Neural correlates of object detection in a simple and complex ecological virtual reality environment

Youlin Li

School of Physical and Occupational Therapy
Faculty of Medicine, McGill University
Montreal, Quebec, Canada

December 2019

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements of the master's degree in Rehabilitation Sciences.

STATEMENT OF AUTHORSHIP

I, Youlin Li, certify that I am the primary author of this thesis. I claim full responsibility for the content and style of the text included herein.

STATEMENT OF ORIGINALITY

This thesis contains no material that has been published elsewhere, except where specific references are made. The study presented in Chapter 3 is original material and represents contributions to knowledge in the fields of virtual reality, neuroscience and rehabilitation. In this study, a virtual reality-based assessment for USN known as 'EVENS' was used along with electroencephalography (EEG) to assess healthy patterns of brain activation in individuals performing object detection tasks. For the very first time, the modulation of brain activation in response to changing scene complexity and target location was examined and quantified. The knowledge derived from this study will further our understanding on how elements such as scene complexity and object location in the visual field modulate brain activation during object detection tasks among healthy individuals. The results obtained will also serve as a basis for comparison to further understand, in the future, the affected object detection performance displayed by persons with visual-perceptual disorders, such as those with post-stroke unilateral spatial neglect (USN). By identifying which regions of the brain are involved in object detection, the results obtained from this study will also provide the mechanistic basis for the development of an individualised brain stimulation protocol to promote USN recovery.

The data presented in this thesis was collected at the Feil & Oberfeld Research Centre of the CISSS-Laval and Jewish Rehabilitation Hospital Site of the Centre for Interdisciplinary Research in Rehabilitation of Greater Montreal (CRIR), affiliated to McGill University. The study presented in this thesis was approved by the Research Ethics Board of CRIR.

DEDICATION

I dedicate this thesis to my loving parents, Li JinLan and Li EnZhi who have always listened, respected and supported my decisions. To my mother, who have always been my role model. While raising me up with love and patience, you hold a full-time job during daytime and still managed to finish a master's degree in English through night classes. I know you didn't need the master's degree for a better job. Believing action speaks louder than words, you wanted to encourage me to study by studying with me. To my father, who taught me to live a disciplined life and to keep my chin up during the tough times.

To my wife, Ren He, who takes care of our kids and who is always be my side to support me throughout the process of graduate studies. You have always been my best friend and spiritual guide. Without you, I would not have had the courage to embark on this journey in the first place.

I also dedicate this thesis to my lovely daughters, Li Audrey and Li Annie, keeping my spirit up with all the laughter. A special thanks to Audrey, my elder daughter, for being such a wonderful sister who cares and plays with her little sister for the past couple months, making it possible for me to complete what I started. In the end, I wish both of you know I love you more than anything in the world.

ACKNOWLEDGEMENTS

The past three years of study has been a bittersweet journey. In this journey, I have encountered more challenges than I ever had in the past, yet I gained the greatest personal growth in more ways than one. Along the way, I have met these awesome people who have helped, enlightened and guided me. I would like to express my sincere gratitude to them.

First and foremost, I want to express my thankfulness to Dr. Anouk Lamontagne, my supervisor, who continuously supported and guided me with her patience, caring and immense knowledge through all this time in academic aspects as well as my personal growth. I still remembered the times when she drove me to Ikea in her cool pickup when I just arrived in this foreign country; when she guided me through the process of scholarship and funding applications; when she patiently guided me in writing of this thesis. I could not have imagined a better advisor and mentor for my master's study.

I also want to express my sincere gratitude to my co-supervisor Marie-Hélène Boudrias for leading me into the EEG world, from EEG system set-up to data analysis. I appreciate she was always ready for my questions and timely provided feedback. I further want to express my gratitude to Dr. Samir Sangani for creating the virtual scene and enlightening me on data analysis, as well as to professor Fabien Dal Maso for providing guidance in data analysis.

My sincere thanks also go to Dr. Isabelle Gélinas, Graduate Program Director, Dr. Eva Kehayia, Scientific Director at CRIR and to all staff members of the School of Physical and Occupational Therapy.

I want to thank my fellow lab mates for the stimulating discussions, advices, experience sharing, and for all the fun we had in the last 3 years.

Last but not the least, I greatly appreciate the financial support I have received during my studies at McGill University. I was a recipient of awards and bursaries from the Centre for Interdisciplinary Research in Rehabilitation of Greater Montreal (CRIR), the School of Physical and Occupational Therapy (SPOT) as well as the Quebec Bio-imaging network (QBIN).

CONTRIBUTION OF AUTHORS

The organization of this manuscript-based thesis adheres to the guidelines for thesis preparation published by McGill Graduate and Postdoctoral Studies. It includes one research manuscript. I, Li Youlin, am the main contributor and lead author of all chapters and the manuscript included in this thesis. My contribution extends to the research design, experimental set up, data collection, data analyses, statistical analyses, interpretation of findings, preparation of figures/tables.

The manuscript presented here were developed under Dr. Anouk Lamontagne's and Dr. Marie-Hélène Boudrias' supervision. Dr. Lamontagne oriented the selection of the research design, experimental set up, data analysis, statistical analysis, interpretation of findings and critically reviewed and provided constructive feedback on both the manuscript and this thesis.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

ADLs	Activities of daily living
CVA	Cerebrovascular accident
CE	Clustered environment
EEG	Electroencephalography
ERP	Event related potential
ESC	Extrastriate Cortex
EVENS	Ecological virtual reality evaluation of neglect symptom
PPC	Posterior parietal cortex
UCE	Uncluttered environment
USN	Unilateral spatial neglect

ABSTRACT

Background: The ability to detect objects of interest in the environment is essential to activities of daily living. Such an ability can be dramatically altered after a central nervous system lesion, especially after a right hemisphere stroke leading to post-stroke unilateral spatial neglect (USN). In this population, deficits in object detection are modulated as a function of object location and environment complexity, yet the mechanisms for such modulation remain unclear. As a first step, we examined in this study the healthy patterns of brain activation involved in a virtual reality-based object detection task performed in an ecological environment representing a grocery shopping scene. **Objectives**: to estimate the extent to which (1) scene complexity impacts on the amplitude and latency of event-related potential (ERP) components and; (2) the amplitude and latency of ERP components are modulated as a function of object location along the horizontal plane. **Methods**: Fifteen healthy adults (45-70 years) were assessed using an immersive virtual reality set-up as they detected a target object (shopping item) located at five possible locations (0°, ±20°, ±40°) in an uncluttered (UCE; item appearing in isolation) or a cluttered virtual environment (CE; item appearing amongst others). Response time was recorded and ERPs components P1, N1 and P3 were extracted from electroencephalography recordings over electrode sites corresponding to bilateral posterior parietal cortex (RPPC, LPPC) and extrastriate cortex (RESC, LESC). **Results**: Larger amplitude of P1 and N1 in PPC clusters as well as larger P3 amplitude in extrastriate cortex clusters were observed for CE vs UCE. Object location has significant effects on amplitude of N1 and P3 only: N1 amplitude (in absolute value) peaked at center and decreased with target eccentricity whereas P3 amplitude is enhanced in the contralateral to hemisphere. Latency of P1, N1, and P3 was longer for UCE vs CE, due to longer latencies in the peripheral (left or right) vs.

centered target location in UCE but not in the CE. **Conclusions:** Present findings indicate that brain activation in the PPC and/or extrastriate cortex during an object detection task performed in an ecological virtual environment vary according to scene complexity and target location. The increase in amplitude for P1 and P3 with the more complex (cluttered) environment may reflect top-down influences on early sensory information processing, whereas the enhancement of N1 for the same condition may reflect the role of this area in the discrimination process itself, which was needed for the complex but not the simple scene. In the simple scene, the bilateral effects of target location of N1 observed in the right hemisphere is in line with presumed involvement of N1 in the orientation of attention to the relevant location, while the enhancement of P3 in response to contralateral target appearances may result from a compound of premotor cortex activation.

Significance: The results obtained provide fundamental knowledge on brain activation patterns involved in object detection in an ecological environment, as required in activities of daily living. While serving as a basis for comparison to determine defective patterns of brain activation in populations such as individuals with post-stroke USN, the present findings constitute a first step towards the development of optimal brain stimulation paradigms to promote USN recovery.

ABRÉGÉ

Contexte: La capacité à détecter des objets d'intérêt dans l'environnement est essentielle aux activités de la vie quotidienne. Une telle capacité peut être considérablement altérée après une lésion du système nerveux central, en particulier après un accident vasculaire cérébral de l'hémisphère droit conduisant à une négligence spatiale unilatérale. Dans cette population, les déficits de détection des objets sont modulés en fonction de la localisation de l'objet et de la complexité de l'environnement, mais les mécanismes de cette modulation restent méconnus. Dans cette étude, nous avons dans un premier temps examiné les patrons d'activation cérébrale impliqués dans une tâche de détection d'objets effectuée dans un environnement virtuel écologique représentant une scène d'épicerie chez des individus sains. Les **objectifs** étaient d'estimer dans quelle mesure: (1) la complexité de la scène influe sur l'amplitude et la latence des composantes du potentiel évoqué et (2) l'amplitude et la latence des composantes du potentiel évoqué sont modulées en fonction de la position de l'objet dans le plan horizontal. **Méthodes**: Quinze adultes en bonne santé (45 à 70 ans) ont été évalués à l'aide d'un casque immersif de réalité virtuelle alors qu'ils détectaient un objet cible (item) situé à cinq endroits possibles (0°, ±20°, ±40°) dans un environnement simple (objet apparaissant isolément) ou dans un environnement virtuel complexe (objet apparaissant parmi d'autres). Le temps de réponse a été enregistré et les composantes P1, N1 et P3 du potentiel évoqué ont été extraites des enregistrements d'électroencéphalographie aux sites d'électrodes correspondant au cortex pariétal postérieur bilatéralement (RPPC, LPPC) et au cortex extrastrié (RESC, LESC). **Résultats** : Une plus grande amplitude de P1 et N1 dans l'aire du PPC ainsi qu'une plus grande amplitude de P3 dans le cortex extrastrié ont été observées pour l'environnement complexe vs. plus simple. La localisation de l'objet a des effets significatifs sur

l'amplitude de N1 et P3 seulement : L'amplitude N1 (en valeur absolue) a culminé au centre et a diminué avec l'excentricité de la cible tandis que l'amplitude P3 est augmentée dans la partie controlatérale de l'hémisphère. La latence de P1, N1 et P3 était plus longue pour l'environnement simple que pour l'environnement complexe, en raison de latences plus longues lorsque la cible était décentrée (à gauche ou droite) vs. centrée dans l'environnement simple exclusivement. **Conclusions**: Les résultats de cette étude indiquent que l'activation cérébrale dans le PPC et/ou le cortex extrastrié au cours d'une tâche de détection d'objet effectuée dans un environnement virtuel écologique varie selon la complexité de la scène et la localisation de l'objet cible. L'augmentation de l'amplitude des composantes P1 et P3 enregistrées dans un environnement plus complexe (encombré) peut refléter des influences descendantes sur le traitement précoce de l'information sensorielle, tandis que l'augmentation de N1 enregistrées lors la même condition peut refléter le rôle de N1 dans le processus de discrimination lui-même, nécessaire dans le contexte d'une scène complexe mais non pas d'une scène plus simple. Dans le cas d'une scène simple, les effets bilatéraux de l'emplacement de la cible sur l'amplitude de N1 dans l'hémisphère droit correspondent à l'implication présumée de cette aire dans l'orientation de l'attention vers l'emplacement pertinent, tandis que l'augmentation de P3 en réponse aux cibles décentrées du côté controlatéral peut résulter de l''activation du cortex pré-moteur. **Implication** : Les résultats de cette étude contribuent à l'amélioration des connaissances fondamentales sur les patrons d'activation cérébrale impliqués dans la détection d'objets dans un environnement écologique, tel que requis dans les activités de la vie quotidienne. Tout en servant de base de comparaison pour déterminer les patrons défectueux d'activation cérébrale chez des populations telles que les personnes ayant une héminégligence spatiale unilatérale suite à un accident vasculaire cérébral, les résultats

obtenus aussi constituent un premier pas vers l'élaboration de paradigmes optimaux de stimulation cérébrale pour favoriser la récupération de l’héminégligence spatiale.

CHAPTER 1: INTRODUCTION

Unilateral special neglect (USN) is a common problem following stroke, which is associated to poor rehabilitation outcomes [13] and a diminished capacity to perform both basic self-care activities and more complex ADLs [14]. USN is defined as the "inability to orient, respond, or report to the stimuli appearing on the contralesional side"[15]. When presented with objects within both visual fields, stroke survivors with USN look at the right object first and may deny the presence of the left object [17]. Based on the visual hierarchy by Warren (1993) [18], USN can affect the fundamental level of visual perceptual abilities needed for object detection, ultimately leading to a disruption in more complex tasks such as goal-directed navigation and the completion of ADLs. Therefore, object detection is fundamental and was the key task examined in this study.

From neuroanatomical perspective, the presence of USN can be the result of lesion to several areas such as the inferior parietal lobe, lateral frontal, posterior superior and middle temporal gyri [19-27]. However, among a complex and extensive neural network, lesion to the posterior parietal cortex (PPC) is directly link to USN [28, 29]. Several studies have also successfully induced neglect-like behaviors by applying inhibitory TMS over the right PPC of healthy individuals [29].

PPC plays a pivotal role in constructing multiple spatial reference frames which are used to guide behaviors [31], as well as in selectively processing information and shaping perceptual experience [32]. Meanwhile, both primates and human studies have found a significant role of extrastriate cortex in visual information processing and distractor filtering [33-35].

Although lesions to key brain regions such as the PPC can explain the presence of USN, the lesion site alone may not explain the variability in performance across USN positive (USN+) individuals in functional tasks such as detecting objects in different locations [36]. Recovery of a certain level of performance can be achieved by a re-routing of activity within a distributed neuronal architecture. In this MSc thesis, I applied electroencephalography (EEG) on healthy older individuals (of a similar age to the typical stroke population) to examine patterns of brain activation involved in an object detection task, with the long-term goal of identifying alterations present in recovered and non-recovered post-stroke USN.

EEG was selected over other brain imaging techniques for its non-invasive, portable characteristics, and more importantly, its ability to provide high temporal resolution to capture the transient brain electrical activity [37, 38]. Data were analyzed using event-related potentials (ERP), which, for the past two decades, have been used to uncover sensory, motor and cognitive neural processes [39] through its waveforms. The voltage changes in response to a particular neural event during a

specific time window constitute the ERP waveform [1, 39], which can either be negative or positive. Common ways to quantify ERP results are to measure the amplitude and latency of the peaks. ERP can track visual processing by reflecting visual cues through its components. Based on current ERP studies involving visual-perceptual tasks, P1, N1, and P3 are considered to be the most informative components [10], where P1 and N1 components are thought to represent stimulus encoding stage [6, 40] whereas the P3 component it knows to be elicited when a fast stimulus related decision has to be made [41].

In the present thesis, I examined ERP results collected from the PPC and extrastriate cortex and analyzed the latency and amplitude of P1, N1, and P3, and how these are modulated as a function of scene complexity and target location. In Chapter 2, I am presenting a literature review on post-stroke USN, its neural correlates and its impact on object detection, as well as on visual streams involved in visual perception and on EEG analyses. Chapter 3 presents a manuscript which has the purpose of testing the modulatory effects of target location and scene complexity during an object detection task on the brain's ERPs among healthy older individuals. Finally, in Chapter 4, the knowledge that came from this study is discussed, as well as the limitations and future directions.

CHAPTER 2: BACKGROUND AND RESEARCH OBJECTIVES

2.1 BACKGROUND

2.1.1 POST-STROKE UNILATERAL SPATIAL NEGLECT (USN)

Stroke is defined by the World Health Organization as "rapidly developing clinical signs of focal (or global) disturbance of cerebral function, with symptoms lasting 24 hours or longer or leading to death, with no apparent cause other than of vascular origin" [42]. Besides being a major cause of death, stroke is also a leading factor to adult disability [43]. In Canada, there is annually estimate of 62,000 strokes generating direct and indirect costs of 3.6 billion [44]. The disabilities resulting from stroke can affect multiple dimensions including strength, communication, cognition, mobility, sensory perception and ultimately activities of daily living (ADLs)[45].

USN in particular is a common problem following stroke, which is associated to poor rehabilitation outcome [13]. USN is defined as the "inability to orient, respond, or report to the stimuli appearing on the contralesional side"[15]. When presented with objects within both visual fields, stroke survivors with USN following a right brain lesion look at the right object first and may deny the presence of the left object [17]. However, when informed of the presence of the left object, they can move their eyes to the left and report seeing that object [46]. Despite selectively attending to

items on their ipsilesional side, post-stroke individuals with USN can have intact visual fields and can initiate eye and limb movements to the contralesional side [46].

Around 25–30% of stroke survivors suffer from USN, which means that 3 to 5 million new stroke survivors worldwide will suffer from USN every year [47]. Compared to right spatial neglect after left hemisphere stroke, left spatial neglect after a right hemisphere stroke is more common, more severe and more persistent [48]. A study showed that 43% of patients with a right cerebrovascular accident (CVA) and 20% of patients with a left CVA presented USN in the acute stage; these proportions decreased to 17% and 5%, respectively, in the subacute stage [49]. Within the acute post-stroke period, only 20% to 45% of USN cases would resolve spontaneously, while the rest would last for a longer time and lead to longer rehabilitation hospital stays [50] and a diminished capacity to perform both basic self-care activities and more complex ADLs [14]. Patients with a right CVA with vs. without USN show lower levels of functional independence, as reflected by lower Functional Independence Measure (FIM) scores, both at admission and discharge from inpatient rehabilitation [51], while experiencing a slower and more attenuated recovery pattern [52].

2.1.2. USN IMPACTS OJECTS DETECTION

When performing activities of daily living, stroke individuals with USN can experience the following neglect behaviors: failure to eat from one side of the tray, to orientate to stimuli on the opposite side of the cerebral lesion, to dress and to wash or groom their contralesional side [53]. Furthermore, when involved in goal-directed walking, stroke individuals with USN demonstrate a lateral deviation of the walking trajectory and may bump into objects or doorposts. Previous studies have reported walking trajectory deviations to the ipsilesional (neglected) side [54], as well as to both the ipsilesional and contralesional sides [55]. This manifestation can be explained by the visual perceptual hierarchy introduced by Warren (1993) [18]. He suggests that visual perception can be conceptualized as a hierarchy of skill levels, where lower level skills are the foundation for each successive level. As a result, the higher-level skills can be affected by a disruption of lower level skills. Based on this model, USN can affect the fundamental level of visual perceptual abilities needed for object detection, ultimately leading to a disruption in more complex tasks such as goal-directed navigation and the completion of ADLs. Therefore, object detection is fundamental and was the key task examined in this study.

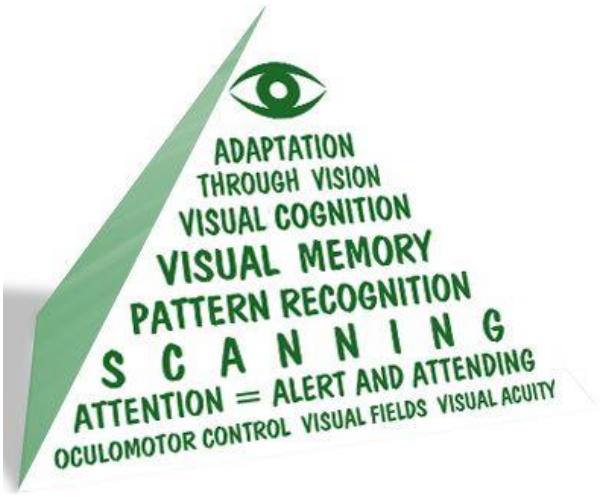

Fig 2-1. Hierarchy of skill levels, as proposed by Warren. Figure taken from Warren (1993) [16].

Individuals with severe USN can be easily identified in the clinical setting, while mild or moderate cases of USN are less observable [56]. Conventionally, paper-and-pencil tests are used to assess the presence of USN for its convenience and easiness to apply and score. However, their lack of sensitivity can lead to misdiagnose (under-reporting) of individuals with mild or moderate USN [57]. With the repetition of paper-and-pencil tests, individuals with USN can use compensation strategies during the assessment, such as rotating their head and gaze towards the contralesional side in order to displace the assessment sheet within the ipsilesional field of view, which can result in a good performance score despite of suffering from USN. Results on conventional paper-and-pencil tests for USN taken alone also fail to predict performance on functional tasks such as goal-directed walking [58-60] and collision avoidance while walking [61].

