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# Decoding Visual Motion Perception: A High-Density EEG Study Exploring Gender Differences within Visual Evoked Potentials in Response to Structured Optic Flow and Random Visual Motion

Bachelor's thesis in Psychology: PSY2910

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## **Preface**

I want to express my gratitude to the NU-lab at NTNU, Dragvoll, for giving me and my fellow students the chance to experience the processes involved in a high-density electroencephalography (EEG) study first-hand. As an aspiring researcher, hoping to someday conduct my own studies and publish my own articles, the insights gained from this project will stay with me. A special thanks to my supervisor, Seth Bonsu Agyei, for guiding us every step of the way. I also want to thank Dina Sofie Djenkova Vollen for her thorough feedback throughout the project, as well as the master's students at the lab for their help when technical jargon got overwhelming.

This project integrated theoretical research with practical experimentation utilizing high-density EEG. This approach allowed us to both conduct the experiment and serve as participants. With sufficient guidance, we independently analysed the raw EEG data using the software BESA and performed statistical analysis using Sigma Plot 14 and SPSS Statistics.

While we had the freedom to develop our own research questions and hypotheses, our thesis was constrained by the predetermined research design and participant population. Nonetheless, we were encouraged to be creative within these boundaries and explore our own inquiries, focusing on mean latency and mean amplitude analysis of the N2 component within three conditions: forward and reversed optic flow, and random visual movement. The thesis was thus formed after thorough independent literature research.

Lastly, I want to thank my fellow students for their support, responsiveness late in the night, and company during the long hours of analysis in the lab.

## **Abstract**

This thesis investigates visual perception through the lens of Gibson's theory of 'direct perception,' emphasizing the dynamic nature of perception within environments. 'Optic flow' elucidates the continuous motion patterns perceived when an observer moves relative to their environment. This phenomenon is thought to be crucial for guiding navigation within surroundings (Gibson, 1950). To investigate the neural correlates of visual processing associated with optic flow perception, high-density electroencephalography (EEG) was employed. This study involved 10 adult participants aged between 22 and 37, comprising an equal distribution of 5 men and 5 women. The analysis focused on the mean latency and amplitude of the 'N2' component, which is associated with visual processing.

In addition to examining overall trends in mean latency and amplitude, gender-based comparisons were conducted. Visual evoked potentials (VEPs) in response to three conditions—forward optic flow, reversed optic flow, and random visual motion—were analysed. Surprisingly, no significant gender differences were observed across the three motion conditions ( $p > .05$ ). However, consistent with previous findings (van der Meer et al., 2008; Agyei et al., 2015; Vilhelmsen et al., 2015; Vilhelmsen et al., 2018), forward optic flow tended to exhibit shorter mean latency compared to reversed optic flow and random visual motion, though this trend was not consistently observed in the grand average analysis.

Several factors may have influenced the outcome, including participant sample size, data quality, and the methodology employed for artifact correction in raw EEG data analysis. Despite the absence of statistically significant findings, the interpretation of the results raises questions about potential effects that may warrant further investigation. However, it's worth noting that the study's sample size may have limited its ability to detect significant effects. A meta-analysis pooling data from similar studies in the future could provide further insights and potentially uncover significant effects, if present.

## Sammendrag

Denne oppgaven undersøker visuell persepsjon gjennom Gibson's teori om 'direkte persepsjon', som legger vekt på den dynamiske naturen av persepsjonen innenfor miljøer. 'Optic flow' belyser de kontinuerlige bevegelsesmønstrene som oppfattes når en beveger seg i omgivelsene. Dette fenomenet er ansett som avgjørende for evnen til selvnavigasjon (Gibson, 1950). Den gjennomsnittlige latenstiden og amplituden av N2-komponenten, knyttet til visuell prosessering ble undersøkt ved bruk av høy-tetthets elektroencefalografi (EEG). Dette innebar en studie av en gruppe bestående av 10 voksne deltakere i alderen 22 til 37 år, hvorav 5 menn, og 5 kvinner. I tillegg til å undersøke generelle trender i latenstid og amplitude, ble det gjennomført kjønnsbaserte sammenligninger. Visuelt fremkalte potensialer (VEP) i respons til tre betingelser - fremover optisk flyt, reversert optisk flyt og tilfeldig visuell bevegelse - ble analysert. Det ble ikke observert noen signifikante kjønnsforskjeller på tvers av de tre bevegelsesbetingelsene ( $p > .05$ ). Imidlertid, i likhet med tidligere funn (van der Meer et al., 2008; Agyei et al., 2015; Vilhelmsen et al., 2015; Vilhelmsen et al., 2018), tenderte fremover optisk flyt til å vise kortere gjennomsnittlig latenstid sammenlignet med reversert optisk flyt og tilfeldig visuell bevegelse, selv om denne trenden ikke ble observert i den samlede gjennomsnittsanalysen (grand average).

Flere faktorer, som deltakerantall, datakvalitet og artefaktkorrigerings i rå EEG-dataanalysen, kan ha påvirket resultatene. Selv om det ikke ble funnet statistisk signifikante funn, åpner tolkningen av resultatene for videre undersøkelser. Studiens begrensede deltakerantall kan imidlertid ha hindret oppdagelse av signifikante effekter. En fremtidig meta-analyse, basert på lignende studier, kan gi ytterligere innsikt og muligens avdekke signifikante effekter, dersom de eksisterer.

## **1.0 Introduction**

Perception is essentially the combined interpretation of our senses within an environment and how these external stimuli are processed and understood by neural cognitive processes (Gordon, 2004). For this thesis, visual perception will be defined by the concept of Gibson's 'direct perception.' According to this theory, direct visual perception involves rich information from the relationship between the environment and the observer, emphasizing a dynamic world and the idea that visual perception is always accompanied by movement (Gordon, 2004, p. 146).

### **1.1) Optic flow**

The concept of optic flow posits that when an object is in motion relative to a static observer, a pattern of relative motion emerges in the retinal image. This continuous motion pattern, referred to as optic flow, becomes apparent when an observer moves continuously in one direction (Forrester et al., 2016). According to the founder of the optic flow theory, J. Gibson, the phenomenon results from the constant changes in the images of objects on the retina (Gibson, 1950). Alterations in optic flow are therefore presumed to play a critical role in guiding an observer's navigation within their environment (Forrester et al., 2016).

During their first year, infants undergo rapid perceptual development as they encounter visual motion stimuli. According to Vilhelmsen et al. (2018), adults tend to prefer expanding radial movement over contracting motion, or movement along a straight line. At about 3 months of age, infants develop direction-specific neuronal pathways, enabling them to perceive expanding and contracting stimuli (Vilhelmsen et al., 2018). This tendency has also been observed in visual preferential study observations (Brosseau-Lachaine et al., 2008) where infants exhibited a preference for outward-expanding radial motion over contracting radial motion. From around 3 months, infants use optic flow fields to stabilize their gaze and head movement, demonstrating



an early reliance on visual perception (Vilhelmsen, 2018). In addition, responsive behaviour to optic flow patterns has been observed in infants as young as 4-8 weeks old (Arteberry & Yonas, 2000). Given these findings, it is reasonable to assume that the maturation of optic flow, along with the development of cognitive processes associated with optic flow processing, constitutes a vital adaptation to the environment, crucial for acquiring the skill to navigate our surroundings effectively (van der Meer et al., 2008). A study conducted by Langrová and colleagues (2006) revealed significant developmental shifts, such as reduced latency observed until the age of 18, followed by a consistent increase in latency from the age of 20. These observations were believed to result from the prolonged maturation of the magnocellular system and motion processing cortex, as well as alterations associated with aging. Similar results were found by Korth et al., (2006), providing reason to assume that latency will exhibit the lowest values around the age of 18, before gradually increasing with the years.

