AGING EFFECT ON EGOCENTRIC AND ALLOCENTRIC FRAMES OF REFERENCE IN VISUAL ATTENTION:

AN EVENT-RELATED POTENTIAL (ERP) STUDY

BRIAN KAI-MING AU

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The Hong Kong Polytechnic University

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The Hong Kong Polytechnic University

Department of Rehabilitation Sciences

Aging Effect on Egocentric and Allocentric Frames of Reference in Visual Attention:

An Event-related Potential (ERP) Study

Brian Kai-Ming AU

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CERTIFICATE OF ORIGNIALITY

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Brian Kai-ming AU

ABSTRACT

Visual attention is the cognitive process that some visual stimuli are selected for processing over others. This process involves directing attention to a spatial location which can improve the accuracy and speed of responses to target stimuli that occur in that location. Visual attention could be modulated by the frame of reference which individual takes when perceiving external visual stimuli. Egocentric (viewer-based) as well as allocentric (object-based) processing can affect visuospatial attention. Nevertheless, not much is known about the mental and cognitive processes which mediate the two encoding reference frames. Besides, not much studies in aging effect on the modulation of visual attention by these two frames of reference. This study aimed to 1) investigate the cognitive processes involved in the allocentric and egocentric reference frames for visual attention; and 2) investigate the possible changes in these cognitive processes in normal aging.

Seventeen young individuals (7 female and 10 male) aged 18-23 years (mean $\pm$ SD = 20.82 $\pm$ 1.19 years) and sixteen older healthy individuals (9 females) aged 60-66 years (mean $\pm$ SD = 62.75 $\pm$ 1.57 years) were successfully recruited in the final data analyses. The behavioral data showed that both groups responded more accurately in valid (Young: 95.11$\pm$1.25%; Older: 91.22$\pm$0.87%) than invalid trial (Young: 90.67$\pm$2.02%; Older: 76.52$\pm$2.50%) ($p<0.001$) but the young group responded faster when the stimuli were presented to their right (651.75$\pm$25.86 ms) compared to their left (689.24$\pm$27.12 ms) visual hemi-fields,

F(1, 16)=18.39, p=0.001. On the other hand, the older group responded more accurately in egocentric (85.64±1.31%) than allocentric (82.09±1.64%) but no such difference was found in the young group (p>0.05). The ERP findings shows that greater P1 amplitude was found in the older group, F(1, 31)=6.28, p=0.018. Interaction effect between group and hemi-field was found in the P1, F(1.00, 31.00)=13.04, p=0.001. It was found larger in the young group when the visual stimuli were presented at right hemi-field than left hemi-field. Similarly, interaction effect between group and hemi-field was also found in the P3, F(1.00, 31.00)=9.91, p=0.004. Larger P3 was found when stimuli appeared at RHF (1.22±0.48 μV) than LHF (0.86±0.55 μV) in the young group. However, it is the other way round for the older adults. Their P3 was larger for the stimuli presented at the LHF (3.25±0.52 μV) than the RHF (2.90±0.49 μV).For the N2, interaction effects were found between group and frames of reference, F(1.00, 31.00)=5.59, p=0.025, suggesting that the young group had shorter latency in egocentric than allocentric conditions. For the contralateral delay activity (CDA), interaction effects were found between group and condition, F(1.00, 31.00)=5.74, p=0.023, suggesting that its amplitude was found larger in egocentric (-0.64±0.09 μV) than allocentric condition for the older adults (-0.47 ±0.07 μV). Overactivation and posterior-anterior shift in aging were also found which indicate the compensation for the age-related decline in the posterior regions.

Although both young and older adults have similar findings in responding faster in egocentric than allocentric condition under behavioral observation, the

reasons for having this phenomenon are different in terms of the cognitive processes involved.

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CHAPTER ONE

INTRODUCTION

The first chapter provides an overview of the research study on the aging effect on visual attention. The chapter begins with a statement of purpose, followed by the background of study and the rationale for the study.

STATEMENT OF PURPOSE

Though previous studies have found that visual attention is affected by aging processing, the cognitive processes being involved are still unclear. Allocation of visual attention can be modulated by the frame of reference being used in encoding the spatial information of an object. These frames of reference include viewer-centred (egocentric) and object-centred (allocentric). As these reference frames are subserved by different brain regions and developed in different milestones of lifespan, their rates of decline during the aging process may differ as well. This study aimed to investigate how aging process would affect the allocation of visual attention by allocentric and egocentric reference frames and their changes in cognitive processing. There were two studies which included two groups of subjects respectively: a young group and an older group with intact cognitive function. The experimental task involved presentation of a visual cue on screen followed by identification of targets. After seeing a cue, the subjects applied an instructed allocentric or egocentric frame of reference to

locate and identify the subsequent target visual stimuli. The electrical activities elicited during the task were captured. Different event-related potentials components were identified and compared between the two frames of references. The results from the two age groups were then compared to explore the aging effect.

