p<.001, meaning that VEPs from the full-term children occurred significantly closer to time-to-collision than those from the preterm children. No significant effect of speed was found, indicating that both groups showed their VEPs at a relatively fixed time-to-collision regardless of loom speed, which is consistent with an efficient timing strategy based on time (see Figure 4).

3.2 Individual VEP analysis

Children in the preterm group that showed SDs above the threshold of *Mean ± (SD*2.5)* calculated from the full-terms' SDs were considered as outliers and highlighted in Table 1. Through this criterion, preterms TA and WM were marked, since their SDs were unusually higher compared to those from the full-term children as well as the rest of the preterm children.

FT	Fast	Medium	Slow	SD	PT	Fast	Medium	Slow	SD
BE	-0.18	-0.18	-0.14	0.11	**AT**	-0.23	-0.20	-0.20	0.07
GE	-0.13	-0.10	-0.12	0.07	**DT**	-0.29	-0.31	-0.30	0.10
JY	-0.24	-0.15	-0.10	0.11	**EL**	-0.38	-0.41	-0.37	0.11
LS	-0.14	-0.15	-0.16	0.06	**MS**	-0.32	-0.32	-0.38	0.09
ST	-0.16	-0.20	-0.14	0.11	**SK**	-0.46	-0.35	-0.41	0.13
SN	-0.11	-0.16	-0.20	0.10	**TA**	-0.46	-0.40	-0.49	0.15
VE	-0.12	-0.16	-0.14	0.08	**WM**	-0.39	-0.48	-0.38	0.14
Mean				0.09					0.11
SD				0.02					0.02
Mean + SD*2.5				**0.14**					

Table 1. *Average looming-related VEPs (s) and SDs across the three speed conditions for all participants from preterm (PT) and full-term (FT) groups. The value of 0.143 corresponds to the threshold calculated through Mean ± (SD*2.5) of the SDs from the full-term group. Preterms TA and WM stood out, since their SD values across all speed conditions were above the criterion. This means that their VEP responses varied across speeds, which could indicate that instead of using a strategy based on time, these children were using a less efficient strategy to estimate the time-to-collision.*

3.3 Button Press analysis

To take into account both negative and positive timing errors, RMS values as an indication of timing error were calculated. For the preterm group, RMS values for button responses for fast, medium, and low speeds were 0.118 s (SD= 0.05), 0.162 s (SD= 0.07) and 0.231 s (SD= 0.08), respectively, and across speeds the average of RMS values was 0.179 s (SD= 0.06). For full-terms, RMS values were 0.158 s (SD= 0.06), 0.218 s (SD= 0.06) and 0.275 s (SD= 0.06) for the 2-s, 3-s and 4-s conditions respectively, with an average RMS value of 0.227 s (SD= 0.05) across speeds. These results show that both groups timed in a similar way their responses, showing more motor response variability as the speed of the loom decreased (see Figures 5, 6 and 7). A two-tailed *t*-test confirmed the lack of significant differences in BP timing errors between groups (p=.377).

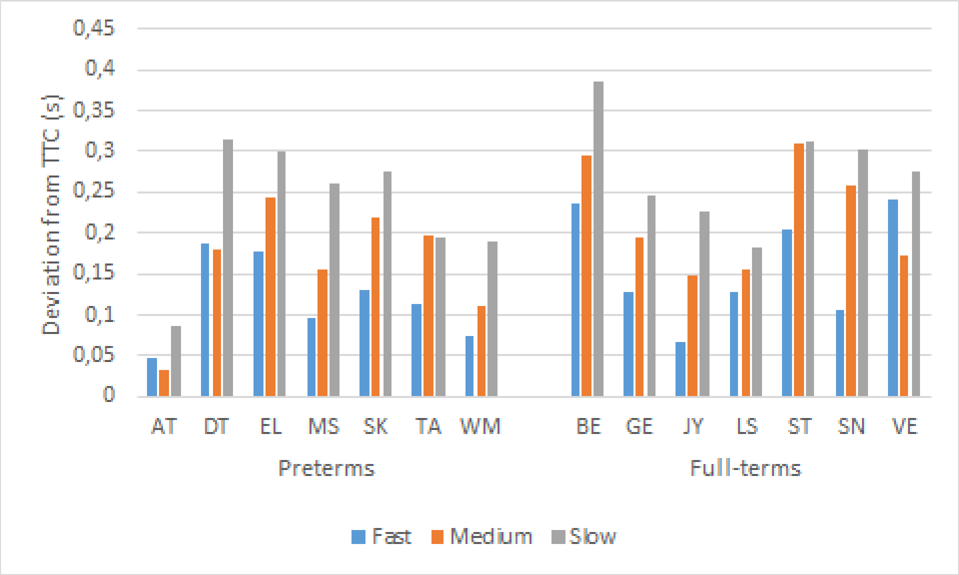

Figure 5. *Individual RMS values for BP responses for the three looming speeds amongst preterm and full-term children at 6 years of age, indicating the amount of motor response deviation from time-to-collision (TTC). Both groups show a similar pattern when timing their prospective responses, since RMS values of BP responses from most participants increase when speed of the loom decreases. Preterm child AT stood out for showing the smallest RMS values (and thus, least amount of variation) regardless of the speed, compared with the rest of the participants in our sample.*