The processing of visual motion stimuli is hypothesised to occur in the dorsal visual pathways, where information travels from the primary visual cortex (V1), through Brodmann's area V2 and V3 – reaching the medial temporal (MT) and medial superior temporal (MST) areas, also known as associative visual cortex V5/V5a. This pathway is thought to serve the purpose of motion analysis. Subsequently, this motion information proceeds to cortical regions within the parietal cortex, where examination of spatial relationships between the observer and environmental objects is thought to occur (Greenlee, 2000).

## **1.2) EEG**

Electroencephalography (EEG) emerges as a valuable tool for studying optic flow. The method's capacity to record rapid fluctuations in neural activity is well-suited to the dynamic characteristics of optic flow processing (Forrester et al., 2016). EEG's temporal precision makes

thorough exploration of the brain's reaction to motion stimuli possible - providing valuable insights into the neural mechanisms that underlie optic flow perception (Kuba et al., 2007).

EEG signals are primarily created as a result of synchronized synaptic activity in cortical neurons, specifically pyramidal cells that are organized along columns. When postsynaptic neurons become excited, they generate a dipole, characterized by a positive charge region that is separated from the negative charge region by a certain distance (Luck, 2014, p. 29; Jackson & Bolger, 2014). Electrodes placed on the scalp pick up the combined positive and negative charges in their proximity. Therefore, if an electrode is equally distant to both the positive and negative ends of a dipole, it will record a neutral signal. Consequently, electrodes can effectively detect dipoles only when positioned closer to either the positive or negative end (Jackson & Bolger, 2014).

### **1.3) From the brain to the recording device**

EEG signals in the brain are detected through volume conduction, a process governed by the basic principles of electrical charge: ions with similar charges repel each other, creating a charge wave in the extracellular space (Jackson & Bolger, 2014). However, the brain's volume conduction is not homogeneous, as myelin-coated nerve tracts and other barriers impede ion travel, preventing uncontrolled flow and potential seizures (Wolters et al., 2006). Tissue density variations, influenced by electrical properties and arrangement, further modulate ion flow. It's noteworthy that larger dipoles transmit signals over more extensive distances compared to smaller dipoles (Jackson & Bolger, 2014).

When it comes to electrode detection of brain activity, the electrical signal must journey through the brain, dura, skull layers, and scalp to reach the electrode. At the volume's edge, volume conduction halts, and signal propagation between volumes depends on capacitance (Nunez &

Srinivasan, 2006, p. 14). This involves capacitors, resembling the layers from the brain to the electrode, with charge pools separated by insulating dielectrics, essentially forming a stack of capacitors (Jackson & Bolger, 2014).

#### **1.4) ERPs – Visual Evoked Potential (VEPs)**

Event-related potentials (ERPs) represent a specific type of measurement sustained from EEG data. While EEG consists of a continuous measure of electrical brain activity, ERPs are subsequently divided into epochs—short segments of data—temporally restricted to specific events of experimental interest. These events often include stimuli onset or the initiation of motor responses, such as eye movements or the act of pressing a button. The concept behind ERPs is to synchronize brain activity with particular events, allowing for the examination of systematic patterns of brain activity in response to these events (Congedo, 2018). ERP waveforms are typically characterized by prominent positive (P) and negative (N) peaks at specific latency ranges following stimulus onset (Luck, 2014, p. 10). This methodology provides a means to discern how the brain responds in a time-locked, or stimulus-locked fashion to experimental stimuli or motor actions (Congedo, 2018).

#### **1.5) N2 Component**

EEG studies, especially those focusing on visual evoked responses (VER/VEP), offer valuable insights into how our brains perceive motion with high precision (Van der Meer et al., 2001). These studies explore executive functions, which are cognitive processes related to goal-directed behaviour (Miller & Cohen, 2001). Researchers have identified specific components in averaged EEG waveforms, marked by positive and negative voltage shifts that result in prominent peaks (Luck, 2014, p. 18-20).

A significant component linked to VEPs is the “N2”. This component is characterized by negative electrical activity in the dorsal extrastriate region of the occipital/parietal cortex, usually observed at an average of 200 ms poststimulus (ranges between 150-400 ms poststimulus) (Brydges et al., 2014). The N2 peak is thought to represent motion-processing activity, typically showing dominance in the right hemisphere. Systematic investigations and research on motion-onset VEPs have provided the current conclusion that the N2 peak in motion-onset VEPs is the primary motion-specific component generated in the extrastriate temporo-occipital or parietal cortex (Kuba et al., 2007).

#### **1.6) Differences in N2 component based on structured optic flow vs. random visual motion – previous findings**

Van der Meer, Fallet & van der Weel (2008) completed a similar study on visual motion perception in infants and adults, comparing the VEPs in structured optic flow versus random visual motion. Their findings revealed significant differences in VEPs when comparing the mean amplitude and latency of the N2 component of optic flow. Adults exhibited N2 with latencies approximately 140 ms poststimulus – consistent with previous similar research (Holliday & Meese, 2005), and the theory of critical time point for neuronal activity in motion perception (Sack et al., 2006). In contrast, infants exhibited N2 latencies around 60 ms later, at about 200 ms poststimulus. This could be due to slower information processing and less neuronal myelination in the white matter tracts. Both groups displayed shorter latencies for structured optic flow, suggesting an innate ability to detect coherence. Infants with crawling experience exhibited earlier responses, linking early mobility to visual information utilization. Infants were more affected by the lack of structure in random motion, aligning with their greater reliance on coherent visual information for posture control (van der Meer et al., 2008).

Building on Gibson's initial theory regarding optic flow and visual motion processing, the following thesis aims to answer the question: Are there gender differences in the processing of visual evoked potentials in response to structured optic flow and random visual motion in adults? Based on previous studies on visual perception (Vilhelmsen et al., 2018; Vilhelmsen et al., 2015; Agyei et al., 2015; Brydges et al., 2014; van der Meer et al., 2008), and gendered differences in lateralisation in perceptual processing (Waber, 1976; Johannes et al. 1996; Kramer et al., 1996; Proverbio et al., 1998; Evans et al., 2000; Gur et al., 2000; Basso & Lowery, 2004; Luders et al., 2005; Roalf et al., 2006, Ingahalikar et al., 2013), it is anticipated that the experiment will provide insights into the underlying processing mechanisms of the N2 component of VEPs, which plays a crucial role in the processing of visual motion. Therefore, the hypothesis posits that distinct characteristics will emerge in the N2 component response to structured optic flow and random visual motion stimuli. Furthermore, it is hypothesized that gender will have an impact on the processing of the N2 component, as visual processing differences have been observed in previous studies (ref. Luders et al., 2005; Roalf et al., 2006, Ingahalikar et al., 2013).

## **2.0 Gender Differences**

While examining gender differences in cognitive processing, it's crucial to acknowledge the potential impact of confounding variables, such as cultural preferences, social biases, inaccuracies in measurements, and non-representative samples. However, due to several studies and research, there appears to be a recurring pattern indicating variations in cognitive functions that are influenced by hemispheric differences in males and females (Roalf et al., 2006).