The objectives for this study included:

1. To investigate the cognitive processes involved in the allocentric and egocentric reference frames for visual attention; and
2. To investigate the possible changes in these cognitive processes in normal aging.

BACKGROUND AND JUSTIFICATION

Although our eyes are confronted with tremendous visual information at the same time, we are still able to appreciate the visual world without effort. The reason is that only some visual stimuli are selected for processing over others (Farah, 2000). Visual attention, which is also known as visual selective attention, is the key to this cognitive process. As our brain has limited processing capacity, attention mechanisms will bias the information processing in the brain, leading to a selective perception of relevant from irrelevant visual information. Posner and colleagues were the pioneers in investigating the behavioural costs and benefits of visual attention (Posner, Snyder, & Davidson, 1980). Performance in terms of reaction time and accuracy rate was found improved by attending to a particular

location. Similar results have been replicated by some other studies (Hillyard, Vogel, & Luck, 1998; Wright, Geffen, & Geffen, 1995).

Viewer-centred (egocentric) and object-centred (allocentric) are the two commonly used frames of reference in our daily life. These frames of reference have been found to modulate the ways that visual attention is located to objects (Behrmann, 2000; Fink et al., 1997; Marshall & Halligan, 1993). With an egocentric reference frame, spatial information is gathered using one's own body, or specific part of one's body as the reference point. On the other hand, an allocentric frame of reference relies on the relative positions among objects to define the spatial information, which is independent from the viewer's position (Vogeley & Fink, 2003).

Egocentric frame of reference was found to be available early in life (Lehnung et al., 2003). Allocentric frame of reference was found to develop later in adolescent age when the temporo-parietal cortex becomes more mature (Pine et al., 2002). Previous studies found that allocentric frame of reference was more robust than that of egocentric because the spatial information collected would remain unchanged in different perceptual encoding positions or situations (Burgess, 2006; Farah, 2000). Spatial information generated from allocentric frame of reference was suggested to be more transferable across individuals than that of the egocentric (Nico & Daprati, 2009). Some lesion studies found that these two frames of references in visual attention may be dissociative from each other (Marsh & Hillis, 2008; Medina et al., 2009). Some studies found that egocentric and allocentric frames of reference involved the dorsal and ventral

streams in the brain respectively (Committeri et al., 2004 Medina et al., 2009). Recent brain imaging studies found that aging process tended to affect some brain regions than the others particularly affected in aging process (Jernigan et al., 2001; Solbakk et al., 2008). More importantly, the brain regions subserving the two distinct reference frames were revealed to decline in different rate. It is likely that the decline in the allocation of visual attention between the allocentric and egocentric frame of reference of older subjects differs when compared with their younger counterpart. .

Although age-related change in visual attention has been a topic of interest for some time, the underlying neural processes being involved still require further investigation. Such aging effect on visual attention may due to the decline in individual's ability on capturing the sensory information, processing the captured spatial information, or both. Most of the previous studies on age effects on visual attention involved the participants to adopt an egocentric reference frame for locating and identifying the visual stimuli (Wang et al., 2012). In the other words, the aging effect of allocentric reference frame on visual attention is not well investigated. A recent brain imaging study found that older people showed involvement of extensive bilateral ventral visual stream when perceiving visual stimuli when compared with involvement of the left ventral visual stream in the younger group (De Sanctis et al., 2008).

Most of the previous studies in aging effect on visual attention adopted the central cue paradigm (Curran et al., 2001; Greenwood, Parasuraman, & Haxby, 1993; Yamaguchi, Tsuchiya, & Kobayashi, 1995). A central cue

paradigm involved subjects to use foveal vision for detecting the visual stimuli resulting in appearance of high resolution and clear images. In contrast to foveal vision, peripheral vision is sensitive for lower resolution and less clear images. Peripheral vision is the ability in spotting objects promptly in our environment to escape swiftly from danger (Crundall, Unerwood, & Chapman, 2002). Peripheral vision has been found to be important to older people and related to fall incidences in the older population (Freeman et al., 2007). With this in mind, the experimental design of this study used peripheral visual orienting as the results would be more appropriate and useful for their application and generalization to real life situations for the older population. In other words, the experimental task involved the subjects to view stimuli cue presented on the peripheral vision while the eyes are persistently fixated on a central position. This study aimed to investigate how aging process would influence the neural processes associated with allocation of visual attention by adopting an allocentric or egocentric reference frame by using a peripheral cue paradigm.