3.4 Joint analyses of VEP and BP responses

3.4.1 Root Mean Square values for VEP and BP

Given our interest in studying VEPs and BPs jointly, we calculated the RMS values for VEPs as well, so as to have both visual and motor timing errors on the same scale for further analyses. The resulting values were as follows: preterms showed an average deviation of 0.380 s (SD= 0.08), 0.379 s (SD= 0.09) and 0.376 s (SD= 0.09) in their visual responses in the 2-s, 3-s and 4-s conditions respectively, and a total average of 0.380 s (0.08) across speeds. Full-terms, on the other hand, showed average deviations for the 2-s, 3-s and 4-s conditions of 0.178 s (SD= 0.04), 0.175 s (SD= 0.04) and 0.167 s (SD= 0.02) respectively, with an average deviation of 0.176 s (SD= 0.02) across speeds (see Figures 6 and 7).

A 2 (group) x 2 (type of response: VEP or BP) x 3 (speed of loom: 2-s, 3-s, 4-s) repeated measures ANOVA was used to test for differences among preterm and full-term participants in averaged RMS values, where group was set as *between-subjects* factor and both *type of response* as well as *speed of loom* were set as *within-subjects* factors. A *Bonferroni* correction was used to adjust for multiple comparisons. Results showed a two-way interaction effect of *group* and *type of response*, F(1,12)=48.09, p<.001, indicating that preterms were more variable when timing their VEP responses than their BP responses, while full-terms showed similar variation between their VEP and BP responses (see Figures 6 and 7). Another two-way interaction effect of *speed* and *type of response* was found (F(2,24)=20.47, p<.001), meaning that speed had an effect on the RMS values in both groups but only for the button responses (see Figure 6).

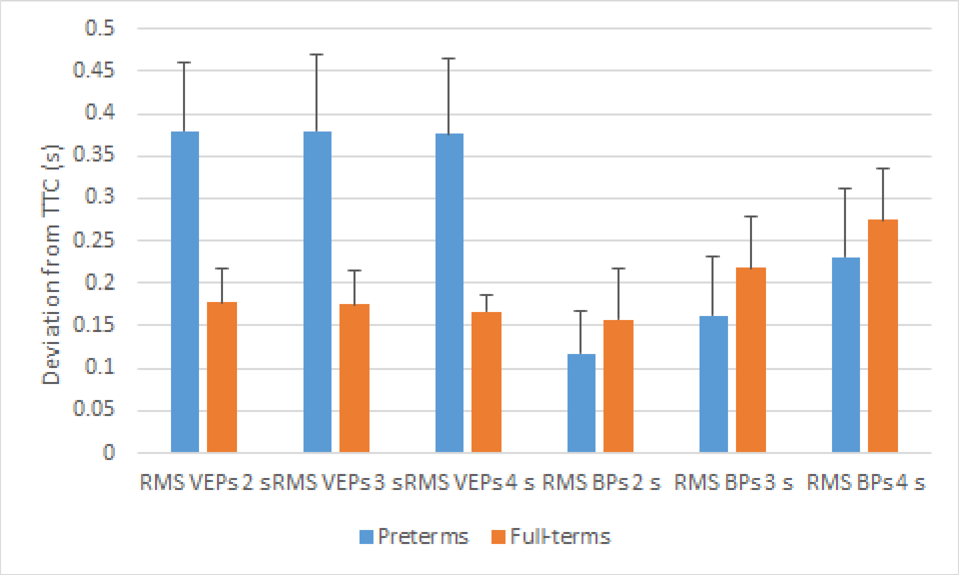

Figure 6. *Comparison of averaged RMS values with SDs for BP and VEP responses per speed condition (2s, 3s, 4s) for preterm and full-term groups at 6 years of age. For both groups across loom speeds, averaged deviations in visual response according to the RMS value were relatively stable, with preterms showing deviations twice as large as full-terms. As for the motor responses, preterm children timed their BP responses closer to TTC (0.179 s, SD= 0.06) than full-terms (0.227 s, SD= 0.05) across speeds. However, this was not a significant difference between groups. Speed did show a significant effect on RMS values of BP responses for both groups (p<.001). RMS values for BP are higher in the slow condition (4s) than in the medium (3s) and fast (2s) conditions for both groups, indicating more motor response deviation from TTC with decreasing speed of the loom.*