Ogourtsova and colleagues conducted a study to examine the impact of USN on object detection and goal-directed navigation abilities when exposed to objects of changing location [62]. Right hemisphere stroke individuals with (USN+) and without USN (USN-) as well as healthy controls were instructed to perform the detection and navigation tasks by using a joystick with their non-paretic hand (or right hand for healthy controls) while seated and immersed in a virtual environment representing grocery shelves with food items (e.g. cereal boxes, etc.) equally distributed horizontally across the visual field. This study revealed that compared to healthy controls and USN- participants, USN+ participant showed longer detection times for objects located on the contralesional side and straight ahead. Further, USN participants took longer and showed more trajectory deviations from the ideal path when navigating towards the object of interest, irrespectively of the object location. The authors concluded on the presence of both spatially lateralized (confined to the neglected side) and non-lateralized (present across the whole visual field) deficits in those with USN. The deficits were exacerbated when the environment was made more complex by the addition of irrelevant objects (cluttered environment).

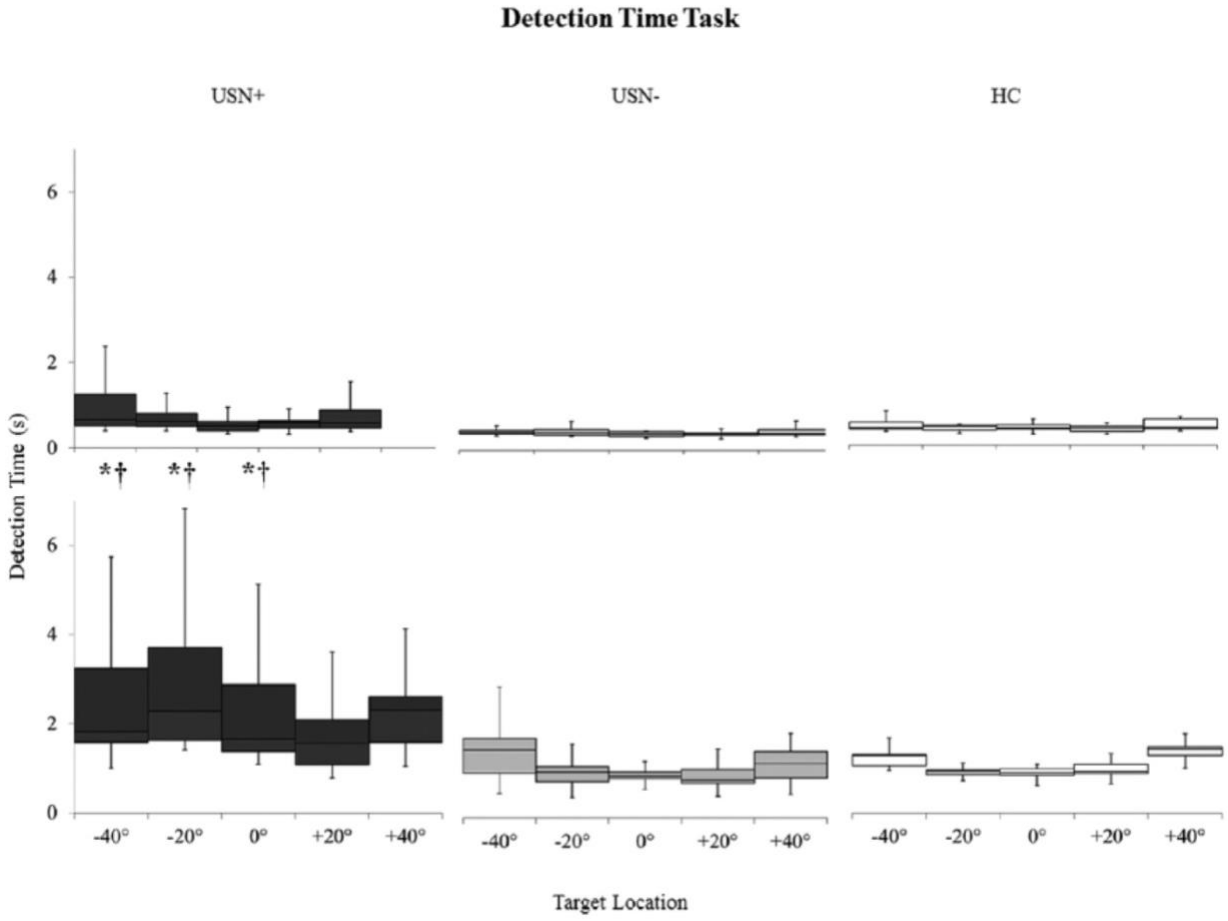

Fig 2-2. Time of detection for objects of changing location across the visual spectrum in individuals with (USN+) and without USN (USN-) and healthy controls for the uncluttered (top graphs) and cluttered environment (bottom graphs). Note the longer detection times in the USN+ group when objects presented in the cluttered environment were located on the contralesional side and in the centre. From Ogourtsova et al, Neurorehabilitation and Neural Repair 2018 [59].

Findings by Ogourtsova [62] also demonstrated the importance of assessing the impact of USN across the entire visual spectrum. In the findings of that study, there also exist a noteworthy variability (shown by large standard deviation values) in the performance of the USN+ group. The authors further reported that the severity of USN, as assessed by clinical paper and pencil tests

(Line bisection, Star cancellation and Apple Tests), was not significantly correlated to the detection time on the object detection task. Other factors like different strategy adoption, age, sex, memory, attention and visuospatial perception [63] could be other explanatory factors for the object detection performance in the USN+ participants. In addition, neuroanatomical and neurofunctional differences [64, 65], resulting from the lesion and subsequent brain plasticity, could also explain this variability to a certain level, yet the exact nature of these changes and how they may be related to the deficits observed in individuals with USN remain unknown.

2.1.3 BRAIN AREAS INVOLVED IN USN

The brain regions involved in USN were first examined in neuroanatomical studies that mapped lesion site and symptoms presented by the individuals (referred to as lesion-symptom mapping). These studies indicate that left-sided USN results from damages to several different cerebral structures in a large-scale neurocognitive network located in the right hemisphere [49] and which includes the inferior parietal lobe [19, 20], lateral frontal (ventral premotor and dorsolateral prefrontal) cortex [19, 21], posterior superior and middle temporal gyri [22], as well as the insular [23, 24] and the cingulate cortices [25]. Besides these cortical regions, neglect can also result from damages to subcortical fibre tracts such as the temporo-parietal paraventricular white matter [26] and the parietal-frontal connection [27].

In summary, from neuroanatomical perspective, the presence of USN can be the result of lesion to a complex network of areas as mentioned above, yet only lesions to the posterior parietal cortex (PPC) was demonstrated to have a causal link with USN [28, 29]. Several studies have successfully induced neglect-like behaviors by applying inhibitory TMS over the right PPC of healthy individuals [29]. PPC also plays a pivotal role in constructing multiple spatial reference frames which are used to guide behaviors [31], as well as in selectively processing information and shaping perceptual experience [32]. Meanwhile, both primates and human studies have found a significant role of extrastriate cortex in visual information processing and distractor filtering [33-35].

Although lesions to key brain regions such as the PPC can explain the presence of USN, the lesion site alone does not explain the variability in performance across USN+ individuals in functional tasks such as detecting objects at different locations [36]. As Dr. Corbetta summarized: brain areas causing behavior deficits do not always reflect the local dysfunction of neurons at the site of injury [34]. In other words, damaged brain area may cause dysfunction in other functional brain network and may impair the function of structurally normal neurons rather than those located at lesion site [35]. Accordingly, function recovery may arise of re-connectivity and re-balance of a structurally normal yet functionally impaired network. Therefore, Dr. Corbetta suggested that the recovery of

a certain function can be achieved by a re-weighting of activity within a distributed neuronal architecture. In order to elucidate whether the lesion site and re-weighting of activity play a role in the performance variability among USN+ individuals, it is important to first understand how the healthy brain processes visual information and supports the successful completion of a visually guided task. Rather than limiting our observation to USN+ participants, it is thus important to first examine the brain activation patterns of healthy controls.

2.1.4 THEORIES OF VISUAL PERCEPTUAL PROCESSING

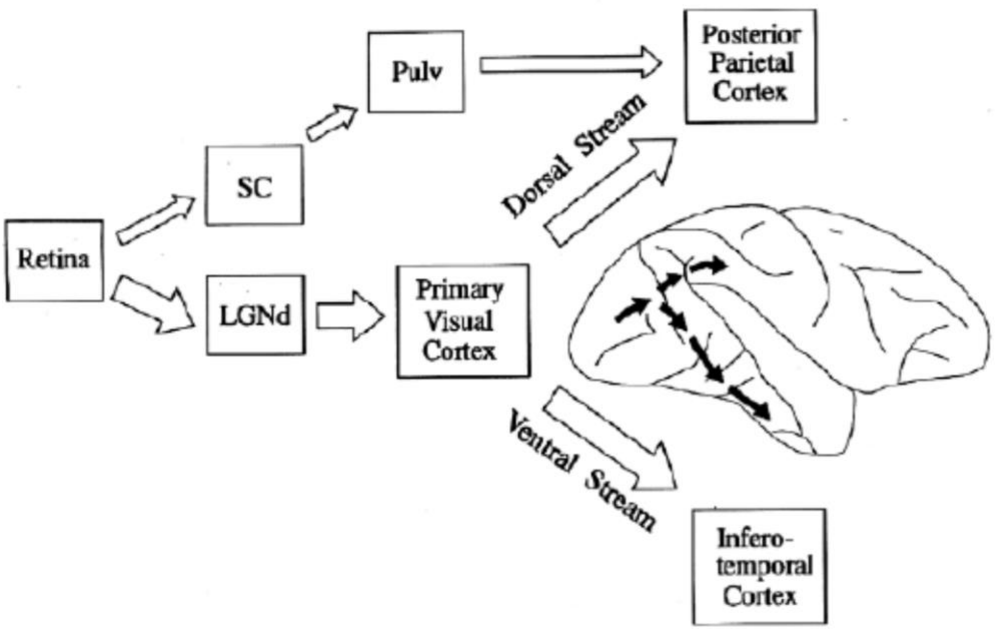

Fig 2-3. Primate's schematic of the pathways of visual information processing in the dorsal and ventral streams. Figure from Goodale, M.A., et al (1994) [66].

As mentioned earlier, visual perceptual ability is fundamental to object detection. To understand the mechanism behind object detection, it is essential to understand how stimuli are processed at visual perceptual level. According to the classical literature, visual processing can be divided in two main streams, i.e. the dorsal and ventral streams [66]. The ventral stream is thought to recognize and identify visual shapes and objects, while the dorsal stream is associated with visually-guided actions such as reaching and grasping based on spatial location, shape and orientation of objects [67]. To simplify, dorsal system is the "where" whereas ventral is the "what" pathway [68]. Both of the ventral and dorsal originates from primary visual cortex (V1); the ventral stream continues along the ventral surface going through the extrastriate cortex [69, 70] and ends in the inferior temporal cortex while the dorsal stream marches along the dorsal surface into the PPC [71].

When the visual information is too abundant or too demanding to be processed simultaneously, the brain will select the most relevant stimuli while filtering out less relevant ones for us to respond. This selection process is referred as attention [72].

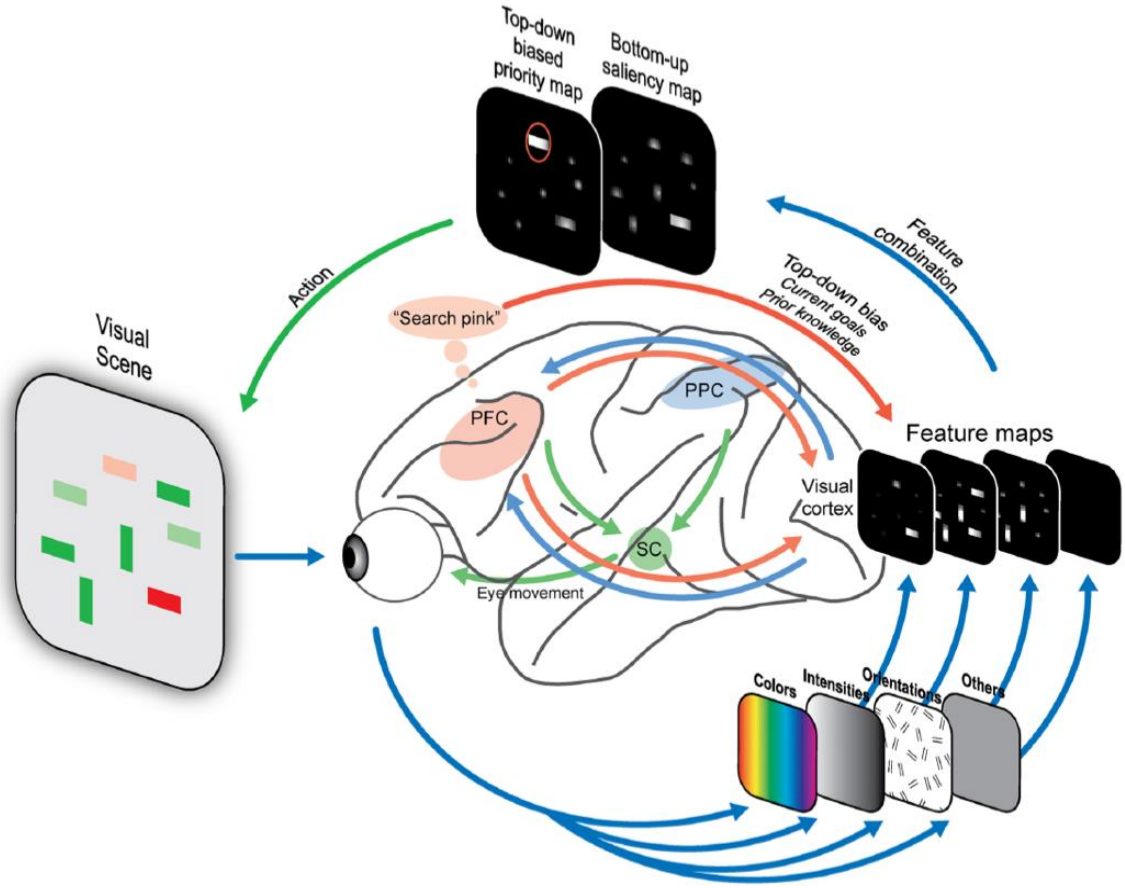

Fig 2-4. Primate's schematics of bottom-up and top-down attentional process. Figure from Fumi Katsuki et al (2013) [72].

Attention is commonly categorized into two types of functions: bottom up and top down. Bottom up involves externally induced processes in which visual information is automatically processed due to its highly salient characteristics while top down involves internally induced processes in which visual information is voluntarily chosen based on known factors [73, 74]. One of the major differences between top down and bottom up attention mechanisms is that for bottom up attention, neurons are activated to a greater extent when salient stimuli appear compared to activation elicited

by background elements. At variance, for top down attention, neural activity is enhanced for the particular location/feature/object of interest compared to behaviorally irrelevant stimuli [72]. For both mechanisms, however, PPC seems to play a crucial role as it is the primary area that represents visual saliency in bottom up attention and PPC areas can provide top down signals [75].

2.1.5 ELECTROENCEPHALOGRAPHY (EEG) & EVENT RELATED POTENTIALS (ERP)

Multiple approaches can be used to study brain activations, such as magnetoencephalography (MEG), positron emission tomography (PET), magnetic resonance imaging (MRI), functional magnetic resonance imaging (fMRI) or near-infrared spectroscopy (NIRS). In this study, EEG was selected over other brain imaging techniques due to three main advantages. The first is that EEG is non-invasive, which allows researchers to detect human brain activity without probing inside the brain and it does not require the injection of radioactive tracers such as PET [38]. The second is that it provides high temporal resolution [37]. EEG records brain electrical activity that happens fast thus high temporal resolution is required to capture the transient activity. The third advantage is that it is a portable device allowing the record of brain activity while the participants are seated as opposed to techniques such as MRI that require participants to stay supine and immobile during data collection. EEG is relatively low cost which is not the case for other similar neuroimaging

techniques such as fMRI, MEG or PET. However, EEG has its disadvantages, a major one being that it provides poor spatial resolution as it is difficult to know where in the brain the electrical activity is generated. EEG, however, does make it possible to tell us where the ERP components are the strongest.

Data collected using EEG can be analyzed by using ERPs, a standard method used in the past couple decades to uncover the neural correlates of sensory, motor or cognitive functions associated with an stimulus presented to an individual [39]. The voltage changes observed during a specific time window constitute the ERP [1]. During EEG recording, an epoch is a specific time window taken out from the continuously recorded EEG signal. When a stimulus is presented to a participant, an epoch that is time-locked to that stimulus can be extracted and as a result, the voltage changes observed within that epoch is response to a given stimulus can be quantified. ERP results are presented in the form of a series of negative and positive going waveforms. Common ways to quantify ERPs are to measure the amplitude and latency of peaks constituting the waveforms. They are computed by choosing a time window surrounding the peak in the waveform and by finding the most positive or negative point in that time window. Amplitude at this point of time represents the magnitude whereas the latency represents the timing of a component. ERP can track visual processing by reflecting visual cues through its components. Based on current ERP studies

involving visual-perceptual tasks, P1, N1, and P3 are considered to be the most informative components of brain activation patterns representative of cognitive functions [10].

P1, N1 are the main features of early stage ERP components. Some argued that they reflect exogenous process that are modulated by physical stimulus attributes like intensity [1] or brightness [2] and are insensitive to cognitive influences, while others believed they are modulated by selective attention, a top-down attention influence present when participants intentionally search for a known target. In more details, P1 is the first positive peak observed at a latency of 80-130ms [76] after stimuli onset while N1 is the first negative peak observed at 140-200ms [8]. From the attentional perspective, P1 reflects a facilitation of early sensory processing that is pre-set prior to stimulus onset [3, 4], while N1 directly correlates with the engagement or orientation of attention to the relevant location [5] and is triggered by the operation of a discrimination process [8]. From a target location perspective, P1 amplitudes are enhanced for all stimuli locations, attended or unattended [5], cued or uncued [6], whereas N1 amplitude is thought to be larger for centrally located target [9], and have stronger activation for both conditions targets located in the middle compared to those located more laterally [10]. Some studies claim that N1 is also a feature associated with selective attention [5], while others further proposed that N1 enlarges as a function of perceptual resources allocation with difficult discrimination tasks taking up the most perceptual resources [7, 11]. The latter theory, however, lacks empirical support since recent findings

demonstrated that both easy and difficult discrimination task can generate same size N1 enlargement [8]. From the neural source perspective, it is suggested that both P1 and N1 components originate from the extrastriate cortex [7], while others argue that only P1 arises from the extrastriate cortex while the origin of N1 remains unknown [77].

Compared to P1 and N1, P3 is observed later in time, that is at around 250-600ms. This component is thought to reflect the processes that bridge perceptual analysis and response initiation, possibly to monitor whether the decision to classify some stimulus is appropriately transformed into an action [12]. Findings from both auditory and visual stimulation studies have further shown that P3 possibly correlates with reaction time, i.e. the higher the P3 amplitude, the shorter the response time [16]. P3 is also thought to reflect the detection task difficulty through overt behavior response, while not being sensitive to target eccentricity [9]. Additionally, the parietal P3 amplitude was found to increase in childhood and to peak in adolescence, then decline for the rest of the lifespan [30], which indicates that the age of the participants might influence P3 modulation. In sum, P1, N1 components seem to represent stimulus encoding stage [6, 40] while P3 component is thought to be elicited when a decision has to be made [41] [9].