With reference to the other visual attention studies, early and later neural processes were expected to involve in detection and identification of the visual stimuli. The early process includes attentional control of sensory processing. The common markers for comparing between the two frames of reference and the young and older groups at this stage included the posteriorly distributed C1, P1 and N1. Although it is still controversial, C1 is thought to be the first event-related component which can be modulated by attention (Fu et al., 2009; Rauss et al., 2009; Rauss et al., 2011; Wang et al., 2012). It was found to reflect the initial

response to visual information in V1 and sensitive to stimulus characteristics e.g. spatial frequency and contrast. P1component is another event-related potential component affected by attention (Mangun et al., 1997). This component was found to associate with perceptual processing of the attended stimuli (Doallo et al., 2004). Posterior P1 is followed by N1 which was revealed to reflect enhanced processing of visual stimuli at the attended location (Luck et al., 1994). It may also relate to visual discriminative process (Mangun & Hillyard, 1991). The latency of P1 and N1 were found to be slower in the older than younger group in the attentional task (Kok, 2000). Both P1 and N1 elicited by the visual cue stimuli were extracted and analyzed in this study.

To further investigate how the priming effect of the visual cue would influence the subsequent spatial orienting and visual working memory (VWM) processes before the onset of the target stimuli, the N2, P3, contralateral delay activity (CDA) and contingent variation negativity (CNV) were explored.

HYPOTHESIS AND SIGNIFICANCE

Since egocentric reference frame develops earlier in life and is relatively implicit and automatic, the orienting processes under this reference frame should be more efficient in terms of reaction time and accuracy rate than those under the allocentric reference frame. Aging process leads to deterioration of orienting function as well as working memory function. As a result, the ability to hold the spatial information provided by the visual cue and to form the anticipation of the

subsequent visual target appearing at a specific location would be affected among the older subjects. The deterioration of these functions were expected to reflect from longer reaction time and lower accuracy rate on detecting and identifying the target visual stimuli by the older than younger subjects. Differences would be observed in the latency and amplitudes of the earlier and/or later ERP components associated with the spatial orienting and working memory processes.

To meet the challenges due to aging population, understanding the age-related changes in cognitive function has become increasing importance. Attention is one of the important cognitive functions in daily lives but it is also affected in aging process. If we can understand more how it is affected and even its underlying decline mechanism, subsequent intervention can be investigated to focusing on ways to preserve the healthy brain (Brayne, 2007). Besides, if the picture of aging effect on neural process in these encoding strategies can be clearer, corresponding intervention may be inspired to develop for the elderly with specifically impaired encoding strategy in visual attention.

CHAPTER TWO

LITERATURE REVIEW

The Importance of Visual Attention

The environment surrounding us provides overwhelming perceptual information at a time. To cope with this, visual attention allows us to select the most relevant information to react. Most importantly, visual attention can help us to prevent from dangers. For instance, when we drive a car, we have to attend to some important things such as traffic lights amidst tremendous other visual stimuli are simultaneously present. Although our eyes are confronted with tremendous visual information at the same time, we are still able to appreciate the visual world without effort. The reason is that only some visual stimuli are selected for processing over others (Farah, 2000). Visual attention, which is also known as visual selective attention, is the key to this cognitive process. As our brain has limited processing capacity, attention mechanisms will bias information processing in the brain, resulting in a selective perception of relevant from irrelevant visual information (Posner, 1980). Visual attention can help us identify the location of a specific object from the surrounding environment (Desimone & Duncan, 1995). For example, when we try to pick up a cup from the table, we need to be aware of the relative position of this cup and its handle in space. Visual attention allows us to orient ourselves and determine the positions of objects in the environment, which is important in our daily activities (Creem & Proffitt, 2001).

Visual attention is found to be involved in modulation of the perception and facilitation in the processing of visual information such as feature discrimination and spatial location (Carrasco, 2011). Different studies have shown that responses to targets are facilitated in terms of speed and accuracy if attention is previously oriented to the location where the target appears (Posner, 1980; Posner & Cohen, 1984).

Control of Visual Attention - Exogenous and Endogenous Mechanism

Visual attention biases information processing in the brain in order to select relevant stimulus from the vast amount of visual information (Carrasco, 2011). There are two fundamental ways from which we select information in the visual environment: we can either pay attention to salient objects (exogenous attention) or to interesting objects (endogenous attention) (Theeuwes et al., 2000).