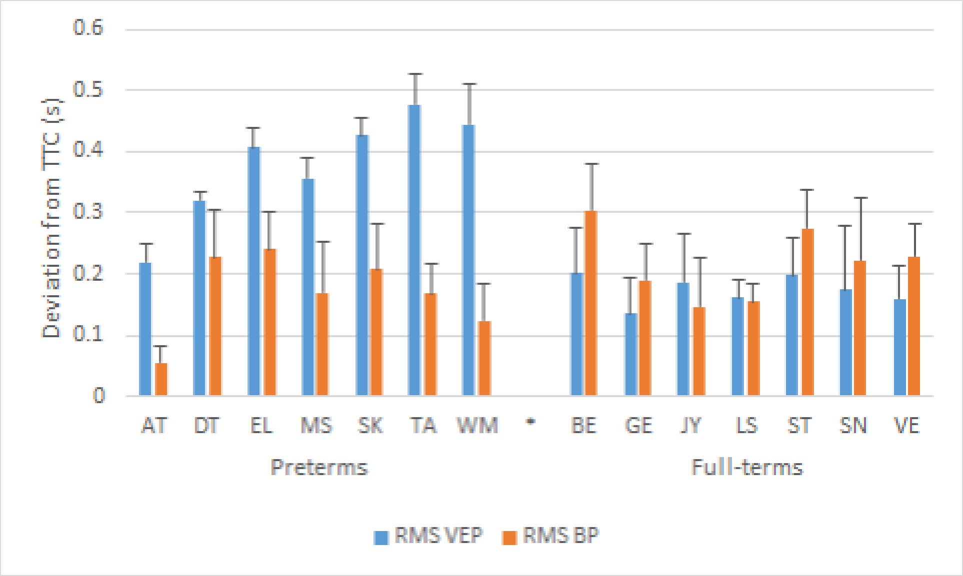

Figure 7. *Comparison of averaged timing errors (RMS values) with SDs for BP and VEP responses across speeds for each participant from both preterm and full-term groups at 6 years of age, indicating the amount of deviation from time-to-collision (TTC). All participants from the preterm group showed significantly larger timing errors in their visual responses compared to their motor responses (p<.001), while full-term participants showed similar deviations in their timing errors regardless of the type of response.*

3.4.2 Time windows between VEP and BP

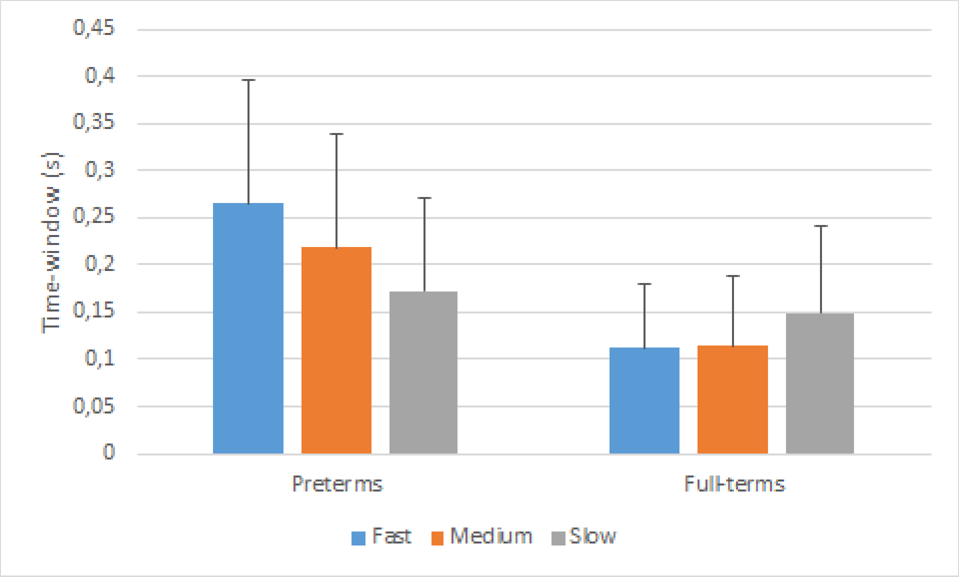

Figure 8. Average time windows per speed condition between preterm and full-term children at 6 years of age. Time window refers to the time points between VEPs and BPs in each trial for each participant, regardless of the order in which they appeared. Preterm children showed significantly larger time windows compared to full-terms (p<.001), and no significant effect of speed was observed.