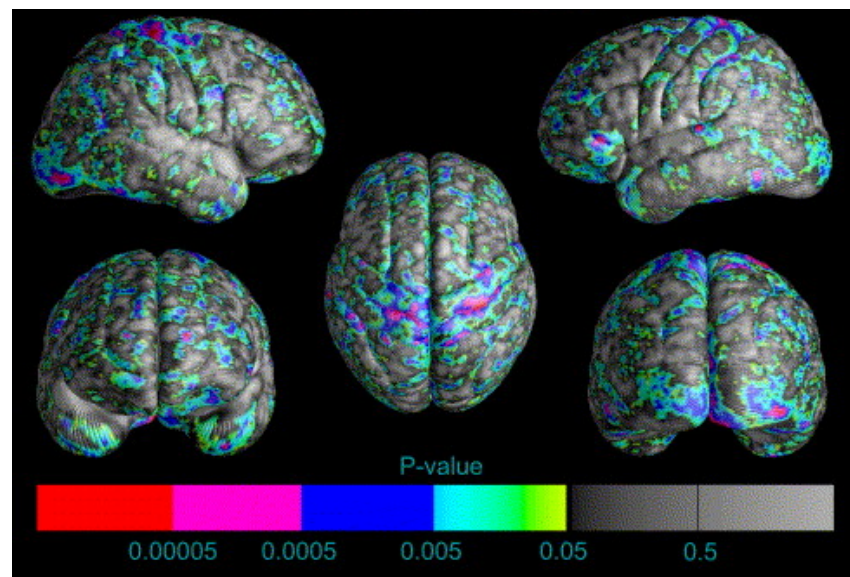
Some research findings indicate significant differences in brain organization and function between males and females. Gur et al. (2000) observed that women displayed reduced lateralized right hemisphere activation compared to men during visual orientation tasks. Additionally, it appears that females tend to process verbal information primarily on the left side of their brain when it comes to visual tasks according to a study by Norbert and Ksenija Jaušovec (2009). A paediatric study conducted by Kramer et al. (1996), found that boys exhibited a relative global processing bias compared to girls. The same tendencies can be found in Norbert and Ksenija Jaušovec (2009), where the study suggests that females, compared to males, have a more detailed way of categorizing events in the visual domain, with clearer sensory input.

Kolb and Whishaw (2015) suggest that hormonal effects play a significant role in explaining sex differences in hemispheric asymmetry. According to their meta-analysis, gonadal hormones likely influence prenatal brain organization and continue to shape neuronal networks into adulthood. The interaction between this unique arrangement and neural activity, coupled with individual experiences, plays a vital role in either amplifying or reducing sex-related distinctions (Kolb & Whishaw, 2015, p. 346).

Eileen Luders and her colleagues (2005) employed MRI scans to explore grey matter characteristics, unveiling distinct patterns in brain organization between men and women. Their research revealed that males exhibit a more uniform grey matter concentration, whereas females display a patchwork of concentration differences across various brain regions. While Luders and colleagues did not directly link these sex differences to cognitive disparities in their study, it is reasonable to consider such connections. For instance, the heightened concentration observed in peri-Sylvian regions, representing finger areas (Figure 1), could potentially correlate with women's noted advantage in fine motor skills (Luders et al., 2005; Kolb & Whishaw, 2015, p. 327-328). This underscores the intricate relationship between brain structure and cognitive abilities, prompting further investigation into the implications of these sex-specific neural characteristics.

### Figure 1

*Statistical Maps of Grey Matter Concentration Differences between Male and Female*



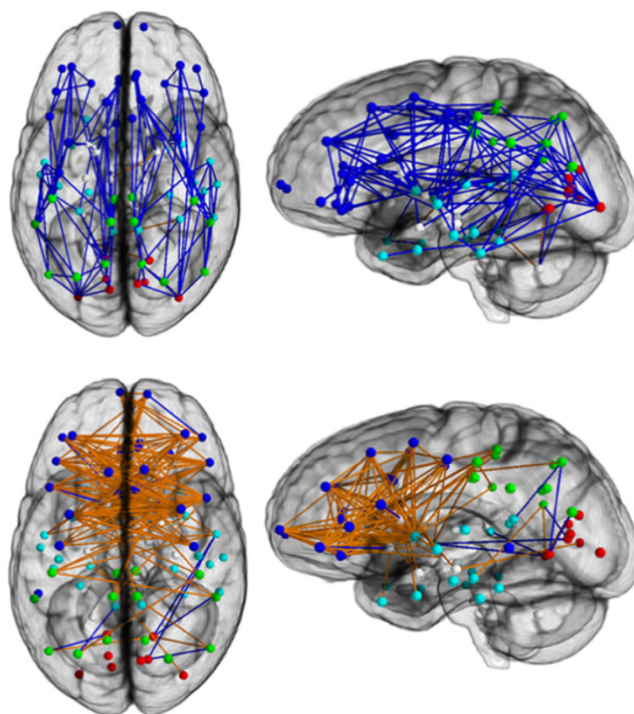
*Note.* From Luders et al., 2005. Uncorrected statistical maps illustrate higher cortical grey matter concentration in women compared to men. Coloured regions denote statistically significant differences, while grey-shaded areas indicate no significant

difference (lighter shades indicate greater similarity). Permutation testing validated a highly significant corrected  $p$ -value of 0.002, confirming that the observed gender effects are not random.

A major study conducted by Madhura Ingalhalikar et al. (2013) utilized diffusion imaging techniques to map the connectome in a large cohort of 949 participants spanning ages 8 to 22, comprising 428 males and 521 females. One key finding that emerged from this study is the notable difference in connectivity patterns between the sexes. Specifically, women exhibited greater interhemispheric connectivity, whereas men demonstrated greater intrahemispheric connectivity (Figure 2). This distinction was evident from a young age and continued to evolve in magnitude throughout adolescence and into adulthood. These findings are supported by earlier post-mortem neuroanatomical investigations, which highlighted increased interhemispheric connectivity in the corpus callosum of females (Ingalhalikar et al., 2013; Kolb & Whishaw, 2015, p. 331-332).

## Figure 2

### *Analysis of Brain Connections Between Male and Female*





*Note.* From Ingalhalikar et al., (2013). Analysis of brain connections. Enhanced connectivity is observed in both males (upper) and females (lower). Blue indicates intrahemispheric connections, while orange represents interhemispheric connections. The displayed edges have been validated through permutation testing at  $p = 0.05$ . Node colours: light blue for frontal, cyan for temporal, green for parietal, red for occipital, and white for subcortical regions.

Ingalhalikar and colleagues suggest that these differential connectivity patterns reflect a unique neural architecture in females that fosters communication between analytical and intuitive processing domains. This potentially contributes to women's superior performance on tasks involving attentional processes, verbal comprehension, and social cognition. The male brain seems to give precedence to connectivity between perception and coordinated action, potentially contributing to the explanation of their proficiency in performing motor and spatial tasks with precision (Ingalhalikar et al., 2013). These findings underscore the findings in studies that have explored the global-processing bias in males compared to the local-processing bias observed in women (Waber, 1976; Johannes et al. 1996; Kramer et al., 1996; Proverbio et al., 1998; Evans et al., 2000; Gur et al., 2000; Basso & Lowery, 2004; Roalf et al., 2006; Jaušovec & Jaušovec, 2009).

## **3.0 Method**

### **3.1) Participants**

Raw EEG data were obtained from in total 10 adult participants between the age of 22 and 37 ( $M = 25$ ,  $SD = 6$ ), of which 5 women ( $M = 25$ ,  $SD = 5$ ) and 5 men ( $M = 26$ ,  $SD = 6$ ). This was conducted at the Developmental Neuroscience Laboratory (Nu-Lab), at NTNU, Dragvoll. The study received approval from the Norwegian Data Services for the Social Sciences and the Regional Committee for Medical and Health Research Ethics (REC Central). Participants were under no obligation to complete the study and were given the liberty to withdraw from the project at any time.

### **3.2) Experimental Stimuli and Paradigm**

The pattern was displayed on a Microsoft Surface Hub 84" (1171.5 mm × 2202.9 mm × 105.4 mm) via an Athen Masterview CS1782 DVI-KVMP switch, with an image resolution of 593 pixels per meter and a refresh rate of 60 Hz. The stimulus part of the screen was transmitted onto a 108 cm wide and 70 cm high section of the hub. The distance between the participant and the display was at a constant 80 cm. Optic flow stimuli were generated using E-prime software (Psychological Software Tools, Inc.). The stimuli comprised a consistent set of 100 black dots, always present, with a virtual radius ranging from a minimum of 5.5 mm to a maximum of 17 mm. These dots were randomly positioned against a white background. Participants were instructed to maintain fixation on a red point (1.69 mm in diameter) placed at the centre of the screen. Throughout the experiment, the number of black dots remained constant by adding new dots when others disappeared from the screen, moving at a speed of 30 mm per frame (60 frames per second).