	STUDY	INTERPRETATIONS
P1	MGH Coles and MD Rugg [1]; CS Herrmann and RT Knight [2]	P1 reflects exogenous process that are modulated by physical stimulus attributes like intensity or brightness and are insensitive to cognitive influences;
	GR Mangun [3]; RG Eason [4]	P1 reflects a facilitation of early sensory processing that is pre-set prior to stimulus onset;
	SJ Luck [5]； VS Störmer, JJ McDonald, and SA Hillyard [6]	P1 amplitudes are enhanced for all stimuli locations, attended or unattended, cued or uncued;
	TC Handy and GR Mangun [7]	P1 arises from the extrastriate cortex;
N1	SJ Luck [5]	N1 directly correlates with the engagement or orientation of attention to the relevant location;
	EK Vogel and SJ Luck [8]	N1 is triggered by the operation of a discrimination process;
	S Schaffer, A Schubo, and C Meinecke[9]; Antonova [10],	N1 amplitude is thought to be larger for centrally located target, and have stronger activation for targets located in the middle compared to those located more laterally;
	TC Handy and GR Mangun [7]; J Duncan and GW Humphreys [11]	N1 enlarges as a function of perceptual resource allocation with difficult discrimination tasks taking up the most perceptual resources;
	EK Vogel and SJ Luck [8]	Both easy and difficult discrimination tasks can generate same size N1 enlargement.
P3	R Verleger, P Jaśkowski, and E Wascher [12]	P3 reflects the processes that bridge perceptual analysis and response initiation, possibly to monitor whether the decision to classify some stimulus is appropriately transformed into an action;
	Verleger [16]	The higher the P3 amplitude, the shorter the response time;
	S Schaffer, A Schubo, and C Meinecke [9]	Reflects the detection task difficulty through overt behavior response, while not being sensitive to target eccentricity;
	R Van Dinteren [30]	Parietal P3 amplitude was found to increase in childhood and to peak in adolescence, then decline for the rest of the lifespan;

Table 2-1. ERP components interpretations.

In spite of the abundant research done on detection tasks, the modulation of P1, N1, and P3 in an ecological scene-based detection task remained unexplored. Furthermore, USN was shown to be characterized by a gradient where the performance of the participants worsen as the stimulus is presented further from the midline into the lateral neglected space (most often the left side) [78, 79]. In some instances, bilateral deficits were also observed [80]. None of the existing studies, however, have examined patterns of brain activation while exposed to targets across the entire spectrum of the visual field. In addition, in most detection task studies, stimuli were monochrome crosses or sinusoidal gratings which are rarely seen in real life[10, 81] . It is thus unclear whether the results can reveal the complexity and challenges people might meet when performing detection tasks in real life. Further, most of the previous studies examined healthy young adults, thus results may not be extended to an older population, as typically seen in rehabilitation. Last but not the least, previous studies have proposed different theories regarding the modulation of P1, N1 and P3 with conflicting results, which might be a result of the particular experimental set-up or lack of certain experimental conditions. For instance, some of the studies did use stimuli that are located in left and right visual field. However, eye movement were not tracked, such that it cannot be confirmed whether participants' gaze was centered at onset of stimulus presentation. As a result, the angular orientation of the stimulus, which is calculated from the center of the visual field (0), may have been under- or underestimated, depending on whether the gaze was already in the same or opposite direction to the stimulus.

2.1.6 THE APPLICATION OF VR IN OBJECT DETECTION TASKS

As part of this thesis, I conducted an EEG experiment as healthy older adults performed object detection tasks while immersed in an ecological virtual environment representing a grocery shopping aisle visualized through a helmet mounted display (HMD). Recent and rapid development in virtual reality technology have made the study of spatial knowledge, object detection and their neural basis in virtual environment easier [82]. Examining brain correlates of natural behavior in real world is challenging, due to difficulties in controlling the experimental conditions [38]. Virtual reality makes it all possible by providing participants with real world experience while being safer and better controlled [83]. By disabling the real-time head tracking function of the HMD, the individuals' perspective on the scene and perceived location of the stimuli can further remain unchanged, which allow to control for changes in head orientation [80]. With an eye tracker integrated within the HMD, eye movements can be recorded to provide a fixation crosshair at the beginning of each trial, which allow controlling for the visual angle at onset of stimulus presentation. Further, such virtual reality set-up allows to examine patterns of brain activation while exposed to ecological scenes of changing complexity (simple vs. complex) and while exposed to targets located across the entire spectrum of the visual field.

Based on the current literature, studies on ERPs have mainly focussed on the latency and amplitude of P1, N1 and P3 in the PPC and extrastriate cortex. Based on these studies, we expect to find enhanced amplitude of P1, N1 in response to scene complexity due to the addition of non-relevant items in the environment; amplitude of P3 to decrease along with the increase of response time since P3 amplitude is believed to negatively correlated. We also expect to find an enlarged N1 amplitude in response to the effects of target location since N1 is regarded to directly correlates with the engagement or orientation of attention to the relevant location [5]. Neither P1 nor P3 amplitude is expected to modulate according to change of target location, since P1 is believed to and P3 is found not sensitive to target eccentricity [9]. Latency of P1, N1 and P3 are expected to change in response to the change of target location.

This study will allow for a better understanding of the healthy brain mechanisms involved in object detection tasks performed in an ecological environment, and their modulation as a function of important variables such as scene complexity and object location. Ultimately, the results obtained will be used as a basis to better understand the defective brain mechanisms explaining poor object detection performance of individuals with post-stroke USN. Such information is essential to guide the development of optimal interventions for post-stroke USN, such as brain stimulation techniques that modulate the activation of key brain areas involved in object detection.

2.2 OBJECTIVES AND HYPOTHESIS

The purpose of this study was to extend the current knowledge on healthy patterns of brain activation associated with object detection in a virtual reality setting. Healthy adults in the age range at risk for stroke were selected, for the purpose of future comparisons with stroke survivors. The following specific objectives were addressed:

1) To estimate, among healthy older individuals, the extent to which scene complexity impacts the amplitude and latency of ERP components during a virtual reality-based detection task.

2) To estimate the extent to which the amplitude and latency of ERP components are modulated as a function of object locations along the horizontal plane.

Due to the presence of distractors and increased background elements in the complex (cluttered) scene, it was hypothesized that the amplitude and latency of ERP components would be enhanced in the complex (cluttered) vs. simple (uncluttered scene), as reflected by larger amplitude of P1, N1, and P3 and possibly longer latencies for the same components. It was also hypothesized that the amplitude and latency of ERP components would be modulated according to target locations, showing a larger amplitude of N1 and possibly laterally or bilaterally lengthened latency of P1, N1 and P3. P1 and P3 amplitude are not expected to be modulated according to target eccentricity.

PREFACE

The general goal of this thesis was to explore the healthy patterns of brain activation involved in an object detection task, with the long-term goal of identifying alterations present in recovered and non-recovered post-stroke USN. Despite abundant research on healthy patterns of brain activation in various visual discrimination tasks, the application of both EEG and virtual reality technology the impact of scene complexity and target location on patterns of brain activation is a first.

In everyday life, we are surrounded by a vast amount of visual information which makes the detection of objects challenging. Nevertheless, most of existing studies that examined object detection used non ecological stimuli (e.g. monochrome crosses or sinusoidal gratings) rarely seen in real life and which were presented exclusively in a bare environment. In the following manuscript presented in Chapter 3, virtual reality was used to recreate an ecological environment (grocery shopping aisle) along with meaningful objects (grocery items) to assess detection performance and patterns of brain activation as a function of scene complexity and object location.

CHAPTER 3: RESEARCH MANUSCRIPT

Neural correlates of object detection in virtual reality vary according to object location and environment complexity amongst healthy individuals

LI, Youlin[1,2] ; SANGANI, Samir[2] ; DAL MASO, Fabien[2,3] ; BOUDRIAS, Marie-Hélène[1,2] ; LAMONTAGNE, Anouk[1,2]

[1] School of Physical & Occupational Therapy, McGill University, Montreal, QC, Canada

[2] Feil and Oberfeld Research Center, Jewish Rehabilitation Hospital – CISSS Laval, QC, Canada

[3] Department of Kinesiology, Université de Montréal, QC, Canada

Corresponding author:

Li Youlin

CRIR - Feil and Oberfeld Research Center

Jewish Rehabilitation Hospital – CISSS-Laval

3205 Place Alton-Goldbloom, Laval, QC, Canada - H7V 1R2

Tel: (450)-688-9550 ext. 4823

Email: youlin.li@mail.mcgill.ca

Manuscript formatted for Clinical Neurophysiology

3.1. ABSTRACT

Objective: Amongst the unilateral spatial neglect (USN) population, deficits in object detection are modulated by object location and environment complexity, yet the mechanisms remain unclear. In this study, we examined the healthy patterns of brain activation involved in a virtual reality-based object detection task performed in an ecological environment to estimate the extent to which scene complexity and object location impacts on the event-related potential components (ERPs). Methods: Fifteen healthy adults were assessed using a virtual reality set-up as they detected a target object located at five possible locations (0°, ±20°, ±40°) in an uncluttered or a cluttered virtual environment. Response time was recorded, and ERPs components were extracted from electrode sites corresponding to bilateral posterior parietal cortex and extrastriate cortex. Results: Larger amplitude of P1, N1 in PPC and larger P3 amplitude in extrastriate cortex clusters were observed for CE vs UCE. Only N1 and P3 amplitude demonstrated strong modulation to object location: N1 amplitude (in absolute value) peaked at center and decreased with target eccentricity; P3 amplitude enhanced contralaterally to the stimulation side. Latency of P1, N1, and P3 was longer for UCE vs CE, due to longer latencies in the shifted (left or right) vs. centered target location in UCE but not in the CE. Conclusion: The increase in amplitude for P1 and P3 for CE may reflect top-down influences on early sensory information processing, whereas the enhancement of N1 for the same

condition may reflect the role of N1 in the discrimination process, which was needed for the complex but not the simple scene. In the simple scene, the bilateral effects of target location of N1 in the right hemisphere is in line with presumed involvement of N1 in the orientation of attention to the relevant location, while the enhancement of P3 in response to contralateral target shifts may result from a compound of premotor cortex activation. Significance: Present findings provide fundamental knowledge on patterns of brain activation involved in object detection in an ecological environment, serving as a basis for comparison to determine defective patterns of brain activation in the USN population.

Keywords: Assessment, Electroencephalography, Object detection, Event related potentials, Virtual reality, Vision

3.2. INTRODUCTION

Unilateral special neglect (USN) is a common problem following stroke, which is associated to poor rehabilitation outcome [13] and a diminished capacity to perform both basic self-care activities and more complex activities of daily living (ADLs) [14]. USN is defined as the "inability to orient, respond, or report to the stimuli appearing on the contralesional side"[15]. When presented with objects within both visual fields, stroke survivors with USN due to a right brain lesion look at the right object first and may deny the presence of the left object [17]. Despite selectively attending to items on their ipsilateral side, post-stroke individuals with USN can have intact visual fields and can initiate eye and limb movements to the contralesional side [46]. Thus, when informed of the presence of the left object, they can move their eyes to the left and report seeing that object [46]. Based on the visual hierarchy by Warren (1993) [18], USN can affect the fundamental level of visual perceptual abilities needed for object detection, ultimately leading to a disruption in more complex tasks such as goal-directed navigation and the completion of ADLs. Therefore, object detection is fundamental and was the key task examined in this study.

From a neuroanatomical perspective, the presence of USN can be the result of lesion to several brain areas such as the inferior parietal lobe as well as lateral frontal, posterior superior and middle temporal gyri [19-27]. However, among a complex and extensive neural network, lesions to the

posterior parietal cortex (PPC) specifically were demonstrated to be directly involved in USN [28, 29]. Several studies have successfully induced neglect-like behaviors by applying inhibitory TMS over the right PPC of healthy individuals [29]. PPC further plays a pivotal role in constructing multiple spatial reference frames which are used to guide behaviors [31], as well as in selectively processing information and shaping perceptual experience [32]. Both primates and human studies have found a significant role of extrastriate cortex in visual information processing and filtering of distractors during in performing object detection[33-35].

Although lesions to key brain regions such as the PPC can explain the presence of USN, the lesion site alone may not explain the variability in performance across USN+ individuals in functional tasks such as detecting objects at different locations [36]. As Maurizio Corbetta summarized: brain areas causing behavior deficits do not always reflect the local dysfunction of neurons at the site of injury [84]. Accordingly, function recovery may arise of re-connectivity and re-balance of structurally normal yet functional impaired network. In this manuscript, we propose to apply electroencephalography (EEG) on healthy elder individuals to examine healthy patterns of brain activation involved in an object detection task, with the long-term goal of identifying alterations present in recovered and non-recovered post-stroke USN in age-matched individuals.

Data collected was analyzed by event-related-potentials (ERPs), which, especially in the past two decades, have been used to uncover the neural process of sensory, motor and cognitive functions [39].

Based on existing ERP studies, visual P1, N1, and P3 are considered to be the most informative components [10]. P1 and N1 are early stage ERP components which are suggested to reflect exogenous process that are modulated by physical stimulus attributes like intensity [1] or brightness [2] and are immune to cognitive influence. Others have rather suggested that they are also modulated by selective attention, a top-down attention influence established when participants intentionally search for a known target [72]. Although both P1 and N1 are both believed to reflect sensory processing information [10], there are differences between them. P1 is the first positive going peak observed at 80-130ms [76] after stimuli onset while N1 is the first negative going peak observed 140-200ms [8]. From an attentional perspective, P1 reflects a facilitation of early sensory processing that is established prior to stimulus onset [3, 4], while N1 directly correlates with the engagement or orientation of attention to the relevant location [5] and is triggered by the discrimination process [8]. From the target location perspective, P1 amplitude is enhanced for all stimuli, attended or unattended [5], cued or uncued [6]. N1 amplitude was found to be larger for foveal vs peripheral stimuli, and stronger for centrally located stimuli vs. stimuli presented in the periphery [9, 10]. Some studies further claim that N1 is also associated with a process of selective

attention [5], such that N1 amplitude would enlarge with difficult discrimination tasks taking up the most perceptual resources [7, 11]. From the neural source perspective, it was suggested that P1 and N1 both originate from the extrastriate cortex [7], even though the origination of N1 remains debated [77].

Compared to P1 and N1, P3 is observed later in time at around 250-600ms and is thought to reflect the process that bridges perceptual analysis and response initiation, and which monitors whether the decision is appropriately transformed into action [12]. Findings from both auditory and visual stimulation studies have further shown that P3 possibly correlates with reaction time, such that higher P3 amplitudes would correspond to shorter response times [16]. P3 amplitude may reflect the detection task difficulty through overt behavior response, but is not sensitive to target eccentricity [9]. Additionally, the parietal P3 amplitude was discovered to increase in childhood, peak in adolescence, then decline for the rest of the lifespan [30], which indicates age of the participants might influence P3 modulation.

Summing up the previous studies, P1 and N1 components can represent stimulus encoding stage [6, 40] and P3 component is elicited when a fast stimulus related decision has to be made [41].

In spite of the abundant research done on visual detection tasks, the modulation of P1, N1, and P3 in an ecological scene-based detection task remained unexplored. Furthermore, as object detection performance is modulated as a function of the location of the target object [36], its warrants an

investigation of the modulation of brain activation as a function of object location across the entire visual spectrum. In the vast majority studies involving visual detection tasks, non-ecological stimuli (e.g. monochrome crosses, sinusoidal gratings) in environments devoid of distractors were used, such that it is unclear whether results can be transferred to the performance of object detection tasks with meaningful objects in more complex environments, as experienced in everyday life.

In the present study, we used EEG to record brain activation of healthy older adults performing an object detection task while immersed in an ecological virtual environment representing a grocery shopping aisle visualized through a helmet mounted display (HMD). The immersive virtual reality set-up allowed to assess participants in an ecological environment under safe and controlled conditions [83].

Specific objectives were: (1) to estimate, among healthy older individuals, the extent to which scene complexity impacts the amplitude and latency of ERP components during a virtual reality-based detection task and; (2) to estimate the extent to which the amplitude and latency of ERP components are modulated in response to participants detecting target object of different locations along the horizontal plane.

Based on previous studies, the analyses of ERP results in this manuscript focussed on the latency and amplitude of P1, N1 and P3 in the PPC and extrastriate cortex. Due to the presence of

distractors and increased background elements in the complex (cluttered) scene, it was hypothesized that the amplitude and latency of ERP components would be enhanced in the complex (cluttered) vs. simple (uncluttered scene), as reflected by larger amplitude of P1, N1, and P3 and possibly longer latencies for the same components. It was also hypothesized that the amplitude and latency of ERP components would be modulated according to target locations, showing a larger amplitude of N1 and possibly laterally or bilaterally lengthened latency of P1, N1 and P3.

3.3. METHODS

This study involved a cross-sectional design where participants were assessed over the course of a single session. Data collection took place in the Brain Lab which is located at the Feil and Oberfeld Research Centre of the Jewish Rehabilitation Hospital, a research site of Centre de recherche interdisciplinaire en réadaptation du Montréal métropolitain (CRIR).

3.3.1. Participants

Fifteen Healthy individuals who are at higher risk of suffering from a stroke (range of age 45-75 [85]) were invited to participate in this experiment with the purpose of later using the data gathered as a basis for comparison with stroke survivors.

The inclusion criteria are as follows: right-handedness individuals (Score > 80 on the Edinburgh Handedness Inventory [86]) who are free of neurological disease and have normal or corrected to normal visual acuity (Score ≥ 20/25 on the Early Treatment Diabetic Retinopathy Study Chart [87]).

Individuals were excluded based on the following criteria: presence of moderate cognitive impairment (Score ≤ 22/30 on the Montreal Cognitive Assessment [88]); presence of USN (as per one or more of the following tests: Line Bisection Test [89], Star Cancellation Test [90],

and/or Apples Test [91] on testing, or history of USN as per medical chart); and presence of a visual field defect (as per medical chart, Goldmann perimetry, or computerized equivalent).

The experiment was approved by the Research Ethics Board of Centre de Recherche Interdisciplinaire en Réadaptation du Montreal Métropolitain. All participants gave written informed consent prior to the experiment.

3.3.2. Visual Stimuli

Participants participated in object detection tasks, which were performed under a virtual reality setting consisting of two virtual environments (cluttered vs. uncluttered) created in the Unity® game engine (Unity Technologies San Francisco, US). The virtual environments were displayed through a head mounted display with an integrated infrared eye tracker (FOVE®, FOVE Inc CA, US). Binocular eye movements were recorded at 120 Hz. The head position tracking system of the FOVE was disabled so that the virtual environment remained centered and unchanged, regardless of the participant's head orientation.

The virtual environments comprised of a symmetrical room that included three storey grocery shelves perceived by the participants as being straight ahead and three meters away (see Fig. 3-1). The target object was a blue 'Pop Start' box that appeared on the middle shelf at one of five possible locations (-40°, -20°, 0°, 20°, 40°) in a random order, with 0° being the center of the

middle shelf. Two types of detection tasks were tested, including: (1) an object detection task in an uncluttered environment (UCE, Fig. 3-1, left panel) and (2) an object detection task in a cluttered environment (CE, Fig. 3-1, right panel). In the UCE, the target object appeared in isolation at one of the five possible target locations, while in the CE the target object appeared at the same five possible locations but along with four other grocery items in the remaining positions. For each environment, the target object was randomly presented 50 times for each location. Additionally, 50 catch trials with no target stimulus were presented to prevent the participants from providing random responses on the detection task. Catch trials were free of the target object in the UCE and contained five irrelevant objects in the CE. This represented 300 trials for each environment for a total of 600 add total time of experiment. A joystick (Attack3®, Logitech, USA) was positioned on the right side of participants and at elbow height, so they would click the joystick button to provide their responses to the object with their right hand. Trials with the target object ended right after the participants responded by a joystick button click and catch trial ended within two seconds while no response was required. A fixation crosshair located in the center of the environment remained present at all times allowing participants to bring back their gaze in center of the display at the beginning of each trial. Further, the stimulus appeared only if the participants stared at the crosshair for a duration of 0.5s. The interstimulus interval range from 1250-2250 ms (See Fig. 3-2).

3.3.3. EEG preparation

EEG activity was recorded using a 64-channel ActiCap cap (Brain Vision, Munich, Germany), the size of which was chosen based on participants' head circumference, with electrodes arranged based on the 10–20 international system. Conductive gel was injected into each electrode cup to keep impedances below 20 kOhms. Surface EEG signals were referenced to the FCz electrode and sampled at a rate of 1024 Hz. To acquire better EEG signals, participants were asked not to wash their hair or consume energy drinks from the night before the experiment.

3.3.4. Data recording procedure

Participants were assessed while seated in a comfortable chair. Once the EEG set-up was completed, the FOVE was positioned on the top of the EEG cap and then calibration of the eye tracker took place. This calibration process started with the appearance of a green dot in the center of a grey background. Participants were then required to visually follow the green dot as it moved to the top, right, down and left respectively. The calibration procedure was repeated for the detection tasks in the UCE and CE.

Participants first familiarized themselves with the detection tasks through habituation trials, until they felt comfortable with the task. They were instructed to bring back their gaze to the center crosshair before stimulus presentation in each trial as well as to provide their response by clicking the joystick button with the index finger of their dominant (right) hand as soon as they perceive the target object. Eye movements and button clicks were recorded in Unity game engine at a 120Hz. In addition, triggers were sent from Unity to EEG system twice within each trial, that is at stimuli onset (target object appearance) and when a response was given (button click). Participants were also instructed to refrain from clicking the joystick button when no target object was present (catch trials). Once all trials were completed in a given environment, a "Test Completed" sign was presented on the screen and participants were allowed to rest for a few minutes.