The number of trials where VEPs were followed by BPs was higher for preterms (316 out of 336) than for full-terms (107 out of 303). On average, full-terms at 6 years of age displayed time windows between visual and motor responses of 0.111 s (SD= 0.06), 0.114 s (SD= 0.07) and 0.148 s (SD=0.09) in the 2-s, 3-s and 4-s conditions respectively, with an average time window of 0.125 s (SD= 0.04) across speeds. Preterms, on the other hand, displayed time windows between VEPs and BPs of 0.265 s (SD= 0.13) in the 2-s condition, 0.218 s (SD= 0.12) in the 3-s condition, and 0.172 s (SD= 0.09) in the 4-s condition, with an average time window across speeds of 0.218 s (SD= 0.04).

A 2 (group) x 3 (loom speed) repeated measures ANOVA was used to test for differences between preterm and full-term groups in averaged time window values, where *group* was set as *between-subjects* factor and *loom speed* was set as *within-subjects* factors. A Bonferroni correction was used to adjust for multiple comparisons. Results showed a significant effect of group, F(1,12)=180.80, p<.001, meaning that there were significantly larger time windows between VEPs and BPs amongst preterms compared to full-terms. However, no significant effect of speed was found, meaning that the length of time windows was similar in all three conditions within groups (see Figure 8).

3.5 Movement ABC test

Table 2 shows the performance results for children in both groups in the Movement ABC test. A total score equal to or above 13.5 might indicate a delay or impairment in motor skills in relation to motor capabilities of children at the same stage in life. At the individual level, preterm child DT and full-term child VE obtained scores indicating motor delays, their results are highlighted in Table 2. On average, however, a two-tailed *t*-test demonstrated no significant differences (p=.929) in scores for motor performance between the preterm group (M= 7.57, SD= 6.91) and the full-term group (M= 7.85, SD= 4.70).

Preterm	Score	Full-term	Score
AT	5.5	**BE**	6
DT	21	**GE**	0
EL	13	**JY**	5
MS	2	**LS**	10
SK	4	**ST**	8
TA	4	**SN**	12
WM	3.5	**VE**	14

Table 2. *Scores for motor performance in the Movement ABC test for preterm and full-term children. All participants except for full-term VE were tested with the M-ABC test corresponding to 4-6 years of age, whilst VE was assessed with the version for 7-8 years of age since she had turned 7 years old at the time of testing. Both VE and preterm DT obtained high scores above 13.5, indicating a possible motor delay.*

4. DISCUSSION

In the present study, high-density EEG was used to assess differences in perception of visual motion and timing of prospective responses between preterm and full-term children at 6 years of age. The visual motion paradigm used was looming, consisting of a stimulus approaching the observer at three different speeds, simulating a direct course collision. The paradigm for motor responses consisted of a response pad that allowed the observer to push a button whenever s/he thought the collision with the virtual object occurred. Analyses of visual evoked potentials (VEPs) and button press responses (BPs) were performed to determine the timing at which children displayed their visual response to the looming stimulus, and the estimation of when the collision took place, respectively. Other analyses were also conducted to evaluate the correlation between VEP and BP responses, including root mean square (RMS) values to determine the amount of deviation from time-to-collision of both types of responses, time windows between VEPs and BPs to compare processing times between groups, and timing strategies used by children when perceiving and responding to the loom at different approaching speeds. Finally, motor performance of participants was also assessed through the Movement-ABC (M-ABC) test. The aim of this paper was to determine whether there were significant differences in visual perception and prospective responses between the groups that could be explained by a dorsal stream vulnerability as a result of being born prematurely.

Analyses performed on the looming-related VEPs showed that both groups displayed their averaged brain responses at relatively fixed time-to-collision with no effect of speed, which suggests that on a group level, both preterms and full-terms are using a visual strategy based on time, which is thought to be less prone to error when calculating the moment at which the approaching object is going to make contact with them. The full-term group, however, displayed their brain responses significantly closer to time-to-collision than the preterm group, which is consistent with previous research that correlates this pattern of response with a more efficient motion processing (Agyei et al., 2016; Stople, 2018; Van der Meer, Svantesson and Van der Weel, 2012). These findings are in line with what was expected to find according to the literature. Despite both groups apparently making use of an efficient timing strategy given the time-fixed arousal of their looming-related VEPs across speeds, earlier VEPs in the looming sequence amongst preterms suggest that these children have less effective motion processing skills. This pattern of brain responses to a looming stimulus has been correlated with a lack of specialized networks to process motion as well as impaired functions of white matter in the visual dorsal stream at earlier stages in life (Van der Meer, Fallet and Van der Weel, 2008; Van der Meer, Svantesson and Van der Weel, 2012; Zotcheva, 2015), which suggests that these cortical impairments are still present amongst preterm children at school-age. This highlights the necessity to keep doing follow-up studies that can assess to what extent these impairments interfere with activities on a daily basis, and if they correct themselves at some point in life.