The experiment includes four different stimulus variations: forward optic flow, reversed optic flow, static non-flow, and random non-flow. Both forward and reversed optic flow represent structured coherent radial motion, visually depicting movement within the participants' environment. This is constructed by the increase in size, from minimum to maximum radius, as the dots are moving either towards or away from the participant. This creates the illusion of either expansion, where the dots start of small and increase in size, or contraction, where the dots start of big and decrease in size (van der Meer et al., 2008). As a consequence, participants will perceive sensations of either forward or backward self-movement. Random non-structured flow is produced by dots moving at the same speed as the structured optic flow, but each dot moves randomly, resulting in the absence of coherent optic arrays. In the static non-flow trials, dots remain stationary throughout the trial, serving as a baseline for EEG data analysis and preventing motion adaptation (Agyei et al., 2015). The motion conditions maintained a consistent speed of 1500 ms, with the stimulus contrast approximately at 99.5% and the mean luminance set at 68 cd/m<sup>2</sup>.

### **3.3) Data Acquisition**

EEG recordings were captured using a Geodesic Sensor Net 200 (GSN200) (Tucker, 1993), featuring 256 silver chloride electrodes evenly distributed across the participants' heads. Amplification of signals with a maximum impedance of 50 k $\Omega$ , recommended for optimal signal-to-noise ratio (Picton et al., 2000), was ensured by a high-input EGI amplifier connected to the net. The Net Station Acquisition software (version 5.4.1.2), operating on a Macintosh computer, recorded the amplifier EEG signals at a sampling rate of 500 Hz, with online filters set at 0.1 Hz high-pass and 200 Hz low-pass. The ClearView software on an HP computer processed video files with eye movement information, while an extra camera captured behavioural data. Eye data files were saved for subsequent offline analysis.

### **3.4) Procedure**

The experiment was conducted at the Developmental Neuroscience Laboratory (Nu-Lab) within the Department of Psychology at the Norwegian University of Science and Technology (NTNU) in Trondheim, Norway. The participants' head circumference was measured to select the appropriate size of the GSN net. The nets were soaked in a lukewarm saline electrolyte solution and soap for about 15 minutes before placement. The electrolyte solution is used to optimize the electrical connectivity while the soap makes the net easier to position on the head, as well as making the experiment more comfortable for the participant. The net was then carefully placed on each participant's head and adjusted for optimal electrode contact. The placement of the net was guided by the top-central reference point of the participant's head, which was found by measuring both the length (forehead to back of the head), and the width (from ear to ear) of the head. Subsequently, the reference electrode at the top of the net was carefully positioned on this mark to ensure standardization in electrode placement across all participants. To further improve the amount of impedance the electrodes were gently massaged into the scalp of the participant in order to achieve direct contact with the scalp and move aside pieces of hair.

Once fitted, participants were escorted to the experimental room and seated in front of the screen. First, the net's connection to the amplifier was checked for impedance, with adjustments made as necessary. In cases of particularly low impedance, additional saline solution was applied to the sponge part of the electrode using a pipette. This method effectively improved impedance at specific sites while ensuring participant comfort. Overall impedance was verified to ensure that at least 90% of the electrodes met the minimum requirement. Simultaneously, two students in an adjoining room, separated by a soundproof window, prepared the computers for software programs and impedance acquisition. Each stimulus condition was randomly

presented 40 times, except for the static condition, which, due to its interspersing between other conditions, resulted in 120 trials. The experiment lasted approximately 6 minutes and 42 seconds. After the session, participants were guided to the fitting room, where the net was removed, washed, and soaked in a sterilizing solution for approximately 10 minutes. Subsequently, it was rinsed and hung up to dry.

### **3.5) Analysis**

#### *3.5.1) Data analysis and preparation*

Initially, the raw EEG data underwent segmentation using Net Station Tools software. Following this, it was transferred to a separate server for offline analysis using Brain Electrical Source Analysis (BESA) 7.1 research software. Epochs were defined for averaging from -200 ms to 800 ms, with a baseline set from -100 to 0 ms. To eliminate line interference, a notch filter was applied at 50 Hz. Additionally, a low cutoff filter at 1.6 Hz was applied to remove low-frequency interference, such as skin potentials, while a high cutoff filter at 80 Hz was utilized to exclude channels containing high-frequency activities and exogenous noise (Luck, 2014; Agyei et al., 2015).

Channels and epochs tainted by artifacts stemming from head or body movements were either removed from subsequent analyses or had their signals estimated through spherical spline interpolation (Picton et al., 2000). Manual artifact correction involved spatial filters with thresholds set at 1.6  $\mu\text{V}$  for low signals and 8  $\mu\text{V}$  for gradients, effectively distinguishing brain activity from eye movement artifacts (Berg & Scherg, 1994). The maximum amplitude was limited to 120-300  $\mu\text{V}$  for all participants. Participants exceeding 10% bad channels or having fewer than 50% acceptable trials after artifact correction and scanning were excluded from further analysis.

### *3.5.2) Peak analysis at electrode level*

Peak analysis focuses on identifying and quantifying specific peaks in the ERP waveform to understand the timing and magnitude of neural responses to experimental stimuli (Marenga et al., 2023). While peaks represent specific points of maximal amplitude or deflection within an ERP waveform, components are broader segments of the waveform – including multiple peaks and reflecting distinct neural processes. Peaks are often components of larger, temporally extended ERP components, characterized by their topography, functional significance and duration (Luck, 2014, p. 51-52). This analysis method was therefore used to investigate responses of VEPs at the electrodes.

In preparation for the VEP analysis, the EEG data was reformatted into the standard 81-electrode layout of the 10-10 international system. Using spherical spline interpolation, a reference-free (10-10) montage signal was generated in order to obtain individual averages (American Electroencephalographic Society, 1991). Initially, the individual averages were analysed and subsequently merged to generate a grand average (Van der Meer et al., 2008). This was then used as a benchmark for identifying individual N2 components. 3D spherical whole-head voltage maps facilitated the identification of N2 components within individual averages by highlighting the maximum N2 activity associated with the dominant waveform over occipito-parietal areas (Perrin et al., 1989). Peak latency indicated the time taken from the onset of the stimulus to reach the peak of each scalp N2 component, while peak amplitude was assessed in comparison to the pre-stimulus baseline.