3.4. DATA ANALYSIS

EEG data was preprocessed and analysed using the Brainstorm Matlab toolbox [92]. EEG signals were resampled to 500Hz and bandpass filtered between 0.5 Hz and 70 Hz, followed by a 60 Hz notch filter. EEG electrodes with atypical power spectrum density were removed. Continuous data were visually inspected and portions of signals with muscle or electrical transient artifacts were rejected. Independent component analysis [93] was run on each dataset (62 components extracted)

and the component associated with eye-blink movement and heart beats were rejected. Criteria for rejection included components' topography and time-history [94]. EEG signals were then average referenced for eliminating the model error in each channel, including the reference channel. In the end, bad electrodes were interpolated by using spherical splines. The resulting dataset was epoched from 500 ms before to 1000 ms after stimuli onset. Each trial was normalized by a time window that spanned from 60 ms pre-stimuli and 20 post-stimuli as baseline. Additionally, epochs were visually inspected again to exclude those that might have been contaminated by muscular contractions or excessive oscillation.

For ERP analysis, EEG signals from all electrodes were analyzed using Brainstorm Matlab toolbox to investigate the cortical activation triggered by the visual stimuli. ERPs were chosen to provide high time resolution measures of neural activity patterns associated with perceptual and cognitive process [95] in our region of interest, which were the (PPC and extrastriate cortex. Evidence have shown both PPC and extrastriate cortex are critical in visual stimuli processing. More specifically, it is thought that PPC would play a vital role in transforming the visual stimuli to action and in the attribution of the awareness to the contralateral visual field [96]. At the same time, as a part of the ventral stream, the extrastriate cortex would help encode visual stimulus features and objects [97].

In addition, several studies have shown that both PPC and extrastriate cortex contribute to the amplitude and latency of ERP components' oscillation [10].

In this study, P1, N1 and P3 components were selected to characterize the pattern of the effects of target location and scene complexity as these components are specifically involved in visual stimuli processing [10]. Based on the assumption that EEG signals were generated by the cortex just beneath the electrodes, four electrodes clusters PC1 (P1, P3, PO3), PC2 (P2, P4, PO4), PC3 (P5, P7, PO7), PC4 (P6, P8, PO8) were selected to analyze our regions of interest (see Fig. 3-3.).

Cluster PC2 corresponds to Brodmann area 7, 39, 19 which is part of PPC [98] and PC4 corresponds to Brodmann area 18, 19, which is part of extrastriate cortex [99]. PC1 and PC3 were electrodes located on same position in the left hemisphere, with PC1 corresponding to the position of PC2 and PC3 corresponding to PC4.

As shown in Fig. 3-4, P1 was defined as the first positive-going peak occurring within a window of 50 to 150 ms [100]. N1 component was observed as the second peak or first negative-going peak occurring approximately between 150ms to 300 ms [101]. P3 was defined as the third peak or second positive going peak occurring approximately between 300ms to 600ms [102]. Peak latency was defined as the time of maximum positivity or negativity occurring between the

selected time window from stimulus onset, whereas peak amplitude was defined as the value of the corresponding peak.

3.5. STATISTICAL ANALYSIS

Two-factor generalized estimated equations (GEE) were used to analyze the effects of virtual environment complexity (CE vs. UCE) and target location (-40°, -20°, 0°, 20°, 40°) on behavioural and EEG outcomes, that is response time as well as peak amplitude and peak latency of P1, N1 and P3 for each cluster separately. When significant, GEEs were followed by Bonferroni post-hoc tests. In addition, Pearson's correlation coefficients were computed between behavioural (response time) and EEG outcomes (peak amplitude and latency). All statistical analyses were performed using SPSS. The level of significance was set at $p < 0.05$.

3.6. RESULTS

Response time

The GEE analysis revealed significant effects of scene complexity ($p<0.0001$), target location ($p<0.0001$) and an interaction of scene complexity X target location ($p<0.0001$) for response time (Figure 3-5). Post-hoc analyses showed that response time was significantly larger for the CE vs UCE, regardless of target location ($p<0.0001$). Furthermore, target location significantly modified response time both for CE and UCE, with symmetrically longer response times being observed at more eccentric target locations, that is at $\pm 40^{o}$ vs. $\pm 20^{o}$ vs. 0^{o} ($p<0.01 – p<0.0001$). The interaction effect was caused by a single difference from what is mentioned above, which consisted of similar response time for the 0^{o} vs. $+20^{o}$ for the UCE only ($p=0.07$).

P1 component

For P1 amplitude (Figure 3-6), there were no significant effects of scene complexity, target location or interaction effects of scene complexity X target location, except for RPPC which showed a main effect of scene complexity ($p<0.0001$). Post-hoc analyses for RPPC showed that P1 amplitude was larger for CE vs. UCE for all target locations ($\pm 20^{o}$ and $\pm 40^{o}$) ($p=0.015$-0.018) except the centre one (0°).

In terms of P1 latency (Figure 3-7), significant main effects of scene complexity ($p \leq 0.0001$), target location ($p=0.000$-0.012) and an interaction effect of scene complexity X target location ($p<0.0001$) were observed. In all clusters (LPPC, RPPC, LESC & RESC), shorter latencies were observed for CE vs UCE when the target was located at ± 40º and sometimes at ± 20º ($p=0.000$-0.024), but not when the target remained centered (0º). An effect of target location on P1 latency was also present in all clusters for UCE, whereby significantly longer latencies ($p=0.000$-0.063) were generally observed for left located targets (-20º and - 40º) in left clusters (LPPC, LESC) and for right located targets (+20º and +40º) in right clusters (RPPC, RESC), compared to the centered target.

N1 component

For N1 amplitude (absolute value), there were significant effects of scene complexity ($p=0.000$-0.043), target location ($p<0.0001$) and interaction effects of scene complexity X target location for all clusters ($p=0.000$-0.014), except for LESC which showed no main or interaction effects (Figure 3-8). Post-hoc analyses indicated that in cluster LPPC, RPPC and RESC, larger N1 amplitude were noted for CE vs UCE for target located at ± 40º and sometimes at ± 20º ($p=0.000$-0.051), but not when target remained centered (0º). The effect of target location on N1 amplitude was observed in both CE and UCE. For UCE the amplitude for the center target was the largest compared to ± 40º and ± 20º ($p=0.00$-0.026); whereas in CE, significant larger N1 amplitude was noticed for right

located targets (+40º and +20º) compared to left located targets (-20º and - 40º) and center target in right clusters (RPPC, RESC)(p=0.004-0.012). In the left hemisphere (cluster LPPC and LESC), the effect of target location was not significant.

N1 latency (Figure 3-9) showed significant main effects of scene complexity (p<0.0001), target location (p=0.000-0.011) and an interaction of scene complexity X target location (p<0.0001) for all clusters (LPPC, RPPC, LESC & RESC). Post-hoc analysis for all clusters showed that N1 latency was longer for UCE vs CE when target was shifted at -40º and sometimes at ± 20º and + 40º (p=0.000-0.005) but not when the target remained centered (0º). An effect of target location on N1 latency was present in all clusters for UCE only, with significantly longer latencies observed for left located targets (-20º and - 40º) in left clusters (LPPC, LESC) (p=0.001-0.012) and for right located targets (+20º and +40º) in right clusters (RPPC, RESC) (p=0.000-0.018), compared to the centered and contralateral target.

P3 component

P3 amplitude (Figure 3-10) showed significant differences due to scene complexity (p=0.000-0.002), target location (p=0.000-0.001) and scene complexity X target location (p<0.0001), except for LPPC and RPPC which remained unchanged with scene complexity, and LPPC which remained unaffected by target location. Post-hoc analysis showed larger P3 amplitude for RPPC,

LESC and RESC for CE vs UCE when target located at +40º and sometimes at -40º, ± 20º (p=0.000-0.038), but not when the target remained centred (0º).

The effect of target location on P3 amplitude was observed in both the CE and UCE for LESC. In CE, P3 amplitude for LESC was significant smaller when the target was centred vs at ± 20º or ± 40º (p=0.000-0.019), At variance, P3 amplitude for LESC in UCE was significantly larger for target presented at +20º compared to ± 40º, center and -20º (p=0.000-0.025). In UCE, P3 amplitude for right clusters (RPPC&RESC) was generally larger for left (-20º and - 40º) vs. right located targets (-20º and - 40º) (p=0.000-0.02).

For P3 latency (Figure 3-11), there were significant effects of target location ($p<0.0001$) and interaction of effects of scene complexity X target location ($p<0.0001$) for all clusters. Additionally, LESC only showed a main effects of scene complexity. P3 latency had the trend to be longer for CE vs. UCE when the target was centrally located for all clusters and was significantly longer for LPPC and RPPC (p=0.001-0.006). Furthermore, P3 latency for right clusters showed longer latency for UCE vs CE for right located targets (i.e. +40º ;p=0.000-0.041), while P3 latency for left clusters (LPPC & LESC) tended to be longer for UCE vs CE for left located targets (-20º and - 40º) , which was particular true for LESC (($p<0.0001$). The effects of target location on P3 latency was observed only in UCE, whereby all clusters displayed longer P3 latencies left located targets

(-20º and - 40º) in left clusters (LPPC, LESC) ($p<0.0001$) and for right located targets (+20º and +40º) in right clusters (RPPC, RESC), compared to the centered target ($p=0.000$-0.011). Summary of results are presented in table 3-1.

Correlational analyses

As shown in Table 3-2, amplitude of P1 for RPPC and LPPC clusters and right extrastriate cortex was found to be negatively correlated with response time for both UCE and CE, such that a larger P1 amplitude as associated with shorter response time ($r= -0.275$ to -0.537; $p<0.001$ - $p<0.027$). In addition, P3 latency for all clusters in the CE only was positively correlated with response time, implying that longer P3 latency was associated with a longer response time ($r = 0.258$ to 0.407; $P<0.01$ - $P<0.38$)**.** P3 amplitude was not found to be correlated with response time in either environment. The amplitude and latency of N1 was not found to be correlated with response time either both in the CE and UCE.

3.7. DISCUSSION

This study examined, for the first time, the extent to which brain activation patterns are associated with an object detection task performed in an immersive virtual environment and how they are modulated as a function of scene complexity and target eccentricity. Relationships between EEG outcomes and performance on the object detection task were also examined. EEG signals were collected from electrode sites distributed over the posterior parietal cortex and extrastriate cortex and were further grouped into four clusters including the LPPC, RPPC, LESC and RESC for ERP analysis. Key findings from the EEG analyses include the presence ERP components that varied in amplitude and/or latency as a function of target location and scene complexity, whether they were lateralized or not. The following sections discuss the potential mechanisms and implications of these findings, as well as future lines of investigation in the area of post-stroke USN.

3.7.1 Behavioral findings

In the current study, response time was observed to be shortest for the centered target object, increasing bilaterally with target eccentricity, which is consistent with previous findings using a similar task in our laboratory [62]. Such finding could be explained by an enhanced sensitivity to

foveal stimuli compared to peripheral stimuli [103]. In agreement with the observations of Ogourstsova and colleagues [62], our participants also took longer to detect the targeted object in the CE vs. UCE. We propose that the addition of non-relevant items in the environment, as experienced in daily life when one search for a specific shopping item in a store, have acted as distractors and have hence increased perceptual-attentional demands. It can further be hypothesized that the object detection task in the UCE vs. CE involves different visual orientation mechanisms. The UCE detection task, where only the target object is present, likely relies on exogenous visual orientating mechanisms, such that participants suddenly shift their gaze and attend to a new object appearing in the visual field. At variance, the task performed in the CE likely involves endogenous orienting whereby voluntary shift attention occurs in the absence of a salient stimulus [104]. One essential difference between these two is in the time course of their development. Endogenous orienting develops gradually whereas exogenous orienting is rapid [105], which could explain the shorter response time in the UCE vs CE.

3.7.2 Modulation of brain activation as a function of scene complexity

Our results show that scene complexity has significant effects over the amplitude of P1, N1 in PPC clusters and P3 in extrastriate cortex clusters. Previous studies have shown that P1 and N1 are

associated with sensory processing of incoming information [1] and that these two components are generally enhanced together. [95] It was suggested that P1 reflects the facilitation of early sensory processing taking place prior to stimulus onset [3, 4] and that it would be strongly modulated by selective attention [106]. Others have instead proposed that P1 is exclusively modulated by the physical properties of the stimulus and that it is not subjected to top-down influence [107]. In line with the first statement, we found enlarged P1 amplitudes in the PPC in the more complex environment, which were modulated by selective attention. Based on the top-down theory, attention can be voluntarily directed to objects or regions of interest when the target needs to be identified through an intentional examination of elements in the absence of substantial differences between the target and background stimuli [108]. In our experiment, the only differences observed between the CE and UCE was the presence of background elements and four other distracting grocery items which were added to the CE. The target objects and four distractors were similar in terms of color, size, and shape making none of the five items salient enough to trigger by themselves bottom-up attention influences. In order to find the target object, the participants had to distinguish the target object from the distractors. Importantly, prior to the appearance of the target, the participants already had knowledge of the target object to be identified, thus a top-down influence had already been established. Given these observations and the fact that P1 amplitude was not modulated in the UCE condition, it is likely that the enlarged P1 amplitude

observed in the PPC area in the CE is the result of the top-down influences, such that P1 amplitude was modulated by selective attention.

While the enlarged P1 amplitude may reflect top-down influences on early sensory information processing, the larger N1 amplitude present in the PPC and right extrastriate cortex clusters for CE vs. UCE might be the result of the discrimination process. Regarding the enlarged N1 amplitude for CE vs. UCE, one could argue, based on the fact that response times were much faster for UCE vs. CE, that effects of motor preparation potentials began in the range of N1latency, so that N1 amplitude for UCE might have been affected by motor preparation, thus accounting for comparatively larger N1 amplitude in the CE. In the present case, however, N1 amplitude was unlikely to be contaminated by premotor activity since N1 was generated from posterior brain areas which was shown to be relatively unaffected by such activity [8]. It could also be hypothesized that N1 amplitude enlargement in the CE vs. UCE reflects a general increase in perceptual load in the former vs. the latter environment [11], as opposed to a change due to specific requirements of the tasks [7]. Such hypothesis, however, would predict that both P1 and N1 enlargements are observable in the extrastriate cortex [7]. Our results, however, show that N1 modulation was present in PPC clusters, in addition to the right extrastriate cortex. The perceptual load theory thus fails to provide an explanation for the modulatory effects of scene complexity on N1 in PPC areas. In fact, the perceptual load theory predicts that N1 amplitude would enlarge with

an increase in task difficulty as a result of an increased load on perceptual resources [7, 11]. Vogel and collaborators, however, found that easy and difficult discrimination tasks engendered a same size N1 effect [8], such that the N1 enlargement in CE vs UCE in the present study may reflect a discrimination process.

P3 amplitude was also found to be enlarged for CE vs UCE in the extrastriate cortex, which could result from top-down attention influences since P3 was shown to be further facilitated for target vs. non-target objects for top-down attended features [109]. As for the absence of enhanced P3 amplitude modulation in PPC clusters for CE vs UCE, it could be due to the fact that i) the extrastriate cortex is the primary site for P3 modulation and/or ii) the discrimination process and response initiation produced canceling effects in PPC areas. P3 is also believed to reflect the process that bridges perceptual analysis and response initiation [12], which is demonstrated by the association existing between P3 amplitude and response time. Some studies have found that higher P3 amplitudes are associated with a faster response times [110]. No correlations between P3 amplitude and response time, however, were found in the present study. Instead, a positive correlation between P3 latency and response time in CE was present, which indicates that longer P3 latency is associated with longer response time when exposed to a complex environment. Response time is likely to be the sum of the duration necessary to complete the whole process of object detection, from stimulus encoding to response execution. However, with response time

alone, it is difficult to estimate separately the time taken in each stage of this process. P3 latency has been suggested to mark the time when the decision was made [111]. The positive correlation between P3 latency and response time in this study could be due to the fact that several processes are embedded within response time, such as stimulus encoding and evaluation, decision process and reaction time, but that would need to be verified as part of a future study.

Regarding the latency change as a result of scene complexity, our study revealed a shorter latency of P1, N1 and P3 for CE vs UCE when targets appeared at the left or right side of the visual field. This effect, however, was not caused by scene complexity but rather by the change of target location in UCE, which will be further explained in the section below.

3.7.3 Modulation of brain activation as a function of object location

For the UCE only, we found N1 but not P1 amplitude to vary as a function of object location, with N1 amplitude peaking for the centrally located object and decreasing bilaterally along with target eccentricity. As discussed earlier, P1 amplitude may reflect bottom-up influence, whereby attention shifts involuntarily to the salient visual stimuli [73, 74]. The fact that the level of visual saliency of the target object was identical regardless of its location explains the identical P1 amplitude across the different locations. N1, however, was shown to be associated with the

engagement or orienting of attention to the relevant location [5, 8]. Therefore, when participants performed object detection in the UCE, N1 amplitude was found to be modulated as a function of target location. As for P3 amplitude, it was observed to be increased for targets located contralaterally to the brain hemisphere. While such finding is not in agreement with the assumption that P3 is not sensitive to target eccentricity [9], they do confirm results from another study which reported an enlarged P3 amplitude on the contralateral side on a 4-choice reaction time task. [10]. In the present study, we also found P1, N1 and P3 latency to be lengthened ipsilaterally to the brain hemisphere. Such findings are consistent with the fact that each hemisphere is responsible for processing the visual information in the opposite visual field. When the target object appears, the activation occurs first in the contralateral brain hemisphere before shifting to the ipsilateral hemisphere. In summary, scene complexity seems to elicit a strong modulation on P1, N1, and P3 amplitude whereas target location engendered significant effects on N1, P3 amplitude and P1, N1, P3 latency.

3.7.4 Limitations and future directions

The identification of healthy patterns of brain activation in the present study represents a first step towards determining the defective brain mechanisms involved in poor object detection

performance in patient populations with visual-perceptual disorders, such as those with post-stroke USN. Compared to traditional detection tasks, the task used in this study (i) provided commonly seen objects in real life as opposed to monochrome crosses or sinusoidal gratings; (ii) tested performance across the entire spectrum of visual field and (iii) allowed controlling the visual angle at onset of stimulus presentation, with the combined use of a crosshair and an eye tracking system. The detection tasks, derived from a standardized assessment called 'EVENS', were already shown to be valid and sensitive tools to identify the presence and severity of USN related deficits in object detection [36]. However, the extent to which exogenous elements, and more precisely features of stimulus presentation such as their color, shape [103], texture, luminance [2] and background of the ecological scene, have influenced the brain activation patterns is unsure. Despite differences in endogenous elements compared to other studies, and as discussed earlier, our EEG findings do however align with many existing literatures that used more traditional detection tasks.

Furthermore, significant effects of target location were observed in UCE but not CE. In CE, in addition to the added background elements to the visual field and the locations of distractors, the different color combination of each distractor may also have impacts on the results of target location in CE. If such effects of color generate canceling effects with target location, then it may explain the reason why insignificant effects of target location was observed for CE.

It is also acknowledged that only individuals who are at higher risk of suffering from a stroke (range of age 45-75 [85]) were recruited to this experiment, limiting the generalizability of results to the healthy older population. However, most of the traditional detection tasks recruited healthy young population as their subjects, which might explain to certain level the differences of results among our study and other detection task studies.

P3 is believed to link perceptual analysis and response initiation [12], we further suggest adding, in the future, an experimental condition that avoid overt responses, such that the effects of observation can be dissociated from that of response initiation. Such an additional task could help elucidate, for instance, whether the absence of P3 modulation in the PPC as a function of scene complexity is due to a compound effect of perceptual analysis and response initiation. An additional limitation of this study includes the absence of source localization techniques [112, 113].