Further analyses performed on the standard deviations (SDs) of the looming-related VEPs across speeds per participant showed that preterm children TA and WM displayed larger SDs than those from the full-term group. These outliers show that the timing of these participants' VEPs varied across speed. Since the hallmark of an efficient strategy based on time is low variation of responses across speeds, these results suggest that these preterm children might be making use of a less efficient strategy to calculate the time-to-collision with the loom. These results are consistent with previous research, stating that by this age most preterm and full-term children are already timing looming danger efficiently, but there can still be cases where at 6 years of age some preterms have not managed to make the shift to a strategy less prone to error (Kayed, Farstad and Van der Meer, 2008; Van der Meer, Agyei, Vilhelmsen et al., 2015; Stople, 2018). It is worth mentioning that both preterm children who stood out in this analysis required therapy for motor development, the first one due to a slow progression of motor milestones during infancy, and the second one due to balance difficulties at 6 years of age. Taking these results with due caution given the small number of our sample, individual analysis of timing strategies through VEPs could nevertheless be useful to detect children who are still at risk of suffering visuo-motor impairments, with dorsal stream vulnerability as a plausible underlying cause.

As for the button press responses, analyses performed with the RMS values of the timings at which BPs happened suggest that there were no significant differences between groups, although a generalized increase in variation of motor responses could be seen as the speed of the approaching loom decreased. These results were quite interesting, since they do not show the typical pattern proper of the speed-accuracy trade-off principle. In motor behavior, such principle states that when a person performs a motor response, s/he tends to favor either accuracy or speed of the response according to the demands of the task. Thus, if s/he favors the former, it will end up negatively affecting the latter, and vice versa (Schmidt, 1982). Nevertheless, there are some exceptions to this principle, one of which is called *velocity effect*. This effect establishes that timing accuracy of a motor response increases when the average movement time decreases, and average velocity increases (Newell et al., 1979; Schmidt, 1982). So, in other words, when a task does not give a lot of time to perform a motor response, aiming to respond quickly might increase the chances of timing the response in a more consistent manner. Results of the RMS values for the BP timing errors might be reflecting this effect, since responses from almost all participants in both groups were performed more consistently in the looming sequence with the fastest speed, while responses in the slow looming sequence were more prone to show higher motor variability. The exceptions were preterms AT and DT, as well as the full-term VE, all of which showed the lowest response variability degree in the looming sequence of medium speed. However, it is still worth noticing that these three children showed less response variability in the fast and medium speeds than in the slow one, which could still be in line with the velocity effect.

In addition, the lack of time-fixation of timing errors across speeds resembles the pattern of a less efficient strategy to time the collision (such as strategies based on visual angle or velocity), which would suggest that children from both groups might be using different strategies in the visual and motor domains to estimate the time-to-collision with the loom. This would be in accordance with some authors who suggest that given the domain-specificity of perceptuo-motor skills, these might be ruled by independent principles that are not directly transferable from one ability to another (Adolph and Berger, 2006; Campos et al., 2000; Kayed and Van der Meer, 2009). Since estimating a collision visually and behaviorally are abilities that pertain to two separate domains, the fact that an efficient timing strategy is being used in one of them might not necessarily imply that it is also being used in the other.

When comparing averaged RMS values for both VEPs and BPs across speeds within and between groups, results showed that the amount of deviation between visual and motor responses was relatively even for the BP responses between groups, and no significant differences in variation between timing errors of VEPs and BPs was found amongst full-term children. However, deviations in VEPs' timing errors amongst preterms were twice as high as those amongst full-terms, and they were also higher than the deviations of BPs' timing errors within the preterm group. This suggests that there was a more uniform performance in prospective responses than in motion perception between groups. The lack of significant differences in deviation of visual and behavioural responses within the full-term group might be an indicator of a steadier visuo-motor development in this group, so further research is needed to see if preterms are able to display a similar deviation pattern in their VEP and BP responses at some point in life. This could indicate a successful catch-up with their full-term peers.