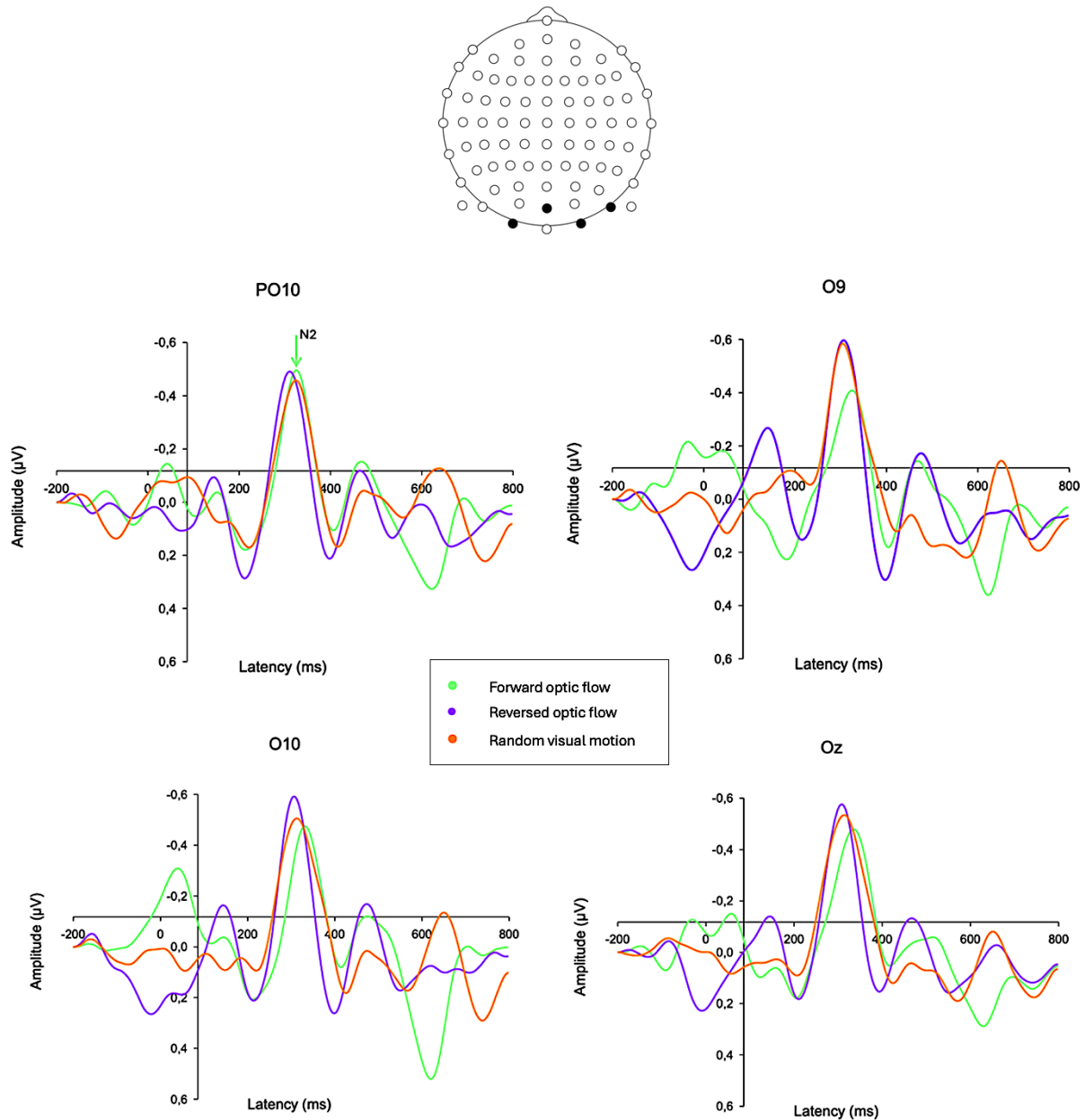
## 4.0) Result

Peak latency and amplitude for the N2 component were recorded for all the accepted trials within each participant. Using van er Meer et al.'s (2008) method of electrode selection, the following four electrodes from the occipital-parietal region were chosen: O9, Oz, O10, and PO10. This method involves computing individual averages of latency and amplitude for all participants, which are then combined to form a grand average. The grand average serves as a benchmark for selecting the four electrodes with the highest mean N2 amplitudes in the forward optic flow condition for further examination. From these four electrodes, one was chosen from each participant based on having the highest mean N2 amplitude in the forward optic flow condition. The data from these selected electrodes in each participant were used when creating separate gender groups.

The graphs in 'Figure 3' are based on the grand average data from all participants, both male and female, within all three motion conditions. Mean latency and amplitude were analysed separately using SPSS. Based on data from all 10 participants, the mean latency for the N2 component in response to forwards optic flow stimuli was observed at 271.4 ms ( $SD = 78.3$ ), 321.8 ms ( $SD = 42.2$ ) for reversed optic flow, and 293.4 ms ( $SD = 54.8$ ) for random visual movement. The mean amplitudes for the same data were calculated as  $M = -0.82 \mu V$  ( $SD = 0.65$ ) for forward optic flow,  $M = -0.89 \mu V$  ( $SD = 0.98$ ) for reversed optic flow, and  $M = -0.97 \mu V$  ( $SD = 1.08$ ) for random visual movement.

### Figure 3

*Grand Average VEPs for Forward Optic Flow, Reversed Optic Flow and Random Visual Motion Across all Participants*



*Note.* The graphs display the grand average ( $N=10$ ) at four selected electrodes, with PO10 and O9 in the top row, and O10 and Oz in the bottom row. These averages represent the combined data of all participants. On the X-axis, epochs range from -200 ms to 800 ms, with the onset stimulus at 0 ms. The Y-axis indicates amplitude in microvolts ( $\mu\text{V}$ ). A green vertical arrow on the top left electrode, PO10, indicates the inferred location of the N2 component. The colour scheme distinguishes between different visual stimuli: green for forwards optic flow, orange for reversed optic flow, and purple for random visual motion. Above the graphs



is a scalp localization map using a standardized 81-electrode distribution, with the selected electrodes highlighted. Among the coloured electrodes: O9 is located furthest to the left, followed by Oz in the middle, and O10 to the right, with PO10 furthest to the right.

The mean latency and amplitude values were recorded separately for both women and men in the forward optic flow condition. Women exhibited a mean latency of 234.4 ms ( $SD = 84.3$  ms) and a mean amplitude of  $-0.48 \mu\text{V}$  ( $SD = 0.25$ ), whereas men showed a mean latency of 308.4 ms ( $SD = 57.1$  ms) and a mean amplitude of  $-1.16 \mu\text{V}$  ( $SD = 0.78$ ). In the reversed optic flow condition, women displayed a mean latency of 333.2 ms ( $SD = 47$  ms) and a mean amplitude of  $-0.40 \mu\text{V}$  ( $SD = 0.33$ ), while men had a mean latency of 310.4 ms ( $SD = 38.5$ ) and a mean amplitude of  $-1.38 \mu\text{V}$  ( $SD = 1.21$ ). Regarding random visual motion, women had a mean latency of 304 ms ( $SD = 30.6$ ) and a mean amplitude of  $-0.49 \mu\text{V}$  ( $SD = 0.31$ ), while men exhibited a mean latency of 282.8 ms ( $SD = 74.6$ ) and a mean amplitude of  $-1.46 \mu\text{V}$  ( $SD = 1.39$ ).

A repeated-measures analysis of variance (ANOVA) was conducted to investigate potential differences in mean N2 latency between genders. The three conditions were used as within-subject variables, while 'gender' was used as the between-subject variable. Bonferroni correction was added to adjust for the multiple comparisons problem of EEG. The results of a test between-subjects effects within the repeated measures analysis revealed a non-significant main effect of gender on mean N2 latency across the 3 types of conditions,  $F(1, 8) = 0.241$ ,  $p = .64$ . This indicates that there was no statistically significant difference in mean N2 latency between male and female participants across the experimental conditions. A pairwise comparison revealed that the biggest mean difference between men and women within the latency condition was between forward and reversed optic flow ( $\Delta M = -50.4$ ,  $SD = p = .27$ ), however this difference was not statistically significant.

The mean amplitude of the N2 component underwent the same repeated-measures analysis of variance across the three conditions. This showed a non-significant main effect between gender and mean N2 amplitude,  $F(1, 8) = 3.05, p = .12$ . Comparing the mean and standard deviation between male and female participants revealed that male participants consistently exhibited a higher overall amplitude across all 3 motion conditions compared to female participants ( $\Delta M = 0.875, p = .12$ ), although neither this result was significant at the .05 alpha level.