3.8. CONCLUSION

Our study used ERPs to characterize healthy patterns of brain activation while performing a virtual reality- based object detection task. We found that brain activation was modulated as a function of scene complexity and object location. The increase in amplitude for P1 in the RPPC and P3 for RPPC and bilateral extrastriate cortex with the more complex (cluttered) environment may reflect top-down influences on early sensory information processing, whereas the enhancement of N1 for LPPC, RPPC and RESC for the same condition may reflect the role of N1 in the discrimination process itself, which was needed for the complex but not the simple scene. An effect of target location was observed in the simple scene, with N1 amplitude (in absolute value) peaking at center location and decreasing with target eccentricity in the right hemisphere and P3 amplitude demonstrating an enhancement to hemisphere for all clusters. The former finding is in line with the theory that N1 is involved in orientation of attention to the relevant location while the latter finding could result from a compound of the activation of premotor cortex. Present findings provide fundamental knowledge on patterns of brain activation involved in an object detection task performed in an ecological environment. While serving as a basis for comparison to determine defective patterns of brain activation explaining poor object detection performance in populations

such as post-stroke USN, present findings will further guide the development of intervention involving brain stimulation techniques to promote object detection performance.

ACKNOWLEGEMENTS

The authors would like to express their sincere gratitude to the participants of this study. Y.L. was the recipient of Master Fellowship from Centre for Interdisciplinary Research on Greater Montreal (CRIR), Graduate Excellence award from the School of Physical & Occupational Therapy, and from Quebec Bio-Imaging Network (QBIN). A.L. was also the recipient of a Senior Research Scientist Award from the Fonds de la recherche du Québec – Santé (FRQS). This project was supported by A.L.'s NSERC funds (RGPIN-2016-04471).

CONFLICT OF INTEREST STATEMENT

All authors declare that they have no conflicts of interest.

Fig 3-1. Representations of the uncluttered (left panel) and cluttered environment (right panel). The ‘Pop Start’ box, that is the object of interest to be detected, appeared at different angular positions either in isolation (uncluttered environment) or amongst other objects (cluttered environment).

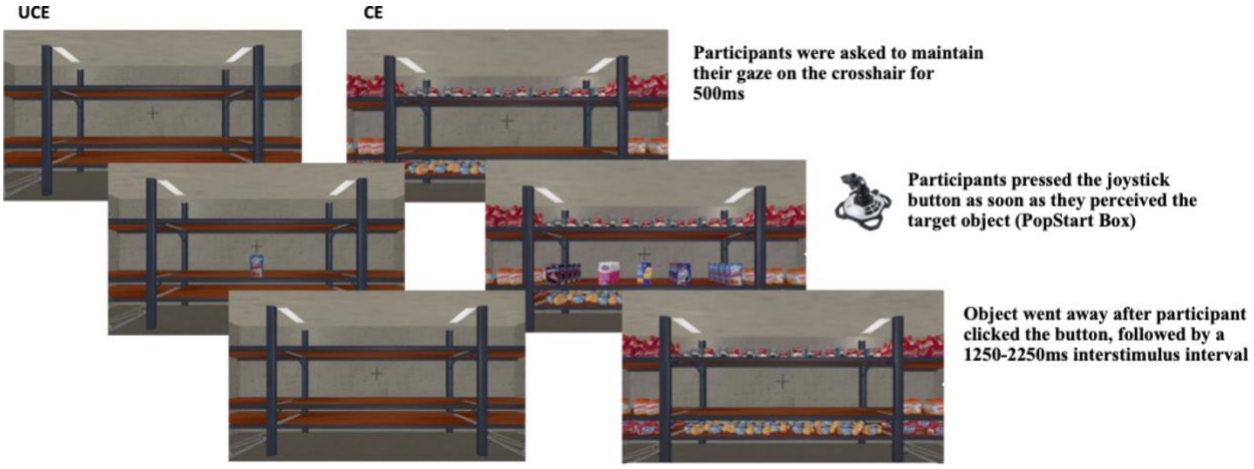

Fig 3-2. Sequence of events for the detection tasks performed in the cluttered (CE) and uncluttered (UCE) environments.

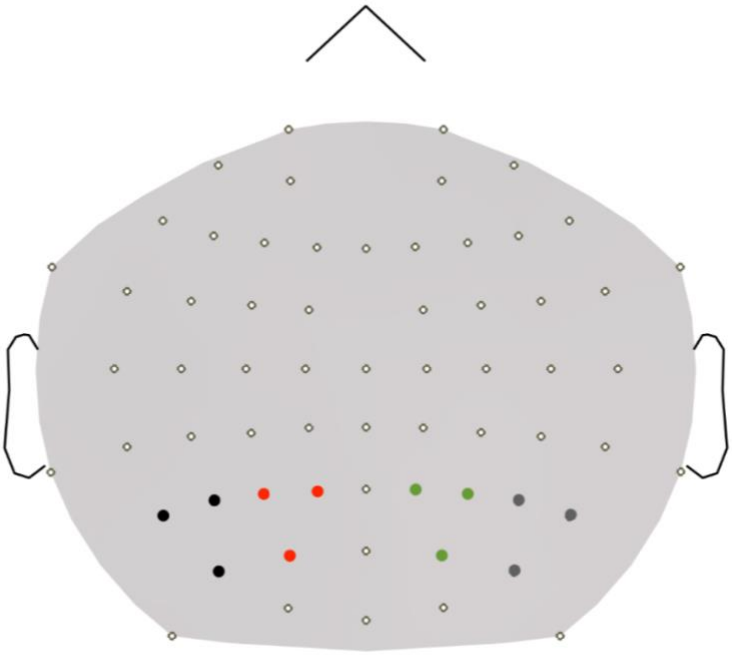

Fig 3-3. Cortical activity was clustered in four groups: PC1 (P1/P3/PO3, red), PC2 (P2/P4/PO4, green), PC3 (P5/P7/PO7, black), and PC4 (P6/P8/PO8, grey), in order to respectively represent the maximal activity at each latency.

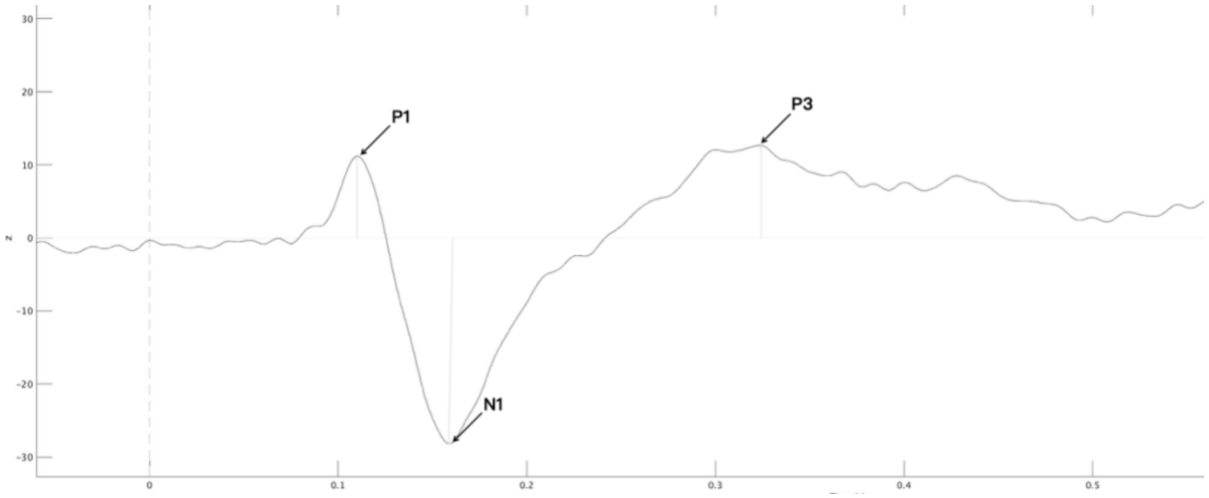

Fig 3-4. Grand average of ERP result from electrode PO4. As shown in the figure, P1 is the first positive going peak, N1 is a negative going peak following P1, and P3 is the second positive going peak occurring after 300ms.

MAIN EFFECTS							
		Scene Complexity		**Target Location**		**Scene Complexity X Target Location**	
		Left hemi	Right hemi	Left hemi	Right hemi	Left hemi	Right hemi
P1	**Amplitude**	NS	RPPC**	NS	NS	NS	NS
	Latency	LPPC***, LESC***,	RPPC***, RESC**	LPPC***, LESC***	RPPC***, RESC*	LPPC***, LESC***,	RPPC***, RESC***
N1	**Amplitude**	LPPC***,	RPPC***, RESC*	LPPC***,	RPPC***, RESC***	LPPC*,	RPPC**, RESC***
	Latency	LPPC***, LESC***,	RPPC***, RESC***	LPPC***, LESC*,	RPPC***, RESC***	LPPC***, LESC***,	RPPC***, RESC***
P3	**Amplitude**	LESC***,	RESC**	LESC**,	RPPC***, RESC**	LPPC***, LESC***,	RPPC***, RESC***
	Latency	LESC***,	NS	LPPC***, LESC***,	RPPC***, RESC***	LPPC***, LESC***,	RPPC***, RESC***

Table 3-1. This table summarizes the significance of the main effects on P1, N1, P3 latency and amplitude in each cluster (LPPC, RPPC, LESC, and RESC). Statistically significant results are indicated. Symbol indicates: * $p<0.05$, ** $p<0.01$, *** $p<0.0001$, NS = not significant.

CORRELATION COEFFICIENT					
			P1	N1	P300
UC	**Amplitude**	**LPPC**	r = -0.275*; p = 0.027	r = 0.208; p = 0.096	r = 0.338**; p = 0.006
		RPPC	r = -0.529**; p = 0.000	r = 0.261*; p = 0.036	r = 0.196; p = 0.117
		LESC	r = -0.205; p = 0.101	r = 0.024; p = 0.848	r = 0.23; p = 0.066
		RESC	r = -0.327**; p = 0.008	r = 0.012; p = 0.923	r = 0.165; p = 0.190
	Latency	**LPPC**	r = -0.098; p = 0.437	r = 0.102; p = 0.421	r = -0.087; p = 0.493
		RPPC	r =0.074; p = 0.556	r = -0.001; p = 0.993	r = 0.14; p = 0.265
		LESC	r = -0.12; p = 0.339	r = -0.083; p = 0.51	r = -0.131; p = 0.300
		RESC	r =0.051; p = 0.684	r = -0.103; p = 0.413	r = 0.154; p = 0.222
C	**Amplitude**	**LPPC**	r = -0.537**; p = 0.000	r = -0.096; p = 0.444	r = 0.185; p = 0.141
		RPPC	r = -0.416**; p = 0.001	r = 0.081; p = 0.522	r = 0.206; p = 0.1
		LESC	r = -0.391; p = 0.001	r = -0.077; p = 0.542	r = -0.052; p = 0.68
		RESC	r = -0.307*; p = 0.013	r = 0.134; p = 0.286	r = 0.03; p = 0.814
	Latency	**LPPC**	r = -0.224; p = 0.073	r = -0.056; p = 0.659	r = 0.348**; p = 0.005
		RPPC	r = -0.043; p = 0.731	r = 0.136; p = 0.280	r = 0.381**; p = 0.002
		LESC	r = -0.146; p = 0.246	r = -0.039; p = 0.758	r = 0.258*; p = 0.038
		RESC	r = 0.020; p = 0.872	r = 0.155; p = 0.217	r = 0.407**; p = 0.001

Table 3-2. This table summarizes the correlation coefficients (r) between response time and i) P1, N1, P3 latency and ii) P1, N1 and P3 amplitude for each cluster (LPPC, RPPC, LESC, and RESC). Statistically significant results are indicated. Symbol indicates * $p<0.05$, ** $p<0.01$, *** $p<0.0001$.

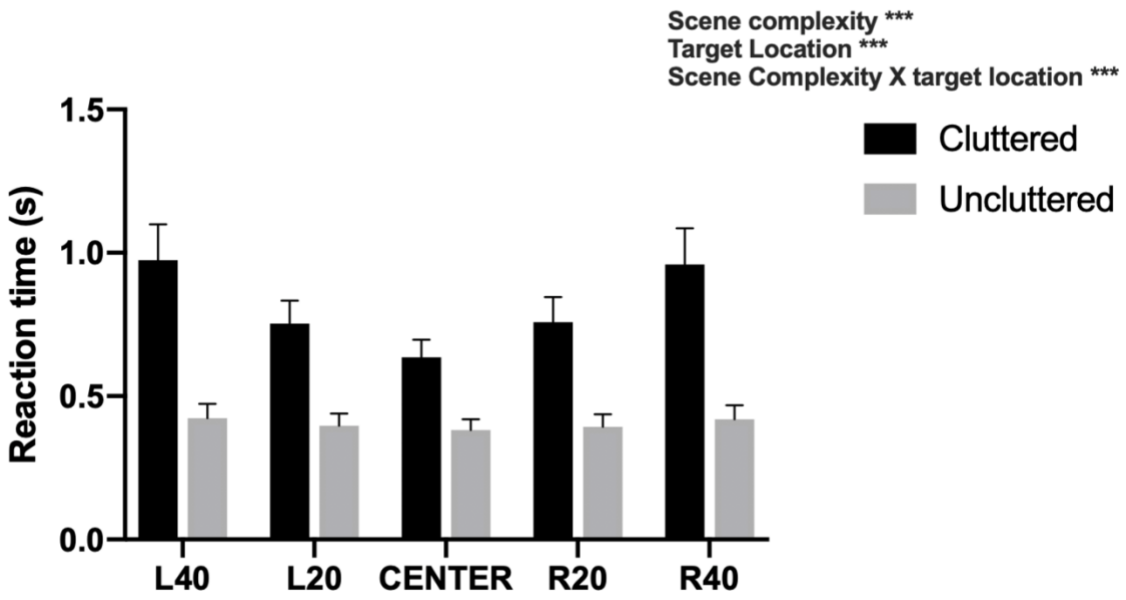

Fig 3-5. Mean ± 2SE values of all participants for average reaction time across five different target locations (0°, as well as ± 20° and ±40° left (L) or right (R)) in the cluttered environment and uncluttered environment. Statistically significant results are indicated. Symbol indicates ***p<0.0001.

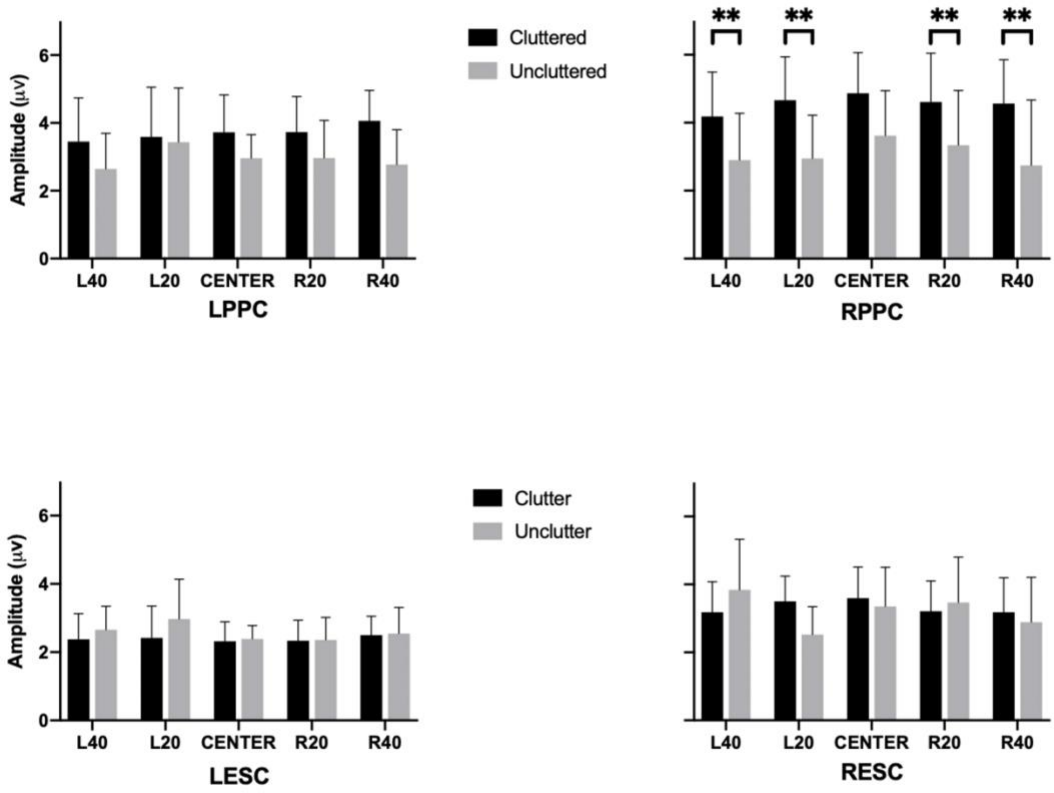

Figure 3-6. Mean ± 2SE values of all participants for average P1 amplitude over 4 posterior clusters across target locations in the cluttered and uncluttered environment. Symbol indicates: ns = not significant, ** p< 0.01, *** p<0.0001.

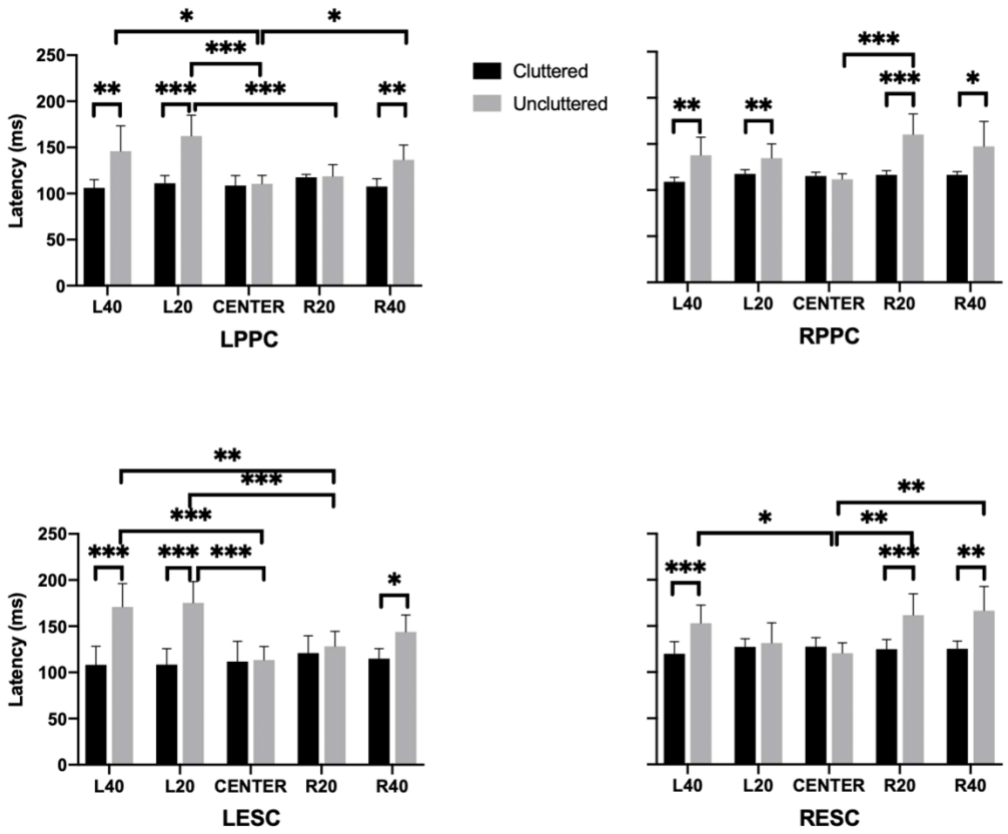

Figure 3-7. Mean ± 2SE values of all participants for P1 latency over 4 posterior clusters across 5 target locations in the cluttered environment and uncluttered environment. Symbol indicates: * $p<0.05$, ** $p<0.01$, *** $p<0.0001$.