Findings related to times between brain and behavioural responses were consistent with the expected outcomes, since preterms displayed larger time windows between both types of responses compared to full-terms, regardless of the loom's speed. In previous studies (Kayed and Van der Meer, 2000; Van der Meer, Svantesson and Van der Weel, 2012), longer time windows between VEPs and a protective motor response have proven to be dangerous, since they convey longer processing times that give more room for error. Longer processing times imply acting on visual information that is not updated efficiently enough, which can lead to the emission of a response that fails to protect the observer, either by happening too early or too late (Van der Meer, Svantesson and Van der Weel, 2012). Thus, given the larger time windows found in our preterm group, these children might experience problems when trying to emit a prospective movement as a response to real looming danger in day-to-day situations, increasing their risks of getting hurt.

Even though the finding of larger time windows amongst preterms makes sense given how early in the looming sequence VEPs arose in this group, one result that was surprising was the sequential display of BPs happening before VEPs in both groups. Again, due to the early arousal of VEPs amongst preterms, this group displayed their VEPs before their BPs on a higher number of trials than their peers at term. However, both groups still managed to present multiple trials where the motor response happened before the brain response. One possible explanation for this would be a lack of inhibitory control, since the prefrontal cortex at this age is still developing and with it, this very important executive function (Datin-Dorrière, Borst, Guillois et al., 2021; Houdé and Borst, 2014). Considering the age of our sample as well as the 'playful' nature of the task, children could have shown more eagerness in not missing their chance to respond before the end of trial, rather than trying to accurately time the button press response with the loom's time-to-collision. Nevertheless, it is important to remember that this was the first time applying this paradigm, so further data recollection is required before drawing more concrete explanations if these results were to be observed again.

According to the results from the M-ABC test, motor performance for most children in both groups was adequate to what was expected from them at their developmental stage. Individual total scores only made two children stand out: preterm child DT and full-term child VE. Yet, it must be mentioned that at the time of the motor testing session, full-term child VE had just reached 7 years of age. Hence, while all the other participants from both groups were assessed with the M-ABC test version for age band 1 corresponding to children between 4 and 6 years of age, VE was assessed with the version for age band 2 corresponding to children between 7 and 8 years of age. Since the version for age band 2 includes a series of tasks that are more complex and demanding than the version for younger children, this could account for the score of VE (i.e., 14), which is just above the score of 13.5 that indicates a possible motor impairment. On the other hand, the score of the preterm child DT (i.e., 21) is quite above this threshold and was due to hardships in the manual dexterity tasks, therefore suggesting that this child presents a certain degree of impairment in the fine motor domain. It is worth mentioning that DT was born very prematurely and had a very low birth weight. This case would then be in line with previous research that correlates these risk factors with complications in motor performance during childhood (Bos, Van Braeckel, Hitzert et al., 2013; Moreira, Magalhães and Alves, 2014).

On the other hand, averaged performance per group in the M-ABC test showed no significant differences between our preterm and full-term participants, which is consistent with the lack of significant differences in deviations of timing errors for the button press responses between groups. Although these results contradict a significant part of the reviewed literature that led to the formulation of our hypotheses in terms of motor performance, this is not the first study in which such results take place. Previous research has demonstrated that preterm and full-term children can present a similar performance in a variety of motor tasks (Cserjesi et al., 2012; Kayed and Van der Meer, 2009) as well as in the M-ABC test at 7 years of age (Bos, Van Braeckel, Hitzert et al., 2013). Thus, despite the unexpectedness of our results in the motor domain -especially considering the differences between groups observed in the other analyses-, they are still consistent with findings from other studies.

Taking all our results into consideration, the data collected in this study seems to suggest that preterm children in our sample showed no evident difference in prospective responses and motor skills compared with full-terms at 6 years of age. However, the significant variations observed between groups in terms of timing at which VEPs arose, along with the length of the time windows between VEPs and BPs suggest that our preterm sample presents some impairments in stages prior to the emission of a prospective response, namely the timing of perception of the stimulus, processing time to analyze its motion, and time to prepare a behavioural response. VEPs happening earlier in the looming sequence point to an inefficient transmission and processing of information to estimate the imminent collision (Vilhelmsen, Van der Meer and Van der Weel, 2020; Van der Meer, Svantesson and Van der Weel), and the larger windows between brain and motor responses amongst preterms might be an indicator of longer processing times required to prepare and emit a protective response to the looming danger (Van der Meer, Svantesson and Van der Weel, 2012).

Longer processing times amongst preterms in this study are reminiscent of the longer times required for emitting a prospective response amongst children with cerebral palsy (Van der Weel, Van der Meer and Lee, 1996), who initiated movement of their affected hand earlier than their non-affected hand in order to intercept and strike an approaching ball at the appropriate time. The importance of this difference in starting times was even more evident when compared with peers who did not suffer from CP, since these children did not present significant differences in times at which they initiated movement with their dominant and non-dominant hand to perform the same task (Van der Weel, Van der Meer and Lee, 1996). These findings in conjunction with our results could indicate that longer times between perception of a moving object and emission of a prospective response might be highly associated with at-risk children than present some degree of neurological impairment.