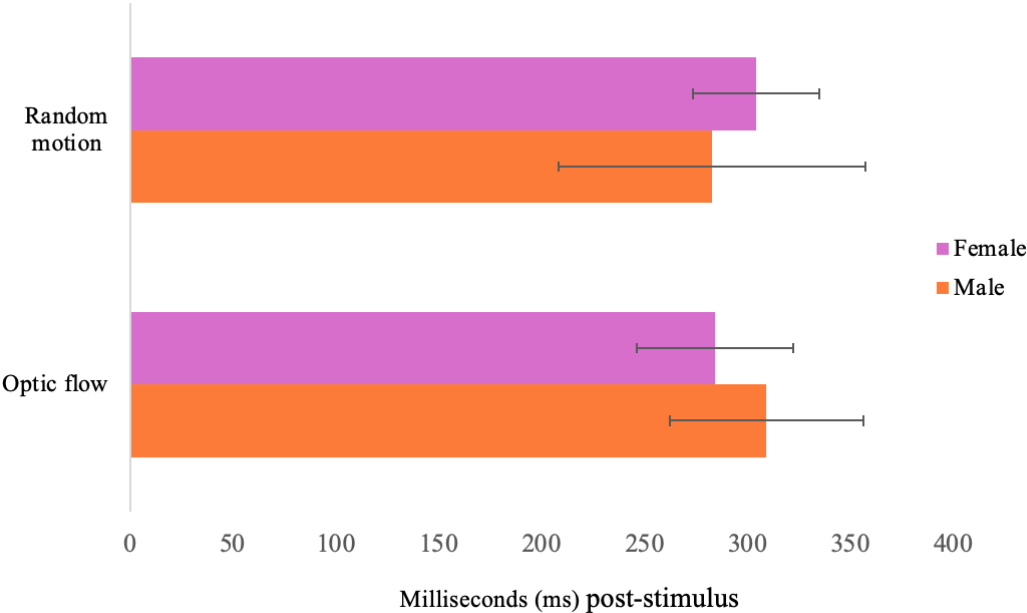
'Forward optic flow' and 'reversed optic flow' were combined to create the new condition of 'optic flow', which was then contrasted with 'random visual motion'. The variable 'optic flow' represented the combined mean latency and amplitude of both forward and reversed optic flow processing. For female participants, the mean latency of optic flow processing was 284 ms ( $SD = 38$ ), with a mean amplitude of  $-0.44 \mu V$  ( $SD = 0.25$ ). In contrast, male participants exhibited a mean optic flow latency of 309 ms ( $SD = 47$ ) and a mean amplitude of  $-1.27 \mu V$  ( $SD = 0.96$ ).

In analysing the variability within the now 2 conditions, using a Levene's test, a  $p$ -value greater than .05 suggests that the variability in the two conditions is approximately equal. This implies that there is not a significant difference in the variability between the two conditions, indicating stability across the measurements (Kim, 2014). When conducting a  $t$ -test, Levene's test was employed to assess equality of variance. The results indicated a  $p$ -value of .92 for optic flow and .22 for random visual movement in terms of mean latency, suggesting no significant deviation from the assumption of equal variances within the groups. Similarly, for mean amplitude, Levene's test revealed  $p$ -values of .18 for optic flow and .10 for random visual motion, further supporting the assumption of equal variances within the respective groups.

An independent samples *t*-test comparing mean optic flow latency between male and female participants indicated that mean optic flow latency tended to be a little higher in the male group than the female. However, this observed difference was not significant ( $t(8) = 0.95, p = .37$ ). While there was a trend towards higher mean latency in males, the *p*-value exceeding .05 prohibits these findings of being statistically significant. Similarly, when examining mean latency within the random motion condition, a *t*-test showed that male participants generally exhibited shorter mean latency for the N2 component compared to female participants. However, like the mean optic flow latency comparison, these differences were not statistically significant ( $t(8) = -0.59, p = .57$ ). These findings are visualised in ‘Figure 4’.

**Figure 4**

*Mean Latency of N2 Component in Conditions of Random Motion and Optic Flow Across Gender Groups*



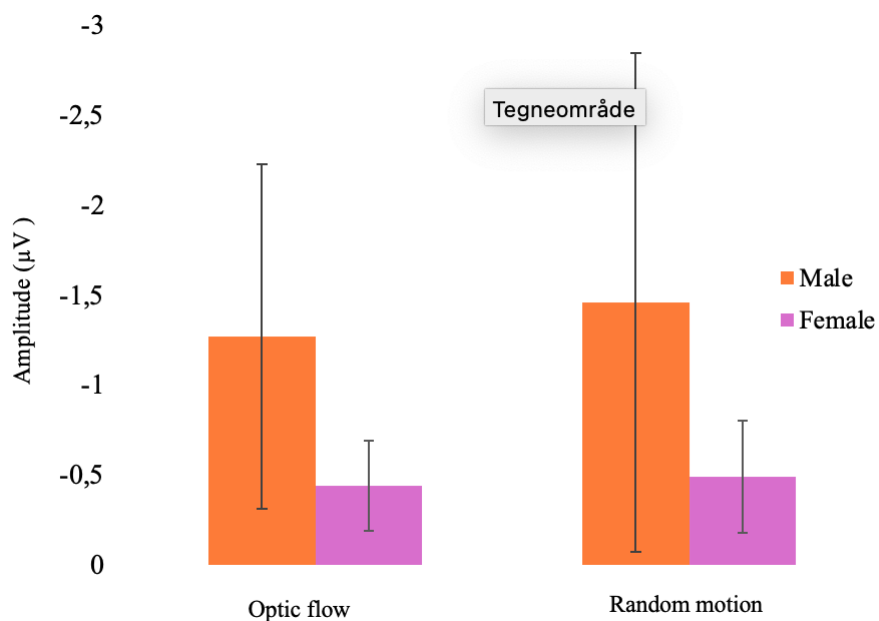
*Note.* Mean latency of the N2 component within the conditions ‘random motion’ and ‘optic flow’ across gender groups. The x-axis represents the conditions 'random motion' and 'optic flow', while the y-axis displays mean milliseconds (ms) post-stimulus. Purple bars represent the female group, and orange bars represent the male group.

Each bar is accompanied by an error bar representing the standard deviation of the mean latency within each condition. No significant differences were observed between conditions or gender groups ( $p > 0.05$ ).

The procedure was repeated for both mean optic flow amplitude and mean random visual motion amplitude. Regarding mean optic flow amplitude, a  $t$ -test indicated a non-significant distinction between women and men ( $t(8) = -1.87, p = .10$ ). Similarly, the  $t$ -test for mean random visual motion amplitude yielded comparable findings ( $t(8) = -1.53, p = .17$ ). Results are visualised in ‘Figure 5’.

### **Figure 5**

*Mean Amplitude of N2 Component in Conditions of Random Motion and Optic Flow Across Gender Groups*



*Note.* Mean amplitude of the N2 component within the conditions ‘random motion’ and ‘optic flow’ across gender groups. The x-axis represents the conditions optic flow (left) and random visual motion (right), while the y-axis represents mean amplitude ( $\mu\text{V}$ ). The orange bars depict data from the male group, while the purple bars represent the female group. Each bar is marked with error bars representing the standard deviation of measurements. There were no significant differences between conditions or gender groups ( $p > 0.05$ ).

## **5.0) Discussion**

Using high-density EEG, this study aimed to explore potential differences between adult male and female participants within the mean latency and amplitude of the N2 component across three motion conditions: forward optic flow, reversed optic flow, and random visual motion. Statistical analyses were conducted to examine gender differences in mean latency and amplitude across the motion conditions, as well as to compare the combined optic flow condition to random visual motion.