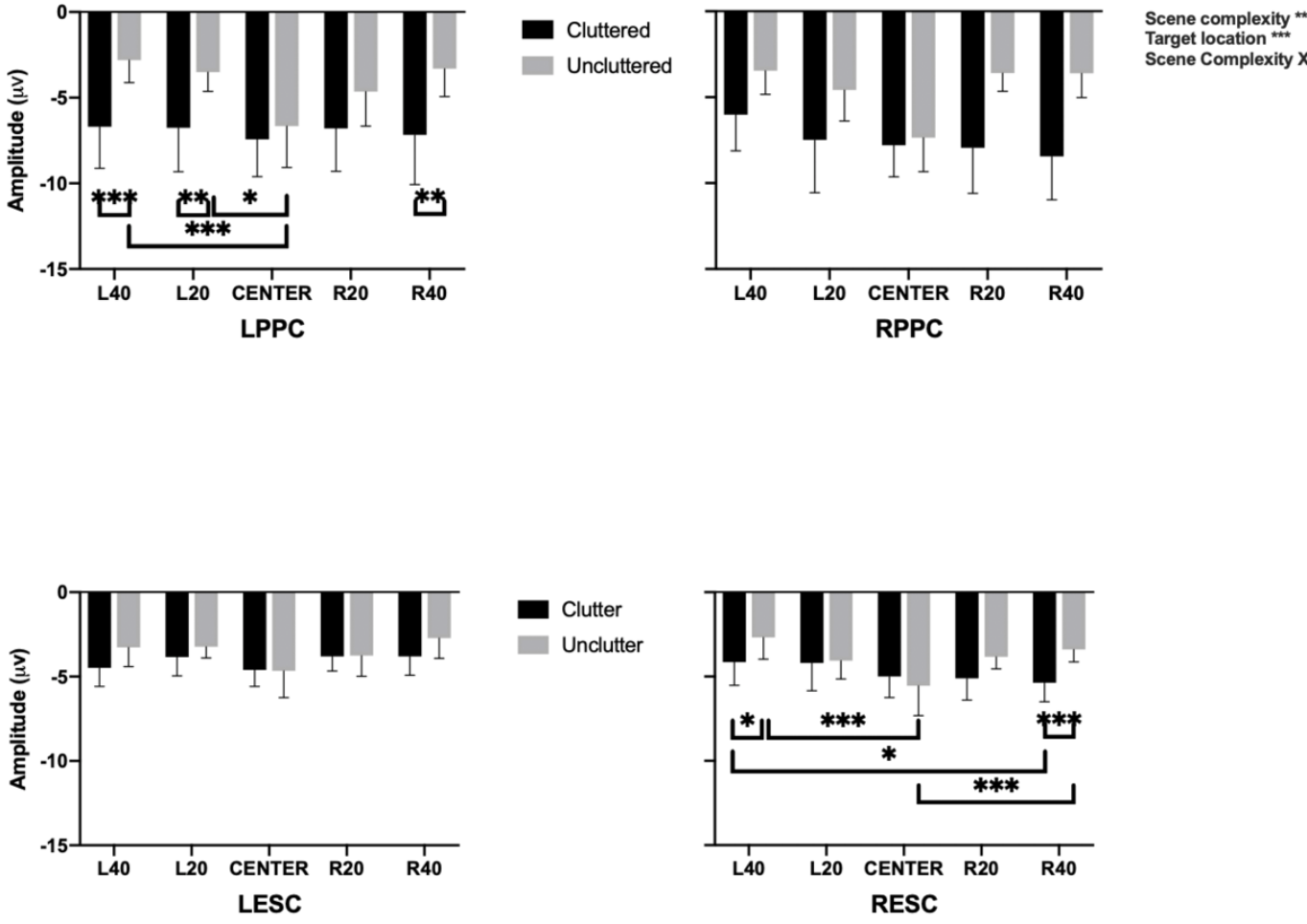

Figure 3-8. Mean ± 2SE values of all participants for average N1 amplitude over 4 posterior clusters across target locations in the cluttered and uncluttered environment. Symbol indicates ns = not significant, * $p<0.05$, ** $p<0.01$, *** $p<0.0001$.

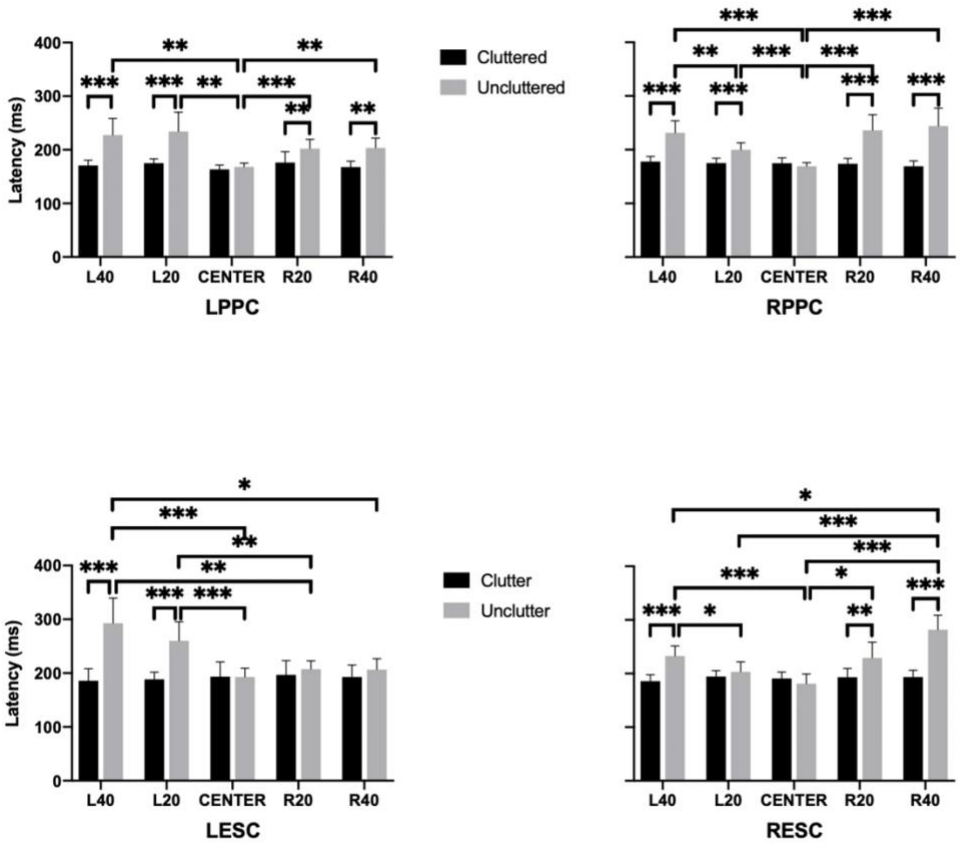

Figure 3-9. Mean ± 2SE values of all participants for average N1 latency over 4 posterior clusters across target locations in the cluttered and uncluttered environment. Symbol indicates: * $p<0.05$, ** $p<0.01$, *** $p<0.0001$.

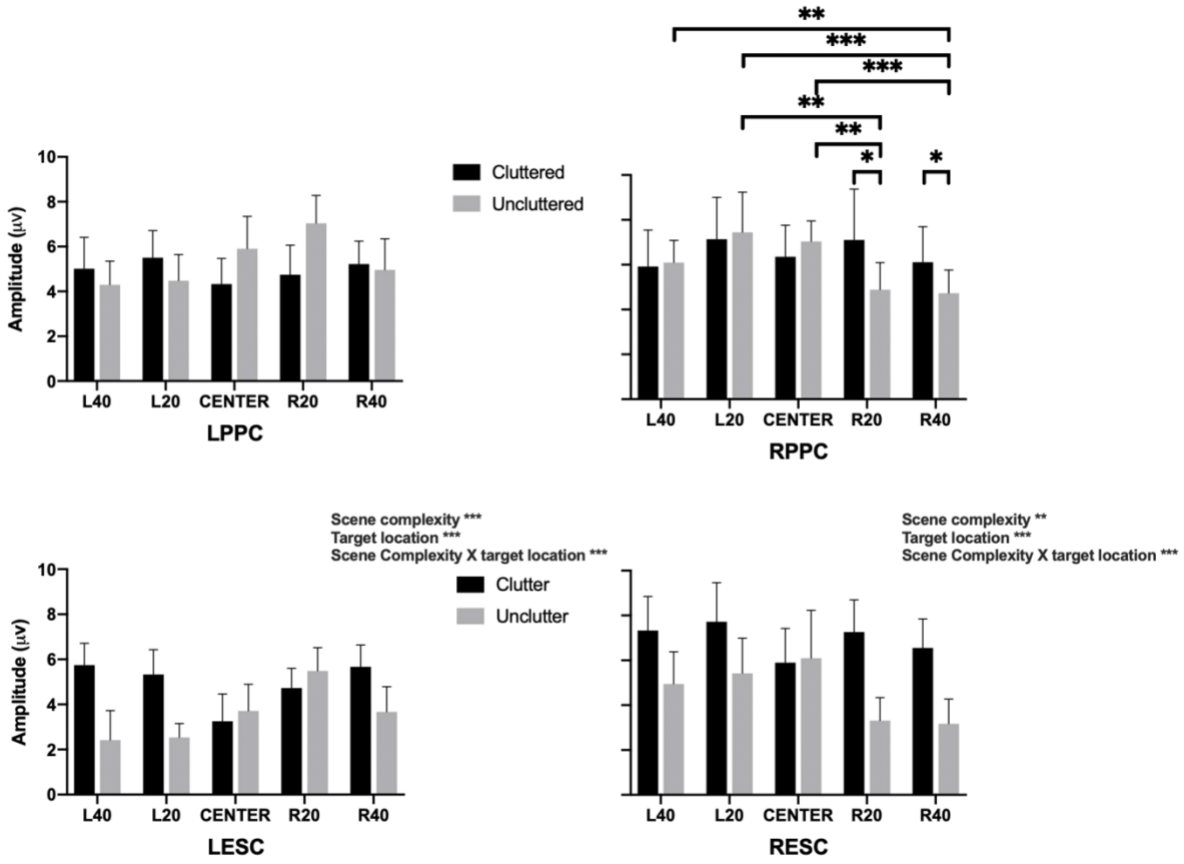

Figure 3-10. Mean ± 2SE values of all participants for average P3 amplitude over 4 posterior clusters across target locations in the cluttered and uncluttered environment. Symbol indicates: ns = not significant, * $p<0.05$, ** $p<0.01$, *** $p<0.0001$.

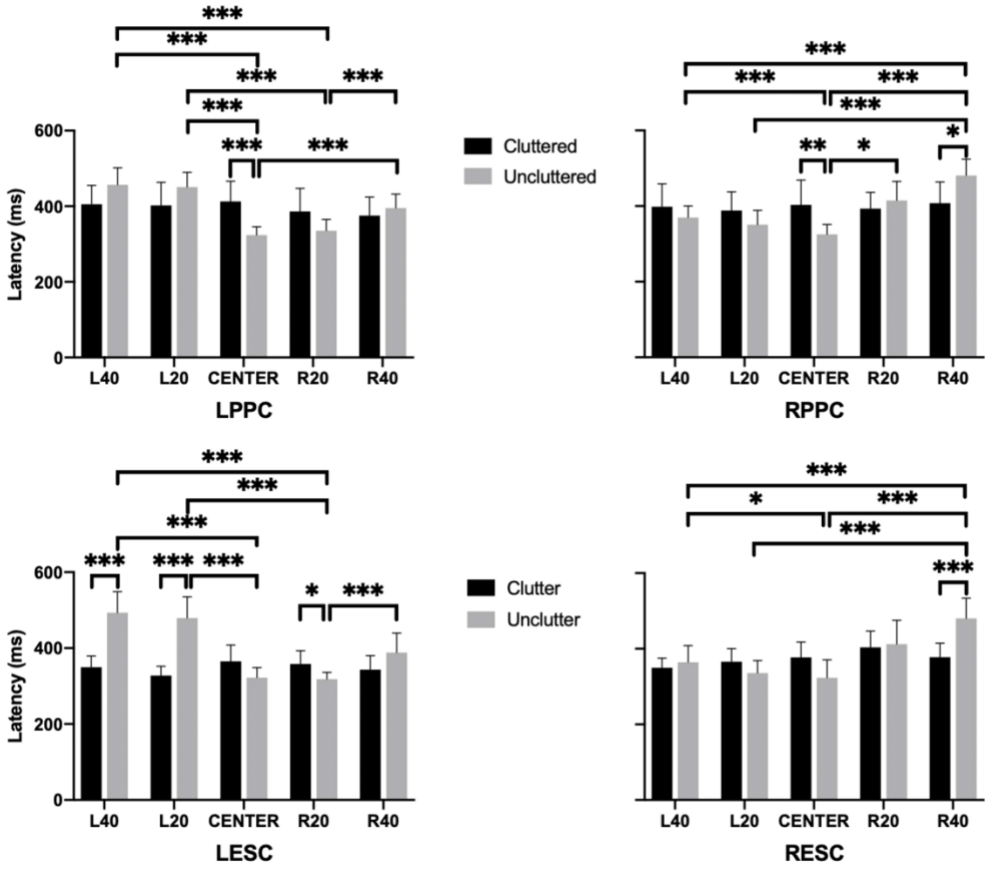

Figure 3-11. Mean ± 2SE values of all participants for average P3 latency over 4 posterior clusters across target locations in the cluttered and uncluttered environment. Symbol indicates ns = not significant, * $p<0.05$, ** $p<0.01$, *** $p<0.0001$.

CHAPTER 4: GENERAL DISCUSSION

Every day, we are surrounded by vast amount of visual information. Detecting an object of interest at various locations amongst non-relevant objects is essential and fundamental to the completion of several activities of daily living, such task the selection of items for dressing, cooking or shopping.

The purpose of this master's thesis was to investigate healthy patterns of brain activation involved in object detection, with the long-term goal of identifying alterations present in recovered and non-recovered post-stroke USN. To achieve this goal, we designed an experiment in which healthy participants were asked to detect a target object in a virtual reality setting consisting of two types of environment: cluttered vs. uncluttered. Confirming our first hypothesis that scene complexity would affect ERP amplitude, the effects of scene complexity elicited a larger amplitude of P1, N1 in PPC clusters and P3 in extrastriate cortex , which could be due to top down attention influence (amplitude of P1 and P3) and the discrimination process (amplitude of N1) involved in the task. Latency of P1, N1, and P3 were also found to be shorter for CE vs UCE for peripherally located targets compared to the centred target. This effect, however, was caused by the significant lateralized modulation of P1, N1, and P3 latency in UCE in response to the effects of target location,

whereby P1, N1, P3 latency were found to be lengthened ipsilaterally to hemisphere due to brain asymmetry. Effect of target location for CE, however, was not significant. It was also hypothesized that amplitude and latency of P1, N1, and P3 would vary due to changes in target locations in the UCE. However, target location did not influence P1 amplitude. In line with the theory that N1 directly correlates with the orientation of attention to the relevant location, the absolute value of N1 amplitude was found to modulate for the effects of target location for UCE, peaking for the center target and decreasing bilaterally with target eccentricity. P3 amplitude was found to be higher for targets located contralaterally to the hemisphere, which can be due to a compound of the activation of premotor cortex.

Unlike other detection tasks, in which larger P3 amplitude was associated with shorter response time, we found the amplitude of P1 for RPPC and LPPC clusters and right extrastriate cortex to be negatively correlated with response time for both UCE and CE, such that a larger P1 amplitude was associated with shorter response time. That is, when participants searched for the known target amongst distractors, P1 was strongly elicited and hence a faster response were triggered. In addition, P3 latency for all clusters in the CE only was positively correlated with response time, implying that longer P3 latency was associated with a longer response time. Assuming response time is the sum of the duration necessary to complete all stages of object detection processing and

that P3 latency is a marker of decision making, the positive correlation between P3 latency and response time may indicate that longer response time is associated with longer decision-making time and vice versa.

Significance and future directions

Despite the vast amount of studies that have explored the neural correlate of object detection, this study examined, for the first time, the extent to which brain activation associated to an object detection task performed in an immersive virtual environment is modulated as a function of scene complexity and target eccentricity. Relationships between EEG outcomes and performance on the object detection task were also examined. The knowledge derived from this study will further our understanding on how elements such as scene complexity and object location in the visual field modulate brain activation during object detection tasks among healthy individuals. Results will also serve as a basis for comparison to further understand the brain pattern of USN individuals. Previous study suggested no significant differences for reaction time between USN- and healthy older individuals when both groups performed VR based detection task [62], therefore, we expect identical brain activation pattern between USN- and healthy older individuals. USN+ group were reported to have a longer reaction time when detecting target object [62] hence we expect to find a longer latency and altered amplitude of both N1 and P3 for

CE and UCE. Amplitude and latency of P1 is expected to be similar to healthy individuals because USN participants have intact visual field, thus they should be able to involuntarily detect all the visual stimuli presented in their vision field.

By identifying which regions of the brain are normally involved in object detection, results will also ultimately provide the mechanistic basis for an optimal use of brain stimulation techniques to promote object detection performance.

CHAPTER 5: REFERENCES

1. Coles, M.G.H. and M.D. Rugg, *Event-related brain potentials: An introduction*, in *Electrophysiology of mind: Event-related brain potentials and cognition.* 1995, Oxford University Press: New York, NY, US. p. 1-26.
2. Herrmann, C.S. and R.T. Knight, *Mechanisms of human attention: event-related potentials and oscillations.* Neurosci Biobehav Rev, 2001. **25**(6): p. 465-76.
3. Mangun, G.R., *Neural mechanisms of visual selective attention.* Psychophysiology, 1995. **32**(1): p. 4-18.
4. Eason, R.G., *Visual evoked potential correlates of early neural filtering during selective attention.* Bulletin of the Psychonomic Society, 1981. **18**(4): p. 203-206.
5. Luck, S.J., et al., *Visual event-related potentials index focused attention within bilateral stimulus arrays. II. Functional dissociation of P1 and N1 components.* Electroencephalography and Clinical Neurophysiology, 1990. **75**(6): p. 528-542.
6. Störmer, V.S., J.J. McDonald, and S.A. Hillyard, *Cross-modal cueing of attention alters appearance and early cortical processing of visual stimuli.* Proceedings of the National Academy of Sciences, 2009. **106**(52): p. 22456.
7. Handy, T.C. and G.R. Mangun, *Attention and spatial selection: electrophysiological evidence for modulation by perceptual load.* Percept Psychophys, 2000. **62**(1): p. 175-86.
8. Vogel, E.K. and S.J. Luck, *The visual N1 component as an index of a discrimination process.* Psychophysiology, 2000. **37**(2): p. 190-203.
9. Schaffer, S., A. Schubo, and C. Meinecke, *Electrophysiological correlates of target eccentricity in texture segmentation.* Int J Psychophysiol, 2011. **80**(3): p. 198-209.
10. Antonova, I., et al., *Reaction Time in a Visual 4-Choice Reaction Time Task: ERP Effects of Motor Preparation and Hemispheric Involvement.* Brain Topogr, 2016. **29**(4): p. 491-505.
11. Duncan, J. and G.W. Humphreys, *Visual search and stimulus similarity.* Psychol Rev, 1989. **96**(3): p. 433-58.
12. Verleger, R., P. Jaśkowski, and E. Wascher, *Evidence for an Integrative Role of P3b in Linking Reaction to Perception.* Journal of Psychophysiology, 2005. **19**(3): p. 165-181.
13. Gillen, R., H. Tennen, and T. McKee, *Unilateral spatial neglect: relation to rehabilitation outcomes in patients with right hemisphere stroke.* Arch Phys Med Rehabil, 2005. **86**(4): p. 763-7.

14. Paolucci, S., et al., *The role of unilateral spatial neglect in rehabilitation of right brain-damaged ischemic stroke patients: A matched comparison.* Archives of Physical Medicine and Rehabilitation, 2001. **82**(6): p. 743-749.
15. Heilman, K.M. and R.T. Watson, *Mechanisms underlying the unilateral neglect syndrome.* Advances in Neurology, 1977. **18**: p. 93-106.
16. Verleger, R., et al., *The hard oddball: effects of difficult response selection on stimulus-related P3 and on response-related negative potentials.* Psychophysiology, 2014. **51**(11): p. 1089-100.
17. Heilman, K.M., et al., *Directional hypokinesia: prolonged reaction times for leftward movements in patients with right hemisphere lesions and neglect.* Neurology, 1985. **35**(6): p. 855-9.
18. Warren, M., *A hierarchical model for evaluation and treatment of visual perceptual dysfunction in adult acquired brain injury, Part 1.* Am J Occup Ther, 1993. **47**(1): p. 42-54.
19. Verdon, V., et al., *Neuroanatomy of hemispatial neglect and its functional components: a study using voxel-based lesion-symptom mapping.* Brain, 2010. **133**(Pt 3): p. 880-94.
20. Mort, D.J., et al., *The anatomy of visual neglect.* Brain, 2003. **126**(Pt 9): p. 1986-97.
21. Committeri, G., et al., *Neural bases of personal and extrapersonal neglect in humans.* Brain, 2007. **130**(Pt 2): p. 431-41.
22. Karnath, H.O., et al., *The anatomy underlying acute versus chronic spatial neglect: a longitudinal study.* Brain, 2011. **134**(Pt 3): p. 903-12.
23. Chatterjee, A., *Picturing unilateral spatial neglect: viewer versus object centred reference frames.* J Neurol Neurosurg Psychiatry, 1994. **57**(10): p. 1236-40.
24. Karnath, H.O. and C. Rorden, *The anatomy of spatial neglect.* Neuropsychologia, 2012. **50**(6): p. 1010-7.
25. Watson, R.T., et al., *Neglect after cingulectomy.* Neurology, 1973. **23**(9): p. 1003-7.
26. Karnath, H.O., C. Rorden, and L.F. Ticini, *Damage to white matter fiber tracts in acute spatial neglect.* Cereb Cortex, 2009. **19**(10): p. 2331-7.
27. Doricchi, F. and F. Tomaiuolo, *The anatomy of neglect without hemianopia: a key role for parietal-frontal disconnection?* Neuroreport, 2003. **14**(17): p. 2239-43.
28. Vandenberghe, R. and C.R. Gillebert, *Parcellation of parietal cortex: Convergence between lesion-symptom mapping and mapping of the intact functioning brain.* Behavioural Brain Research, 2009. **199**(2): p. 171-182.
29. Ricci, R., et al., *Imaging the neural mechanisms of TMS neglect-like bias in healthy volunteers with the interleaved TMS/fMRI technique: preliminary evidence.* Front Hum Neurosci, 2012. **6**: p. 326.