The fact that children with an underlying cortical impairment can still emit their prospective responses accurately enough within an interception task suggests the existence of coping mechanisms, which some studies seem to corroborate (Leung et al., 2017; Naoi, Fuchino, Shibata et al., 2013). For instance, different patterns of cerebral activation amongst full-term and preterm adults have been observed in visual tasks, which has led to hypothesize that preterm adults might rely on low-level visual information when they present an inability to process higher-order information (Leung et al., 2017). Other authors suggest that differences in patterns of cortical activation between preterm and full-term infants while perceiving the same stimulus could be due to a differing developmental trajectory and brain connectivity occurring after birth (Naoi, Fuchino, Shibata et al., 2013). In any case, emergence of this type of coping mechanism is intimately related to neuroplasticity which has proven to be highly dependent on environmental stimulation and experience to create and sustain enduring connections within the neural tissue (Baroncelli, Braschi, Spolidoro et al., 2010). And even more, plasticity of neural networks relies greatly on white matter, since it is the myelin that creates the pathway for information to pass efficiently between neurons (Bruckert, Borchers, Dodson et al., 2019; Sampaio-Baptista and Johansen-Berg, 2017). Thus, a feedback loop is present between environmental stimulation, obtention of stimulating experience through our self-produced movement in the environment, adequate myelination, neuroplasticity, and cognitive development, which in conjunction allow for catch-up strategies and coping mechanisms to take place. Since one key element in this loop is white matter and preterms are at risk of injuries in this tissue (Shoykhet and Clark, 2011), it is necessary to keep doing research on the other elements that play a role for this coping mechanisms to take place, in order to develop intervention programs that allow preterms to catch-up with their peers at-term. Results from our paper suggest that cortical impairments exist amongst preterm children, yet performance in the motor domain seems to be equivalent to that of the full-term group. Thus, this might imply that our preterm sample has developed coping mechanisms and might be on the path to catch-up with their full-term peers.

Something that could account for similar performances in the motor domain between our groups would be motor experience along with good prematurity health care. Considering that ours was a Norwegian sample, granted access to highly developed postnatal care for premature infants represents a huge protective factor that can help minimize the side-effects of being born too soon. Since the services cover not only doctors and NICU, but extend to specialties relevant to the scope of this paper like physiotherapists, ergotherapists, and neurologists (St. Olavs Hospital, 2020), this could explain the motor performance of our preterm group. Additionally, sports are a very important part of Norwegian culture (Sen, 2021), and with 3 out of 7 preterm children in our sample practicing one or more sports, this could also account for the lack of significant differences observed at the behavioural level.

In fact, one child that stood out in the BP timing errors' analysis was the preterm AT, since he displayed the shortest deviations across all three speed conditions compared to the rest of our participants including the full-term group. Additionally, this child also displayed looming-related VEPs closest to time-to-collision compared to the rest of the preterm group in all speed conditions. Results were even more outstanding given the fact that AT was born very prematurely and with a very low birth weight, which are significant risk factors for visuo-motor impairments (references). Bearing in mind the role that self-generated motor experience has on cognitive and prospective control development according to the Gibsonian ecological theory, something that could account for this child's performance is practicing hockey on a regular basis. Being a very demanding sport that requires a constant adaptation of posture and balance while navigating, along with the need for timing and emitting accurate movements to intercept and hit the puck, hockey promotes a swift feedback between optic flow and behavioral responses to adapt to a challenging environment. Hence, all visuo-motor skills addressed in the present study -visual timing, motion processing, estimation to time-to-collision, and prospective control- are being put into practice constantly by this child under demanding circumstances, possibly explaining AT's performance in our tasks. This case provides a significant insight into the possibility of including sports within intervention programs targeted for preterm population, in order to promote catching-up with peers born at term.

Nevertheless, other possible explanations exist for the observed motor responses, one of them being the way in which prospective responses were assessed. The exploratory nature of this innovative study implies experimenting with new paradigms and evaluating how they work. In this case, since the response pad was placed on the children's lap, they used to hold it between their hands with both thumbs over the buttons. Hence, timing the moment of collision required only to put some pressure on their preferred button, and then their response was recorded. This could have made it easier to assess timing of motor responses (particularly due to the EEG, which benefits from minimal muscular movement), but less accurate than the more complex prospective movements required in a natural setting, preventing to test for more subtle differences between groups.