### **5.1) Interpretation of ERP**

EEG provides precise temporal resolution for conducting event-related potential experiments. However, its limited spatial resolution makes it challenging to determine the exact origin of neural processes (Luck, 2014, p. 22-24). A thorough understanding of how electroencephalogram measurements are recorded and performed is necessary for conducting high-quality data and research. Understanding the impact of intrinsic and exogenous factors on data measurement is vital to avoid research pitfalls. These include noise during data collection and misinterpreting positive or negative waves as signs of activation or inhibition. Equalizing EEG generator locations with measured peaks at the scalp has previously led to inaccuracies in neurophysiological interpretations (Luck, 2014, p. 17-21). This is due to the mistake of assuming that the location where measured electrical brain activity is generated is accurately and directly linked to measured peaks in the EEG signal from electrodes on the scalp (Jackson & Bolger, 2014). In reality, EEG signals recorded at the scalp symbolise the summation of postsynaptic electrical activity from various brain regions (Luck, 2014, p. 18-20). Assuming a one-to-one relationship between measured peaks from the scalp and locations of neural generation will end in an inaccurate understanding of the brain and its functions.

EEG electrodes lack the sensitivity to capture the dipole of an individual neuron. Hence, we rely on the cumulative charges in close proximity to detect electrical activity within the brain. This results in a measurable dipole whose strength reflects the number of neurons involved. Detectable signals require the excitation of neurons to be simultaneous but also necessitate a parallel arrangement. Only neurons aligning in the same orientation have the ability to combine to form a larger detectable signal (Luck, 2014, p. 18-20). EEG measurements commonly identify two main types of dipoles: radial dipoles, which run parallel to the scalp surface, and tangential dipoles, positioned perpendicular to the surface (Ahlfors et al., 2010). In any other arrangement, the positive and negative ends of the dipoles will cancel each other out, and no signal will be detected (Luck, 2014, p. 30-31; Jackson & Bolger, 2014).

Aside from encoding stimulus events, EEG signals incorporate 2 types of noise: movement artefacts from actions such as blinking and head adjustments and background brain activity. Unlike the background brain activity, the ERP signal synchronizes with stimulus onset, prompting the averaging of numerous trials to estimate an ERP. Eye and head-motion movement artefacts are often much larger than the ERP signal and can therefore be detected via artefact correction before analysis (Fujioka et al., 2010). When interpreting results, it's vital to acknowledge both the strengths and weaknesses of EEG recordings. Various known and unknown confounding variables could influence the recorded data, potentially leading to statistical errors like type 1 (falsely concluding an effect is present when it's not, thus incorrectly rejecting the null hypothesis) or type 2 (falsely concluding there's no effect when there is one, maintaining a false null hypothesis) errors.

### 5.3) Gender Differences in Visual Motion Processing

This study's results indicated a tendency for higher optic flow amplitudes in male participants compared to females ( $t(8) = -1.87, p = .10$ ), although not statistically significant. Similar non-significant differences were observed for random visual motion ( $t(8) = -1.53, p = .17$ ). The male group showed consistently higher amplitudes across all of the motion conditions ( $\Delta M = 0.875, p = .12$ ). The notable standard deviation (0.5) might account for the elevated  $p$ -values, reflecting a considerable amplitude range among male participants compared to females. Despite the lack of statistical significance, the relatively high  $F$ -value across all 3 motion conditions compared to the gender groups ( $F(1, 8) = 3.05, p = .12$ ) suggests that there is a noteworthy difference in N2 amplitude worth acknowledging, although not statistically significant.

For mean latency, the low  $F$ -value ( $F(1, 8) = 0.241, p = 0.64$ ) suggests that the variance between the two groups is smaller compared to the variance within each group. An  $F$ -value below 1 is indicating that the groups are very similar in within-group variability, including little difference between the gender groups. Consequently, this often translates to a lack of a significant effect (Kim, 2014). The non-significant  $p$ -value at 0.64 further supports this interpretation. While the inconsistency in mean latency within the groups is not sufficient to reject Levene's test of variability, it could be a potential reason as to why there were no significant differences found.

The practical implication of these results is that there is not sufficient evidence to conclude that there is a significant difference in mean amplitude or latency between men and women across the three conditions. While there may be some differences observed, these differences are not statistically significant based on the  $p$ -value obtained from the ANOVA or independent samples  $t$ -tests. However, failing to reject the null hypothesis does not necessarily mean that there is no effect; it simply means that there is insufficient evidence to conclude that there is an actual

effect (Schneider, 2015). While this study's findings do not allow for definitive conclusions regarding the significance or validity of these observations, they are noteworthy in light of previous research indicating differences in hemispheric activity between male and female participants, as well as local and global processing of visual information (i.e., Ingahalikar et al., 2013; Kramer et al., 1996; Gur et al., 2000; Roalf et al., 2006). Therefore, these findings underscore the importance of further investigation in future research in order to conclude whether these preferences are based on structural differences or random findings.

## **5.2) Perceptual development**

Based on prior empirical research (van der Meer et al., 2008; Agyei et al., 2015; Vilhelmsen et al., 2015; Vilhelmsen et al., 2018), the leading hypothesis in optic flow and random visual motion perception suggests that forward optic flow induces shorter optic flow latency, followed by reversed optic flow, and with random visual motion associated with the longest latency. The reason for this arrangement is thought to be related to the assumption that already from early age, infants tend to develop the ability to perceive coherent radial motion at a faster rate than their ability to perceive non-coherent random motion (Agyei et al., 2014). Moreover, the preference towards faster processing of forward motion is thought to be associated with the significance of efficient self-navigation (Agyei et al., 2014; Warren et al., 2001), alongside considerations of neuroplasticity and Hebbian learning theory (Hebb, 1949; Keyzers & Gazzola, 2014; Gulyaeva, 2017), given the higher occurrence of encountering forward optic flow compared to reversed or random motion.

Neuroplasticity operates across various scales, with learning, adaptive behaviour and memory representing the pinnacle of its hierarchy. A fundamental aspect of neuroplasticity is that the dynamic nature of synaptic connections, which are continuously being removed and formed,



are heavily influenced by the neural activity (Gulyaeva, 2017). As Donald Hebb famously put it; “Neurons that fire together, wire together” (Keysers & Gazzola, 2014). Different types of activity-driven changes in synaptic strength are observed throughout the brain, highlighting the importance of synaptic plasticity in memory and learning theories based on experience-induced changes (Gulyaeva, 2017). The occurrence of forward optic flow surpasses that of reversed optic flow or random visual motion simply because our typical movement direction is forward. Whether we're moving ourselves or stationary within a moving vehicle, we consequently consistently encounter and adapt to the perception of coherent forward optical patterns.

Gilmore, Baker, and Grobman (2004) conducted research experiments with the aim of investigating whether sensitivity develops before infants start crawling and whether infants' ability to detect changes in heading direction relies solely on optic flow or on other visual cues, including optical speed, shading, texture, and deletion patterns. Their findings suggest that infants might utilize a combination of both low-level and high-level cues to discriminate between visual displays simulating self-motion. Low-level cues being basic features processed early in the visual system, such as motion direction, texture gradients, and speed. High-level cues involve context-dependent information and higher cognitive processes, including object recognition, depth perception, and scene interpretation, which are influenced by prior knowledge and experience (Gilmore et al., 2004). It therefore seems like the integration of lower cognitive functions, such as processing optic flow direction and speed, with higher-order cognitive functions shapes our perception and understanding of affordances within the environment.

Basic awareness of optic flow patterns, mimicking either an object moving towards the observer's face, or the observer's forwards/reversed motion, develops within the initial weeks

and months after birth (Gilmore et al., 2004). There is limited data discussing to which degree infants discern between optic flow patterns, indicating distinct directions of movement, and how this discrimination evolves with age. However, some authors have noted substantial developmental changes in some aspects of spatial perception and cognition during the first months of life (Atkinson, 2000; Gilmore & Johnson, 1997a, 1997b). Changes are believed to be a result of maturation of processing circuitry linked to the dorsal visual processing stream, as well as perceptual and motor experiences (Gilmore et al., 2004). As infants begin development of locomotion and start to crawl and explore autonomously, it's natural that these experiences would reshape their perception of the world and its functions. These first-hand encounters become integrated into both memory and neuroplastic changes, which in combination with the development of cognitive abilities alters their understanding of their environment (Adolph et al., 1997, p. 10-13).