30. van Dinteren, R., et al., *Differences in Cortical Sources of the Event-Related P3 Potential Between Young and Old Participants Indicate Frontal Compensation.* Brain Topogr, 2018. **31**(1): p. 35-46.
31. Colby, C.L. and M.E. Goldberg, *Space and attention in parietal cortex.* Annual Review of Neuroscience, 1999. **22**: p. 319-349.
32. Murphy, A.P., et al., *Lesions to right posterior parietal cortex impair visual depth perception from disparity but not motion cues.* Philos Trans R Soc Lond B Biol Sci, 2016. **371**(1697).
33. Kastner, S., et al., *Increased activity in human visual cortex during directed attention in the absence of visual stimulation.* Neuron, 1999. **22**(4): p. 751-61.
34. Hopfinger, J.B., M.H. Buonocore, and G.R. Mangun, *The neural mechanisms of top-down attentional control.* Nat Neurosci, 2000. **3**(3): p. 284-91.
35. Moran, J. and R. Desimone, *Selective attention gates visual processing in the extrastriate cortex.* Science, 1985. **229**(4715): p. 782-4.
36. Ogourtsova, T., et al., *Ecological Virtual Reality Evaluation of Neglect Symptoms (EVENS): Effects of Virtual Scene Complexity in the Assessment of Poststroke Unilateral Spatial Neglect.* Neurorehabilitation and Neural Repair, 2018. **32**: p. 154596831775167.
37. Masterton, R.A.J., G.D. Jackson, and D.F. Abbott, *Mapping brain activity using event-related independent components analysis (eICA): Specific advantages for EEG-fMRI.* NeuroImage, 2013. **70**(Supplement C): p. 164-174.
38. Kober, S.E., G. Wood, and C. Neuper, *Measuring brain activation during spatial navigation in virtual reality: a combined EEG-NIRS study.* International Journal of Computer Research, 2013. **20**(1): p. 1.
39. Kappenman, E.S., et al., *ERP Components: The Ups and Downs of Brainwave Recordings*. 2012, Oxford University Press.
40. Mangun, G.R. and S.A. Hillyard, *Modulations of sensory-evoked brain potentials indicate changes in perceptual processing during visual-spatial priming.* Journal of Experimental Psychology: Human Perception and Performance, 1991. **17**(4): p. 1057-1074.
41. Verleger, R., *On the utility of P3 latency as an index of mental chronometry.* Psychophysiology, 1997. **34**(2): p. 131-56.
42. Roth, G.A., et al., *Methods for Estimating the Global Burden of Cerebrovascular Diseases.* Neuroepidemiology, 2015. **45**(3): p. 146-151.
43. Lui, S.K. and M.H. Nguyen, *Elderly Stroke Rehabilitation: Overcoming the Complications and Its Associated Challenges.* Curr Gerontol Geriatr Res, 2018. **2018**: p. 9853837.
44. Lapchak, P.A. and J.H. Zhang, *The High Cost of Stroke and Stroke Cytoprotection Research.* Transl Stroke Res, 2017. **8**(4): p. 307-317.

45. Hatem, S.M., et al., *Rehabilitation of Motor Function after Stroke: A Multiple Systematic Review Focused on Techniques to Stimulate Upper Extremity Recovery.* Front Hum Neurosci, 2016. **10**: p. 442.
46. Malhotra, P., E. Coulthard, and M. Husain, *Hemispatial neglect, balance and eye-movement control.* Current Opinion in Neurology, 2006. **19**(1): p. 14-20.
47. Kerkhoff, G. and Y. Rossetti, *Plasticity in spatial neglect: recovery and rehabilitation.* Restor Neurol Neurosci, 2006. **24**(4-6): p. 201-6.
48. Stone, S.P., et al., *The assessment of visuo-spatial neglect after acute stroke.* J Neurol Neurosurg Psychiatry, 1991. **54**(4): p. 345-50.
49. Ringman, J.M., et al., *Frequency, risk factors, anatomy, and course of unilateral neglect in an acute stroke cohort.* Neurology, 2004. **63**(3): p. 468-74.
50. Kalra, L., et al., *The influence of visual neglect on stroke rehabilitation.* Stroke, 1997. **28**(7): p. 1386-91.
51. Cherney, L.R., et al., *Recovery of functional status after right hemisphere stroke: relationship with unilateral neglect.* Arch Phys Med Rehabil, 2001. **82**(3): p. 322-8.
52. Katz, N., et al., *Functional disability and rehabilitation outcome in right hemisphere damaged patients with and without unilateral spatial neglect.* Arch Phys Med Rehabil, 1999. **80**(4): p. 379-84.
53. Sacher, Y., et al., *Role of disengagement failure and attentional gradient in unilateral spatial neglect - a longitudinal study.* Disabil Rehabil, 2004. **26**(12): p. 746-55.
54. Robertson, I.H., et al., *Walking trajectory and hand movements in unilateral left neglect: a vestibular hypothesis.* Neuropsychologia, 1994. **32**(12): p. 1495-502.
55. Tromp, S., et al., *Are rape memories different? A comparison of rape, other unpleasant, and pleasant memories among employed women.* J Trauma Stress, 1995. **8**(4): p. 607-27.
56. Jutai, J.W., et al., *Treatment of visual perceptual disorders post stroke.* Top Stroke Rehabil, 2003. **10**(2): p. 77-106.
57. Buxbaum, L.J., et al., *Hemispatial neglect: Subtypes, neuroanatomy, and disability.* Neurology, 2004. **62**(5): p. 749-56.
58. Goodale, M.A., et al., *Kinematic analysis of limb movements in neuropsychological research: subtle deficits and recovery of function.* Can J Psychol, 1990. **44**(2): p. 180-95.
59. Ogourtsova, T., P.S. Archambault, and A. Lamontagne, *Post-stroke unilateral spatial neglect: virtual reality-based navigation and detection tasks reveal lateralized and non-lateralized deficits in tasks of varying perceptual and cognitive demands.* J Neuroeng Rehabil, 2018. **15**(1): p. 34.
60. Berard, J., J. Fung, and A. Lamontagne, *Visuomotor Control Post Stroke Can be Affected by a History of Visuospatial Neglect.* Journal of Neurology & Neurophysiology, 2012. **s8**.

61. Aravind, G. and A. Lamontagne, *Dual tasking negatively impacts obstacle avoidance abilities in post-stroke individuals with visuospatial neglect: Task complexity matters!* Restor Neurol Neurosci, 2017. **35**(4): p. 423-436.
62. Ogourtsova, T., P.S. Archambault, and A. Lamontagne. *Let's do groceries - a novel virtual assessment for post-stroke unilateral spatial neglect*. in *2017 International Conference on Virtual Rehabilitation (ICVR)*. 2017.
63. Hegarty, M., et al., *Spatial abilities at different scales: Individual differences in aptitude-test performance and spatial-layout learning.* Intelligence, 2006. **34**(2): p. 151-176.
64. Maguire, E.A., K. Woollett, and H.J. Spiers, *London taxi drivers and bus drivers: a structural MRI and neuropsychological analysis.* Hippocampus, 2006. **16**(12): p. 1091-101.
65. Iaria, G., et al., *The contribution of the fusiform gyrus and superior temporal sulcus in processing facial attractiveness: neuropsychological and neuroimaging evidence.* Neuroscience, 2008. **155**(2): p. 409-22.
66. Goodale, M.A., et al., *Separate neural pathways for the visual analysis of object shape in perception and prehension.* Curr Biol, 1994. **4**(7): p. 604-10.
67. Hebart, M.N. and G. Hesselmann, *What Visual Information Is Processed in the Human Dorsal Stream?* The Journal of Neuroscience, 2012. **32**(24): p. 8107-8109.
68. Lehky, S.R. and A.B. Sereno, *Comparison of shape encoding in primate dorsal and ventral visual pathways.* J Neurophysiol, 2007. **97**(1): p. 307-19.
69. Bitar, A.W., M.M. Mansour, and A. Chehab. *Algorithmic Optimizations in the HMAX Model Targeted for Efficient Object Recognition*. in *Computer Vision, Imaging and Computer Graphics Theory and Applications*. 2016. Cham: Springer International Publishing.
70. Huff, T. and P. Tadi, *Neuroanatomy, Visual Cortex*, in *StatPearls*. 2019: Treasure Island (FL).
71. Milner, A.D. and M.A. Goodale, *The visual brain in action*. 2nd ed. Oxford psychology series. 2006, Oxford ; New York: Oxford University Press. xxii, 297 p.
72. Katsuki, F. and C. Constantinidis, *Bottom-up and top-down attention: different processes and overlapping neural systems.* Neuroscientist, 2014. **20**(5): p. 509-21.
73. Connor, C.E., H.E. Egeth, and S. Yantis, *Visual attention: bottom-up versus top-down.* Curr Biol, 2004. **14**(19): p. R850-2.
74. Corbetta, M. and G.L. Shulman, *Control of goal-directed and stimulus-driven attention in the brain.* Nat Rev Neurosci, 2002. **3**(3): p. 201-15.

75. Katsuki, F. and C. Constantinidis, *Unique and shared roles of the posterior parietal and dorsolateral prefrontal cortex in cognitive functions.* Front Integr Neurosci, 2012. **6**: p. 17.
76. Hillyard, S.A. and L. Anllo-Vento, *Event-related brain potentials in the study of visual selective attention.* Proceedings of the National Academy of Sciences, 1998. **95**(3): p. 781.
77. Mangun, G.R., et al., *Covariations in ERP and PET measures of spatial selective attention in human extrastriate visual cortex.* Human Brain Mapping, 1997. **5**(4): p. 273-279.
78. Aravind, G., et al., *Virtual Reality-Based Navigation Task to Reveal Obstacle Avoidance Performance in Individuals With Visuospatial Neglect.* Ieee Transactions on Neural Systems and Rehabilitation Engineering, 2015. **23**(2): p. 179-188.
79. Y. Dvorkin, A., et al., *Assessment and Monitoring of Recovery of Spatial Neglect within a Virtual Environment*. 2008. 88-92.
80. Ogourtsova, T., et al., *Virtual reality treatment and assessments for post-stroke unilateral spatial neglect: A systematic literature review.* Neuropsychological Rehabilitation, 2017. **27**(3): p. 409-454.
81. Mizuno, K., et al., *Early Visual Processing is Affected by Clinical Subtype in Patients with Unilateral Spatial Neglect: A Magnetoencephalography Study.* Front Hum Neurosci, 2013. **7**: p. 432.
82. Tarr, M.J. and W.H. Warren, *Virtual reality in behavioral neuroscience and beyond.* Nat Neurosci, 2002. **5 Suppl**: p. 1089-92.
83. Cogne, M., et al., *The contribution of virtual reality to the diagnosis of spatial navigation disorders and to the study of the role of navigational aids: A systematic literature review.* Ann Phys Rehabil Med, 2017. **60**(3): p. 164-176.
84. Corbetta, M., et al., *Neural basis and recovery of spatial attention deficits in spatial neglect.* Nat Neurosci, 2005. **8**(11): p. 1603-10.
85. Kelly-Hayes, M., *Influence of age and health behaviors on stroke risk: lessons from longitudinal studies.* Journal of the American Geriatrics Society, 2010. **58 Suppl 2**(Suppl 2): p. S325-S328.
86. Oldfield, R.C., *The Assessment and Analysis of Handedness: The Edinburgh Inventory.* Neuropsychologia, 1971. **9**(1): p. 97-113.
87. Kaiser, P.K., *Prospective evaluation of visual acuity assessment: a comparison of snellen versus ETDRS charts in clinical practice (An AOS Thesis).* Trans Am Ophthalmol Soc, 2009. **107**: p. 311-24.
88. Carson, N., L. Leach, and K.J. Murphy, *A re-examination of Montreal Cognitive Assessment (MoCA) cutoff scores.* Int J Geriatr Psychiatry, 2018. **33**(2): p. 379-388.

89. Bartolomeo, P. and S. Chokron, *Left unilateral neglect or right hyperattention?* Neurology, 1999. **53**(9): p. 2023-7.
90. Friedman, P.J., *The Star Cancellation Test in acute stroke.* Clinical Rehabilitation, 1992. **6**(1): p. 23-30.
91. Bickerton, W.L., et al., *Separating Forms of Neglect Using the Apples Test: Validation and Functional Prediction in Chronic and Acute Stroke.* Neuropsychology, 2011. **25**(5): p. 567-580.
92. Fran, et al., *Brainstorm: a user-friendly application for MEG/EEG analysis.* Intell. Neuroscience, 2011. **2011**: p. 1-13.
93. Makeig, S., et al., *Mining event-related brain dynamics.* Trends in Cognitive Sciences, 2004. **8**(5): p. 204-210.
94. Delorme, A. and S. Makeig, *EEGLAB: an open source toolbox for analysis of single-trial EEG dynamics including independent component analysis.* J Neurosci Methods, 2004. **134**(1): p. 9-21.
95. Hillyard, S.A. and L. Anllo-Vento, *Event-related brain potentials in the study of visual selective attention.* Proceedings of the National Academy of Sciences, 1998. **95**(3): p. 781-787.
96. Cabeza, R., et al., *The parietal cortex and episodic memory: an attentional account.* Nature reviews. Neuroscience, 2008. **9**(8): p. 613-625.
97. Desimone, R., et al., *Attentional control of visual perception: cortical and subcortical mechanisms.* Cold Spring Harb Symp Quant Biol, 1990. **55**: p. 963-71.
98. Cabeza, R., et al., *The parietal cortex and episodic memory: an attentional account.* Nat Rev Neurosci, 2008. **9**(8): p. 613-25.
99. Schmidt, R.F. and G. Thews, *Human physiology*. 1983, Berlin ; New York: Springer-Verlag. xxi, 725 p.
100. Gu, X., et al., *Spatial-temporal analysis of face processing using an ERP study of the Thatcher illusion.* Conf Proc IEEE Eng Med Biol Soc, 2007. **2007**: p. 2496-9.
101. Störmer, V.S., J.J. McDonald, and S.A. Hillyard, *Cross-modal cueing of attention alters appearance and early cortical processing of visual stimuli.* Proceedings of the National Academy of Sciences, 2009. **106**(52): p. 22456-22461.
102. Mikami, K. and K. Oura, *Event Related Hemodynamics and Potentials evoked by Visual Attention Task.* システム制御情報学会論文誌, 2019. **32**(2): p. 63-68.
103. Karim, A.K. and H. Kojima, *The what and why of perceptual asymmetries in the visual domain.* Adv Cogn Psychol, 2010. **6**: p. 103-15.

104. Guzman-Martinez, E., et al., *A unique role of endogenous visual-spatial attention in rapid processing of multiple targets.* J Exp Psychol Hum Percept Perform, 2011. **37**(4): p. 1065-73.
105. Shepherd, M. and H.J. Muller, *Movement versus focusing of visual attention.* Percept Psychophys, 1989. **46**(2): p. 146-54.
106. Bacon, W.F. and H.E. Egeth, *Overriding stimulus-driven attentional capture.* Percept Psychophys, 1994. **55**(5): p. 485-96.
107. Hickey, C., J.J. McDonald, and J. Theeuwes, *Electrophysiological evidence of the capture of visual attention.* J Cogn Neurosci, 2006. **18**(4): p. 604-13.
108. Koch, C. and S. Ullman, *Shifts in selective visual attention: towards the underlying neural circuitry.* Hum Neurobiol, 1985. **4**(4): p. 219-27.
109. Sawaki, R. and J. Katayama, *Top-down directed attention to stimulus features and attentional allocation to bottom-up deviations.* J Vis, 2008. **8**(15): p. 4 1-8.
110. Ramchurn, A., et al., *Intraindividual reaction time variability affects P300 amplitude rather than latency.* Frontiers in Human Neuroscience, 2014. **8**(557).
111. Ford, J.M., et al., *On the Utility of P3 Latency and RT for Studying Cognitive Processes**This research was supported by the Medical Research Services of the Veterans Administration and NIMH Research Grant MH 31072, and was performed at the VA Medical Center, Palo Alto, Calif., U.S.A*, in *Progress in Brain Research*, H.H. Kornhubek and L. Deecke, Editors. 1980, Elsevier. p. 661-667.
112. Beres, A.M., *Time is of the Essence: A Review of Electroencephalography (EEG) and Event-Related Brain Potentials (ERPs) in Language Research.* Applied psychophysiology and biofeedback, 2017. **42**(4): p. 247-255.
113. Green, R.M., et al., *Benefits, shortcomings, and costs of EEG monitoring.* Annals of surgery, 1985. **201**(6): p. 785-792.

CHAPTER 6: APPENDIX

CONSENT FORM FOR PARTICIPATING IN A RESEARCH PROJECT

1. TITLE OF THE PROJECT

Neural correlates of object detection in post-stroke hemineglect

2. PROJECT LEADERS

Anouk Lamontagne, PT, PhD
Associate Professor
School of Physical & Occupational Therapy, McGill University
Researcher
Jewish Rehabilitation Hospital – CISSS Laval
Email : anouk.lamontagne@mcgill.ca

Marie-Hélène Boudrias, PT, PhD
Assistant Professor
School of Physical & Occupational Therapy, McGill University
Researcher
Jewish Rehabilitation Hospital – CISSS Laval
Email: mh.boudrias@mcgill.ca

Youlin Li, BSc
Master's Degree Candidate
School of Physical & Occupational Therapy, McGill University
Email: youlin.li@mail.mcgill.ca

3. INTRODUCTION

We are asking you to participate in a research project. The aim of this study is to explore the patterns of brain activation and connectivity among post-stroke individuals with and without hemineglect as they perform an object detection task in a virtual environment. Before agreeing to participate in this project, please take the time to read and carefully consider the following information.

This consent form explains the aims of this study, the procedure, advantages, risks and inconveniences as well as the persons to contact if necessary.

This consent form may contain words that you do not understand. We invite you to ask the researchers and other members of our research team to explain word or information that is not clear to you.

4. DESCRIPTION AND OBJECTIVES OF THE PROJECT

Post-stroke hemineglect is a common disorder after a right brain stroke. It leads to a failure to attend and respond to stimuli located on the side opposite to the brain lesion (i.e. in the case of a right brain stroke, people neglect the left visual space). As a result, persons with post-stroke hemineglect may experience difficulty performing functional activities of daily living, such as finding shopping items in a grocery store. Past research studies have reported changes in the way the brain is activated when persons with post-stroke hemineglect perform a visual discrimination task. To date, however, we don't know if these patterns of activation are modified by the complexity of the task being performed and if they explain the functional performance of the individuals with hemineglect.

In this project, we are using electroencephalography (EEG) as a non-invasive method to record the activity of the brain as participants with and without post-stroke hemineglect perform an object detection task in the virtual world. The object detection task involves the detection of objects located at different positions in space which are presented in a simple (uncluttered) environment and a more complex (cluttered) environment.

We anticipate that the analysis of brain activation during the object detection task will help explain why some persons with hemineglect are more affected (or perform better) than others. Results will further help understand the impact of factors such as object location and scene complexity on the object detection performance and patterns of brain activation. This information is important for the development of future intervention strategies for hemineglect recovery.

The specific objectives of this project are:

1) To characterize brain activation patterns in persons with and without hemineglect as they perform VR-based detection tasks.
2) To explore the impact of factors such as target location and scene complexity on brain activation patterns.
3) To explore the relationship between brain activation patterns and the performance on the detection tasks.