One limitation of this study was the small number of participants as well as their heterogeneity in terms of gestational age and birth weight, which makes it difficult to draw general conclusions about visual perception and prospective control amongst the worldwide population of preterm children at school-age (Bruckert, Borchers, Dodson et al., 2019; Ioannidis, 2005).

Another limitation was that, given the paradigm of having a virtual stimulus that just simulates a collision but does not physically collide with the participants, it can be difficult for children to assess their own performance in order to correct it, since there is no immediate feedback or consequence that prompts them to recalculate and modify their motor response (Bedard, 2017). The absence of physical feedback could imply a lower level of engagement in the activity, and thus, prospective responses in the form of a button pressing could happen for other reasons besides trying to time the exact moment of collision, as mentioned before. Nevertheless, the significance of the differences found between both groups in our sample points to the fact that we are indeed on the right track, and thus further research is needed.

In terms of future research, there are several suggestions that can be made. Since the methodology of this study is quite new and some results were somewhat counterintuitive, replication of this paradigm with larger samples is advised in order to confirm the reliability of our findings (Ioannidis, 2005), especially emphasizing the sequence in which VEPs and BPs occur. With enough participants, subgroup analyses based on gestational age and low birth weight could shed more light on differences in visual perception of looming danger and prospective responses related to the subcategories of these risk factors (Bruckert, Borchers, Dodson et al., 2019).

In the past, VEP analysis has been successfully combined with temporal spectral evolution (TSE) analysis, which helps to explore the variation in frequency bands of the brain’s electrical activity through a given period of time (Vázquez, Vaquero, Cardoso et al., 2001). Previous longitudinal studies using TSE to analyze brain responses of preterm and full-term infants in a looming task have discovered significant differences between groups, mainly that full-terms managed to display activity in higher band frequencies with age (from 4-8 Hz at 4-5 months of age to 10-60 Hz at 1 and 6 years of age) unlike preterm children, who sometimes even showed a decrease in frequencies in neuronal oscillations with increasing age (Vilhelmsen, Van der Weel and Van der Meer, 2020). TSE analysis also allows to test for synchronization or desynchronization of neuronal assemblies. Higher desynchronization is associated with smaller but more specialized areas of the brain preparing to respond to a stimulus, and thus, is considered a more adult-like pattern of response to motion. On the contrary, higher levels of synchronization are related to a resting state in the neural networks, being more associated with a higher quantity of less specialized neurons. Previous research done with visual motion paradigms has found differences in these patterns of brain activity at 12 months and 6 years of age between preterm and full-term infants, where full-terms have shown higher levels of desynchronization during motion perception (Stople, 2018; Vilhelmsen, Van der Weel and Van der Meer, 2020; Zotcheva, 2015). Thus, it could be helpful to test how much synchronization or desynchronization exists within the neural networks of preterm children at 6 years of age (and later stages in life) when perceiving the loom and when preparing to emit a prospective response, in order to compare the observed activity with that of full-term children at the same age. It could also be worth investigating the apparent velocity effect observed in the prospective responses of our sample under this light, to test for possible differences in neuronal synchronization or desynchronization related to the approaching time of the loom, and consequently, the available time to emit a response.

In conclusion, the present study showed that preterm and full-term children at 6 years of age seem to use an efficient strategy based on time to estimate the collision with an approaching object. However, full-terms seem to detect and process visual motion more effectively, requiring less time to emit a prospective response. Larger processing windows between perception and action amongst preterms might set them in danger of responding too early or too late to effectively protect themselves from looming danger in real-life situations. No evident differences in motor performance were observed between groups, which suggests that drawbacks in the preterm group can be due to impaired white matter in the dorsal visual stream as a result of prematurity or low birth weight. Individual analysis of VEPs per child might have the potential to detect at-risk children at this age who are still relying on inefficient strategies to estimate the time-to- collision with an object. Similar deviations from time-to-collision between brain and behavioral responses could be an early indicator of a steadier visuomotor development in children at this age. The special case of one preterm seems to suggest the role of sport as a potential intervention to catch-up with full-term peers. Finally, further research is needed to keep testing the outcomes of the innovative methodology presented in this paper.

Despite the increasing number of preterm births worldwide, efforts to assess the long-term effects of being born prematurely remain insufficient. It is imperative to have longitudinal studies that allow us to see the course of development that the premature brain follows and the way in which it engages and co-evolves with daily environmental demands. This will facilitate the detection of key times and activities that promote perceptual, cognitive, and motor development within this population, in such a way that interventions aimed at catching-up with their peers can be generated. Research like the present lays the foundations for the development and preservation of a better quality of life amongst those who defy death since their very first breath simply for being born too soon.

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