The overall findings of this study's grand average analysis deviate from previous research, as the N2 component for random visual motion and reversed optic flow showed shorter mean latencies compared to forward optic flow. However, it is important to note that this analysis was only conducted based on the four selected electrodes with the highest N2 amplitudes. While the grand average analysis did not reveal shorter mean latency for forward optic flow, an examination of the overall mean latency, across all 10 participants, supports the theory of faster processing of forward optic flow compared to reversed optic flow and random motion (forward optic flow:  $M = 271.4$  ms,  $SD = 78.3$ ; reversed optic flow:  $M = 321.8$  ms,  $SD = 42.2$ ; random visual motion:  $M = 293.4$  ms,  $SD = 54.8$ ). This inconsistency, along with the lack of significant results, may stem from factors such as the limited number of participants and the methodology used for artifact correction, as well as data quality. While all data had to meet predefined quality standards for inclusion in the analysis, some sections within the accepted data were excluded

due to poor recording quality. While this issue might be less pronounced in a larger sample, the small sample size notably increases the fragility of the present study's results, challenging both the representativeness and statistical power. In addition, considering the insights derived from Langrová et al. (2006) and Korth et al. (2000), it's worth noting that the age range of participants, spanning from 22 to 37 years old, could have influenced the outcomes, given that latency appears to rise with age after the age of 20.

#### **5. 4) Combining forward and reversed optic flow**

The decision to combine forwards and reversed optic flow into the variable "optic flow" was inspired by Gibson's principles of ecological optics. As mentioned previously, Gibson's theory of optic flow focuses on the continuous shifting of light patterns on the retina as we navigate our surroundings. This creates an optic flow field within the visual field comprised of structured optic arrays, which, when integrated with our kinaesthetic and proprioceptive senses, enables us to perceive the environment directly (Gibson, 1966). Additionally, Warren et al. (1988) proposed that route/pathway knowledge is acquired and perceived through a sequential progression of viewpoint alterations within the consistent framework of the environment.

Initially, based on the hypothesis that optic flow arises from structured optic arrays in the optic field, it was assumed that the processing of both forward and reversed optic flow would be similar. It was anticipated that regardless of the direction of optic flow, as long as coherent optic flow arrays were present, some correlation or similarity between these conditions would be observed. Although this assumption has not been discarded, it has been somewhat refined as subsequent research and findings have contributed to an enhanced comprehension of the differences between forwards and reversed motion processing. For instance, a study by Tan et al. (2003), found that participants were faster and more accurate when recalling paths that were

going in the forward direction compared to reversed. They concluded with the assumption that reversed navigation required the participants to perform an extra cognitive step, causing the cognitive load to slow down the process.

Cutmore et al. (2000) discussed similar pathway experiments, distinguishing between spatial encoding and sequential path representation. This phenomenon was associated with the ease of reciting the alphabet from A to Z, contrasting with the difficulty many individuals encounter when attempting the same task in reverse order. The theory proposes that individuals who utilize spatial encoding create a mental map of their environment, potentially gaining an advantage in navigation-related tasks (Roskos-Ewoldsen et al., 1998). However, in Tan et al.'s (2003) study, no such effect was observed, as it is also hypothesised that these encoding methods are not mutually exclusive, but that one method is dominantly used over the other.

Building upon previous literature and research (Tan et al., 2003; van der Meer et al., 2008; Agyei et al., 2015; Vilhelmsen et al., 2015; Vilhelmsen et al., 2018), which demonstrated faster processing of both forward and reversed structural optic flow compared to random visual motion, the present study aimed to explore the comparative processing speed of directional optic flow and random visual motion. Hence, this study aimed to examine how structured, visually rich stimuli affect cognitive processing. However, results may have been affected by the presence of confounding variables, such as differences in higher order cognitive processing between forward and reversed optic flow. Furthermore, the variability in mean latency between forward and reversed optic flow may have contributed to the inconsistent results. When these conditions were combined, the differences in mean latency based on movement direction were not clearly discernible due to the high standard deviations within the participants' data. Consequently, despite forward optic flow showing shorter latency when analysed separately,

no statistically significant results were found in combination with reversed optic flow and compared to random visual motion. While the study considered numerous variables, the complexity of human perception suggests that additional exploration is needed to fully comprehend the subtle effects involved as direction of optic flow could interfere with unknown cognitive processes and pathways. Therefore, I would recommend avoiding the combination of forward and reversed optic flow in future research to prevent the risk of potentially misleading statistical outcomes.

### **5.5) Considerations**

The study excluded variables related to pathology during participant testing. While factors associated with participants' condition on the testing day were considered, many others were not accounted for. Consequently, we cannot dismiss the possibility of unaccounted factors like behavioural disorders or visual acuity, which could impact cognitive processing during tasks requiring prolonged focus and stillness. The study exclusively focused on relatively healthy individuals and did not address pathological factors. Furthermore, the predetermined methodological approach limited the exploration of variables associated with prior experience or expertise due to time constraints. Thus, the decision was made to concentrate on investigating potential gender differences within this research framework.

The study's limited sample size compromises its reliability for future interpretations, unless data can be pooled in a meta-analysis with similar studies. This is arguably one of the main drawbacks of brain imaging research, as it demands significant resources in terms of both finances and time. Moreover, the artifact correction analysis method is primarily manual, leaving room for both deliberate and inadvertent manipulation of the data. In other words, the same dataset corrected by two different individuals could exhibit different results depending on

which corrections are emphasized and which are not. However, despite the study's notable limitations, the findings consistently revealed a robust N2 component across all experimental conditions within all 10 participants. Therefore, although the results deviate from previous research in latency, they underscore the significance of the dorsal stream processing pathway in visually evoked responses (Galletti & Fattori, 2018).

## **6.0) Conclusion**

The investigation into the main mean latency and amplitude of the visually evoked N2 component across three conditions—forward optic flow, reversed optic flow, and random visual motion—in separate male and female groups revealed non-significant differences ( $p > .05$ ). This lack of significance may be attributed to the limited number of participants, as well as variations in data quality and methods for artifact correction. While not statistically significant, there was a trend towards higher mean amplitude observed in the male group compared to the female group when comparing optic flow (forward and reversed combined) and random visual motion. Additional factors contributing to the deviation from previously observed trends (van der Meer et al., 2008; Agyei et al., 2015; Vilhelmsen et al., 2015; Vilhelmsen et al., 2018) could be attributed to neuroplasticity theories. These theories emphasize the importance of experience and memory, shedding light on how individual differences in synaptic activity generate unique wiring within each brain (ref. Hebb, 1949; Keysers & Gazzola, 2014; Gulyaeva, 2017). However, when all 10 participants were combined into one group, forward optic flow exhibited shorter mean latency than reversed optic flow and random visual motion, supporting previous findings of faster processing of forward optic flow.

The combination of forward and reversed optic flow into ‘optic flow’ may have hindered significant results between gender groups, and future research should investigate each

directional condition separately. To avoid reaching misleading conclusions, it's crucial to ensure that participant groups are representative of the specific demographic being studied. This limitation cannot be addressed solely within this study. Therefore, given the lack of statistical significance, there is insufficient evidence to reject the null hypothesis. Thus, the conclusion suggests no significant effect of gender on mean latency and amplitude within the N2 component when comparing structured optic flow and random visual motion. Despite limitations, the study consistently demonstrated a robust N2 component across conditions and participants, underscoring the importance of the dorsal stream in visual responses, despite latency differences from previous research.

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