5. NATURE OF YOUR PARTICIPATION

The experiment will take place in the BRAIN Lab of the Jewish Rehabilitation Hospital–CISSS-Laval. You will be invited to participate in two (2) evaluation sessions lasting 2 to 3 hours each. The first session will include the presentation of the study, a clinical evaluation and the assessment of the object detection task. The second session will be devoted to the remaining part of the object detection task assessment. The two sessions will ideally take place in the same week.

Clinical evaluation session (40 minutes):
At the beginning of this session, you will be given enough time to read and sign the consent form. All questions that you may have regarding the experiments will be answered.
You will then be evaluated on clinical tests to evaluate your hand dominance, cognitive ability, visual functions as well as the presence of hemineglect.

Object detection evaluation (2 hours):

Preparation (40 min):

Electroencephalography (EEG) is a method that measures brain activation and it uses electrodes placed on the skull to capture and amplify the electrical activity of the neurons at the surface of the brain. It is a non-invasive, safe, and painless technique. This study will focus on the information

flow between electrodes located over a network of areas related to visual perception and the motor function of the hand.

We will firstly measure your head circumference for EEG cap fitting. Then we will fill all the electrode with gel to get a good impedance, and in return to get a good EEG signal. After this step, virtual reality goggles will be placed on your head, on top of the EEG cap, to display the virtual scenes. We will conduct several sample trials to get you familiar with each task. The formal data recording will start after your fully understand of the task to be performed.

Data collection (1h20):

You will be invited to perform series of 4 object detection tasks that comprise of 240 trials each. Each trial lasts from 1s to a few seconds. You will first be invited to sit in a chair as comfortably as possible and to stay still as much as possible during the whole experimental session. A virtual world representing a grocery store with shelves and shopping items will then be displayed using the virtual reality goggles fitted on your head. The virtual reality goggles also allow recording the movements of your eyes. You will be instructed to click a joystick button with the index of your non-paretic hand when you perceive the object to be detected (a blue Pop Start Cereal Box). Your response will be provided immediately after detecting the object (Immediate response detection task) or after a short delay of 0.5s (Delayed response detection task), both for the uncluttered and cluttered scene. Mandatory rest periods will be provided between each detection task. In addition, participants will be provided pauses as often as needed throughout the data collection process.

6. BENEFITS FROM YOUR PARTICIPATION

You will personally not benefit from taking part in this study. However, the result of this study will help better understand how brain functions are altered by hemineglect. In the longer term, results may further help to optimize the rehabilitation of hemineglect after stroke.

7. RISKS AND INCONVENIENCES ASSOCIATED WITH YOUR PARTICIPATION

Risks associated with your participation in this study are minimal. Due to the usage of electrodes, you may have a minimal risk of skin irritation on the scalp and this skin irritation will resolved on its own. Participants may also experience fatigue and nausea following the repeated exposure to the virtual scenarios. The feeling of fatigue or nausea, if present, will wear off with rest, which will be provided as often as needed. It is also possible that the EEG cap and virtual reality goggles feel a bit uncomfortable at times due to their weight. Finally, the total time invested by the participants in this study may also be perceived as a disadvantage.

8. ACCESS TO RESULTS AT THE END OF THE STUDY

At the end of the study, you may have access to the results of the study if desired. If you want us to send them to you, please indicate your email address.

EMAIL: _____

9. ACCESS TO MEDICAL RECORDS

The research team will need to access information in your medical records, such as: the onset date of the stroke, etiology and localization of the stroke, the cognitive status, visual function, as well as the absence or presence of hemineglect.

10. CONFIDENTIALITY

All personal information gathered about you during the study will be coded in order to ensure your confidentiality. Only the members of the research team will have access to this information. However, for monitoring purposes, your research records may be consulted by a person mandated by the Research Ethics Committee of CRIR or by an Ethics Unit of the Minister of Health and Social Services of Quebec, who adhere to a policy of strict confidentiality. The data collected in this project (both paper and electronic files) will be kept under lock and key at the Jewish Rehabilitation Hospital by the person in charge of this study for a period of five years following the end of the study, after which it will be destroyed. In the event that the results of this study are presented or published, no information identifying you will be included.

12. VOLUNTARY PARTICIPATION AND WITHDRAWAL

You are free to accept or refuse your participation in this research project. You can withdraw from the study at any time without giving any reason or being subjected to prejudice of any kind. You simply have to notify the contact person of the research team. In case of withdrawal from the study, all documents concerning you will be destroyed if that is your decision.

13. FUTURE RESEARCH STUDIES

It may be that the results obtained following this study result in another research study. In this case, do you accept to be contacted by the same researchers to participate in other scientific studies done in a similar area of research?

- ☐ no
- ☐ yes for one year*
- ☐ yes for two years*
- ☐ yes for three years*

* Note that if you select one of these three cases, your personal details will be kept by the principal investigator for the period to which you consent.

14. RESPONSIBILITY CLAUSE

By agreeing to participate in this study, you do not give up any of your legal rights nor release the researchers or institutions involved of their legal and professional obligations.

15. COMPENSATORY INDEMNITY

You will receive an amount up to a maximum of $30 to cover your travel and parking costs based on receipts.

16. CONTACT PERSON

If you have any questions about the research project, if you wish to withdraw from the study or if you want to speak with the research team, please contact Anouk Lamontagne, PhD, PT, at 450-688-9550 extension 531 or by email at the following address: Anouk.lamontagne@mcgill.ca. You can also contact Marie-Hélène Boudrias, PhD, PT at (514) 398-5457 or by email at mh.boudrias@mcgill.ca.

If you have questions about your rights and recourse or your participation in this research project, you can contact Me Anik Nolet, coordinator of the Research Ethics Committee of CRIR establishments (Tel: (514) 527-4527 ext. 3795; email: anolet.crir@ssss.gouv.qc.ca). You can also contact Hélène Bousquet, local complaints commissioner of CISSS-Laval at 450-668-1010 ext. 23628 or by e-mail at: plaintes.csssl@ssss.gouv.qc.ca.

17. CONSENT

I state that I have read and understood this project, the nature and extent of my participation, as well as the benefits and risks/inconveniences to which I will be exposed as presented in this form. I have been given the opportunity to ask questions concerning any aspects of the study and have received answers to my satisfaction. A signed copy of this consent form will be given to me.

I, the undersigned, voluntary agree to take part in this study. I can withdraw from the study at any time without prejudice of any kind. I certify that I have had sufficient time to consider my decision.

NAME OF PARTICIPANT SIGNATURE

_____ _____

Signed at _____, the _____, 20_____

THE RESEARCHER PROVIDES A COPY OF THE SIGNED CONSENT FORM TO THE PARTCIPANT AND KEEPS ONE IN THE RESEARCH CHART.

FORMULAIRE DE CONSENTEMENT POUR LA PARTICIPATION À UN PROJET DE RECHERCHE

1. TITRE DU PROJET

Substrats cérébraux de la détection d'objets chez des personnes ayant une héminégligence spatiale suite à un accident vasculaire cérébral

2. CHERCHEURS

Anouk Lamontagne, PT, PhD
Professeure Agrégée
École de physiothérapie et d'ergothérapie,
Université McGill
Chercheuse
Hôpital Juif de Réadaptation – CISSS Laval
Courriel : anouk.lamontagne@mcgill.ca

Marie-Hélène Boudrias, PT, PhD
Professeure Adjointe
École de physiothérapie et d'ergothérapie,
Université McGill
Chercheuse
Hôpital Juif de Réadaptation – CISSS Laval
Courriel : mh.boudrias@mcgill.ca

Youlin Li, BSc
Candidat à la Maîtrise
École de physiothérapie et d'ergothérapie,
Université McGill
Courriel : youlin.li@mail.mcgill.ca

3. INTRODUCTION

Nous vous demandons de participer à un projet de recherche. Le but de cette étude est d'explorer les patrons d'activation et de connexion cérébrale chez des personnes atteintes d'héminégligence suite un accident vasculaire cérébral (AVC) lors de la réalisation d'une tâche de détection d'objets dans un environnement virtuel. Avant d'accepter de participer à ce projet, veuillez prendre le temps de lire et de considérer attentivement les informations suivantes.

Ce formulaire de consentement vous explique le but de cette étude, les procédures, les avantages, les risques et inconvénients, de même que les personnes à contacter en cas de besoin.

Ce formulaire de consentement pourrait contenir des mots que vous ne comprenez pas.
Nous vous invitons à demander au chercheur ou aux autres membres de notre équipe de recherche de vous expliquer les mots ou informations qui ne vous semblent pas clair.

4. DESCRIPTION ET OBJECTIFS DU PROJET

L'héminégligence est un syndrome fréquemment observé après un AVC dans l'hémisphère droit. Elle entraine une incapacité à porter attention et à répondre à des stimuli situés du côté opposé à la lésion cérébrale (par exemple dans le cas d'un AVC dans l'hémisphère droit, les personnes négligent le champ visuel situé à gauche). En conséquence, les personnes avec de l'héminégligence peuvent éprouver des difficultés à effectuer des tâches de la vie quotidienne, comme par exemple trouver les items qu'ils doivent acheter dans une épicerie. Les études précédentes ont montré des changements au niveau de l'activité du cerveau des personnes ayant une héminégligence lorsque celles-ci effectuaient des tâches de discrimination visuelle. Cependant, à ce jour, nous ne savons pas si cette activation cérébrale est modifiée selon la complexité de la tâche réalisée et si elles expliquent la performance fonctionnelle des personnes avec une héminégligence.

Dans le cadre de ce projet, nous utiliserons l'électroencéphalographie (EEG) qui est une méthode non invasive d'enregistrement de l'activité cérébrale. Celle-ci sera enregistrée pendant que des participants avec et sans héminégligence spatiale réaliseront une tâche de détection d'objets dans un environnement virtuel. Cette tâche consistera à trouver des objets situés à différents emplacements, présentés dans un environnement simple (épuré) ou un environnement plus complexe (encombré).

L'analyse de l'activité cérébrale pendant la tâche de détection nous aidera à expliquer pourquoi certaines personnes atteintes d'héminégligence sont plus affectées (ou ont une meilleure performance) que d'autres. Les résultats permettront également de mieux comprendre l'impact de certains facteurs, tel que la localisation d'un objet ou la complexité de l'environnement, sur la capacité à détecter des objets et les patrons d'activation cérébrale. Cette information est importante pour le développement de futures stratégies d'intervention visant la réadaptation des personnes atteintes d'héminégligence.

Les objectifs spécifiques de ce projet sont :

1) De caractériser les patrons d'activation cérébrale chez les personnes avec ou sans héminégligence pendant la réalisation de tâches de détection d'objets dans un environnement virtuel.
2) D'explorer l'impact de facteurs comme la localisation de l'objet et la complexité de l'environnement sur les patrons d'activation cérébrale.
3) D'explorer la relation entre les patrons d'activation cérébrale et la performance au cours des tâches de détection.

5. NATURE DE VOTRE PARTICIPATION

L'expérience aura lieu au laboratoire BRAIN à l'hôpital Juif de Réadaptation du CISSS de Laval. Vous serez invité à participer à deux (2) sessions d'évaluation d'une durée de 2 à 3 heures chacune. La première session inclura la présentation de l'étude, une évaluation clinique et l'évaluation de la tâche de détection d'objets. La deuxième session sera dédiée à la seconde partie de la tâche de détection d'objets.

Session d'évaluation clinique (40 minutes) :

Au début de cette session nous vous donnerons suffisamment de temps pour lire et signer le formulaire de consentement. Nous répondrons à toutes les questions que vous pourriez avoir concernant les expériences. Vous serez ensuite évalués à l'aide de tests cliniques afin de recueillir

de l'information sur votre main dominante, vos capacités cognitives, vos fonctions visuelles de même que la présence d'héminégligence.

Évaluation de la détection d'objets (2 heures) :

Préparation (40 min) :

L'électroencéphalographie (EEG) est une méthode qui mesure l'activation cérébrale à l'aide d'électrodes placées sur la tête. Ces électrodes captent et amplifient l'activité électrique des neurones à la surface du cerveau. C'est une technique non invasive, sécuritaire et sans douleur. Cette étude s'intéressera au flux d'information capté entre des électrodes localisées au niveau des aires cérébrales qui contrôlent la perception visuelle et la motricité de la main.

Nous mesurerons d'abord votre tour de tête afin d'ajuster le casque d'EEG. Ensuite, nous remplirons les électrodes de gel afin d'avoir une bonne impédance et ainsi d'assurer un bon signal EEG. Après cette étape, les lunettes de réalité virtuelle seront placées sur votre tête, par dessus le casque d'EEG, afin d'afficher les scènes de réalité virtuelle. Nous mènerons ensuite plusieurs essais de pratique afin que vous vous familiarisiez avec chacun des tâches. L'enregistrement des données ne commencera que lorsque vous aurez entièrement compris la tâche à accomplir.

Collecte des données (1h20) :

Vous serez invité à réaliser une série de 4 tâches de détection d'objets qui comprennent 240 essais chacune. Chaque essai dure de 1 seconde à quelques secondes. Durant toute la session expérimentale, vous serez confortablement assis sur une chaise. Un environnement virtuel représentant une épicerie avec des étagères et des articles de nourriture apparaîtra alors à travers les lunettes de réalité virtuelle portées sur votre tête. Les lunettes de réalité virtuelle permettront également d'enregistrer les mouvements de vos yeux. Nous vous demanderons ensuite de cliquer sur un bouton avec l'index de votre main non-parétique quand vous identifierai l'objet recherché (une boîte de céréale Pop Start bleue). Votre réponse sera donnée soit immédiatement après la détection de l'objet (réponse de détection immédiate), soit après un court délai de 0.5 s (réponse de détection différée) aussi bien dans l'environnement épuré que dans l'environnement encombré. Vous pourrez prendre autant de périodes de repos que vous le souhaitez pendant la collecte des données.

6. BÉNÉFICES LIÉS À VOTRE PARTICIPATION

Vous ne retirerez personnellement aucun bénéfice à participer à cette étude. Cependant, les résultats de cette étude pourraient permettre de mieux comprendre comment le fonctionnement du cerveau est modifié par l'héminégligence spatiale. À plus long terme, les résultats pourraient aider à optimiser la réadaptation des personnes ayant un AVC qui sont atteintes d'héminégligence.

7. RISQUES ET INCONVÉNIENTS ASSOCIÉS À VOTRE PARTICIPATION

Les risques associés à votre participation à cette étude sont minimes. L'usage des électrodes comporte un risque minime d'irritation du cuir chevelu mais celle-ci se résorbera d'elle-même. Les participants pourraient aussi ressentir de la fatigue et des nausées causées par l'exposition répétée aux scènes de réalité virtuelle. Si tel est le cas, la sensation de fatigue et de nausée disparaitra avec les périodes de repos qui seront offertes aussi souvent que nécessaire. Il est aussi possible que le casque d'EEG et les lunettes de réalité virtuelle deviennent un peu inconfortable avec le temps à cause de leur poids. Finalement, le temps alloué par les participants à cette étude pourrait être perçu comme un inconvénient.

8. ACCÈS AUX RÉSULTATS À LA FIN DE L'ÉTUDE

À la fin de l'étude, vous pourrez avoir accès aux résultats. Si vous souhaitez les recevoir, merci de nous indiquer l'adresse courriel à laquelle nous pourrons vous les transmettre.

Courriel : _____

9. ACCÈS AU DOSSIER MÉDICAL

L'équipe de recherche aura besoin d'accéder aux informations de votre dossier médical, tel que la date de votre AVC, l'étiologie et la localisation de la lésion, vos fonctions cognitives et visuelles, ainsi que l'absence et la présence d'une héminégligence.

10. CONFIDENTIALITÉ

Toutes les informations personnelles recueillies sur vous durant l'étude seront codées afin de garantir votre confidentialité. Seuls les membres de l'équipe de recherche auront accès à ces informations. Cependant, à des fins de surveillance, votre dossier de recherche pourra être consulté par une personne mandatée par le Comité d'Éthique de la Recherche du CRIR ou par une Unité d'Éthique du Ministère de la Santé et des Services Sociaux du Québec, qui adhère à une politique de stricte confidentialité. Ces données (fichiers papier et électronique) seront conservées sous clé à l'Hôpital Juif de Réadaptation par la personne en charge de l'étude pendant une durée de 5 ans suivant la fin de l'étude et seront détruites après cette période. Dans l'éventualité où les résultats de cette étude sont présentés ou publiés, aucune information ne permettant de vous identifier ne sera inclue.

12. PARTICIPATION VOLONTAIRE ET DROIT DE RETRAIT

Vous êtes libre d'accepter ou de refuser de participer à ce projet de recherche. Vous pouvez vous retirer de l'étude à tout moment, sans avoir à donner de raisons et sans que cela n'entraine aucun préjudice à votre égard. Vous avez simplement à informer la personne contact au sein de l'équipe de recherche. En cas de retrait de l'étude, tous les documents concernant votre participation seront détruits si vous le décidez.

13. FUTURES ÉTUDES DE RECHERCHE

Il est possible que les résultats obtenus à la suite de cette étude donnent lieu à un autre projet de recherche. Dans ce cas, acceptez-vous d'être contacté pour participer à d'autres études scientifiques dans le même domaine de recherche?

- ___ non
- ___ oui pour un an*
- ___ oui pour deux ans*
- ___ oui pour trois ans*

*Veuillez noter que si vous sélectionnez une de ces trois cases, vos coordonnées personnelles seront conservées par le chercheur principal durant la période pour laquelle vous aurez consenti.

14. CLAUSE DE RESPONSABILITÉ

En acceptant de participer à cette étude, vous ne renoncez à aucun de vos droits ni ne libérez les chercheurs, ou les établissements impliqués de leurs obligations juridiques et professionnelles.

15. COMPENSATION FINANCIÈRE

Vous recevrez un montant d'un maximum de 30$ pour couvrir vos frais de déplacement et de parking, sur présentation de vos reçus.

16. PERSONNES À CONTACTER

Pour toutes questions à propos du projet de recherche, si vous souhaitez vous retirer de l'étude ou si vous désirez parler à un membre de l'équipe de recherche, merci de bien vouloir contacter Anouk Lamontagne, PhD, PT par téléphone au 450-688-9550 poste 531 ou par courriel (Anouk.lamontagne@mcgill.ca). Vous pouvez aussi contacter Marie-Hélène Boudrias, PhD, PT au 514-398-5457 ou par courriel à mh.boudrias@mcgill.ca.

Si vous avez des questions concernant vos droits et recours, ou votre participation à ce projet de recherche, vous pouvez contacter Me Anik Nolet, coordonnatrice du comité d'Éthique de la recherche des établissements du CRIR (Tel: (514) 527-9565 poste 3795; courriel: anolet.crir@ssss.gouv.qc.ca). Vous pouvez aussi contacter Hélène Bousquet, commissaire aux plaintes locales du CISSS de Laval au 450-668-1010 poste 23628 ou par courriel à : plaintes.csssl@ssss.gouv.qc.ca.

17. CONSENTEMENT

Je déclare avoir lu et compris ce projet, la nature et l'étendue de ma participation, de même que les bénéfices et risques/inconvénients auxquels je serai exposé, comme présenté dans ce formulaire. J'ai eu l'opportunité de poser des questions relatives à tous les aspects du projet et j'ai reçu des réponses satisfaisantes. Une copie signée de ce formulaire de consentement me sera remise.

Je, soussigné(e), accepte volontairement de participer à cette étude. Je peux retirer ma participation à n'importe quel moment sans préjudice d'aucune sorte. Je certifie avoir eu suffisamment de temps pour considérer ma décision.

NOM DU PARTICIPANT _____ SIGNATURE _____

Signé à _____, le _____, 20_____

LE CHERCHEUR FOUNIT UNE COPIE DU FORMULAIRE DE CONSENTEMENT SIGNÉ AU PARTICIPANT ET CONSERVE UNE COPIE DANS LE CLASSEUR DE RECHERCHE.

18. ENGAGEMENT DU CHERCHEUR PRINCIPAL OU DE SON REPRÉSENTANT

Je, soussigné(e) _____, certifie que j'ai

a) expliqué les termes de ce formulaire au participant
b) répondu aux questions en lien avec ce projet de recherche
c) expliqué clairement qu'il/elle demeure libre en tout temps de mettre fin à son/sa participation au projet de recherche décrit ci-dessus

_____

Signature du chercheur principal ou de son représentant

Signé à_____, le _____ 20___

18. COMMITMENT OF RESEARCHER OR REPRESENTATIVE

I, the undersigned _____, certify that I have

d) explained the terms of this form to the participant
e) answered the questions regarding this research study
f) explained clearly that the he/she remains, at all times free to end his/her participation in the research project described above.

_____

Signature of the Principal Investigator or representative

Signed at_____, the _____ 20___