Exogenous Attention

A salient object has distinguishing features against their surroundings to produce a pop-out effect which can easily draw our attention. In this situation, it is called exogenous mechanism of visual attention. This mechanism is regarded as involuntary, bottom-up or stimulus driven. It can be triggered by a salient stimulus appeared in the visual field, i.e. attention is spontaneously oriented towards an oncoming stimulus. For example, bright colour objects that stand out from the background, or a sudden flash in the dark will capture our attention

reflexively. The nature of such object's presentation is known as abrupt onsets or luminance transients (Yantis & Jonides, 1984). The exogenous mechanism of attention facilitates target identification, which occurs rapidly and is less susceptible to interference. It strongly correlates with activation of the right temporoparietal junction (TPJ) and inferior frontal gyrus (IFG) which are parts of a ventral frontoparietal network (Corbetta et al., 2002). The common experimental paradigm used to study exogenous orienting of attention is the application of peripheral stimuli as spatial cues and subjects are required to predict the locations of potential targets. Before the onset of the target, a cue is shown which may indicate the probable subsequent target location correctly (cued/ valid cued), or may indicate the subsequent target location incorrectly (uncued/ invalid cued). Facilitative effect is observed for cued trials in which reaction time for detection of the target is faster than uncued trials (Posner, 1980; Posner & Petersen, 1990). It is explained that the facilitative effect at the cued location represents saving of time in having already oriented to the target location by cue, whereas longer reaction time to uncued targets are resulted from the time required to disengage from an incorrect location and then reorient attention to a correct spatial location. Facilitative effect of exogenous orienting develops much rapid than endogenous (Muller and Rabbitt, 1989). The asymptote is reached at 150 ms cue-target onset asynchrony (CTOA). That means the facilitative effect for cued locations maximal at 150 ms after cue onset and declines with further increases in CTOA. On the other hand, if the target comes out after a longer cue-target interval (e.g. 300 or 500ms), an inhibition of return (IOR) effect is found, i.e., reaction time is slower for cued than uncued

trials (Muller & Rabbit, 1989; Posner & Cohen, 1984). This phenomenon in delayed response is named as inhibition of return (IOR) (Posner, Rafal, Choate, & Vaughan, 1985). IOR is explained as an inhibitory bias which prevents returning attention to previously attended locations (Lupianez, Klein, & Bartolomeo, 2006). It was believed previously that IOR was a robust and inflexible effect (Posner et al., 1985) but latter findings show that IOR is considered to be flexible and determined by the perceptual demands and sensory-motor complexity of the task (Lupianez et al., 2000). In general, the facilitative effect induced by exogenous orienting is larger in discrimination than detection tasks. On the other hand, IOR is smaller and later in discrimination than detection tasks (Chica, Lupianez, & Bartolomeo, 2006; Lupianez et al., 2001). Although peripheral cue was thought to induce IOR reflexively in long CTOA, a study found that it did not occur when the high-validity peripheral cues were used (Wright & Richard, 2000). This suggests that IOR can be cognitively mediated like goal-driven processes (Wright & Ward, 2008).

Endogenous Attention

Another attention mechanism is endogenous orienting of which preference would be placed on specific stimulus which is deemed congruent to the goal in mind (Moore et al., 2012), e.g. one looks for a known friend in a party. It is a top-down or internally driven process which involves effortful orienting (Lavie, 2005; Mayer et al., 2004). As a result, the process of endogenous mechanism demands more cognitive resources than that involved in the exogenous

mechanism (Cheal & Lyon, 1991). For endogenous mechanism, when locating an object among the others appeared in the visual field, an individual is required to tap on the knowledge-driven mechanism and put up the features and parameters which define that specific object (Carrasco, 2011). These parameters would guide a person to look for the relevant but discriminate the irrelevant objects. These processes require the prior knowledge of the features and parameters associated with the target object (Sarter et al., 2001). These processes were found to associate with BOLD responses in the bilateral dorsal intraparietal sulcus (IPS) and frontal eye field (FEF) (Shulman & Corbetta, 2012).

Typical paradigm design in endogenous orienting used centrally presented symbolic cue such as an arrow (Kastner, De Weerd, & Ungerleider, 2000). The time required for developing the facilitative effect in an endogenous cued condition was found to double that of an exogenous counterpart (Muller & Rabbit, 1989). It may due to the time required to focus the attention on the cue and then interpret it before executing a response (Wright & Ward, 2008). Such facilitative effect can sustain for one to two seconds (Muller & Rabbit, 1989; Posner, Nissen, & Ogden, 1978). Facilitative effect induced by endogenous cue is less dependent on the cue-target onset asynchrony (CTOA) (Yamaguchi, Tsuchiya, & Kobayashi, 1994) and not likely develop IOR effects (Posner & Cohen, 1984). IOR is a robust effect which inhibits the response to the visual stimuli appearing at recently cued or attended locations in terms of increasing the response times (Posner & Cohen, 1984).

How peripheral cues being modulated by the endogenous orienting mechanisms has been investigated with varying the CTOA. Exogenous cueing effect appears to decline rapidly, for instance a CTOA of 150 ms, while endogenous cueing effect sustain a longer period of time (McCormic, 1997). In this study, the subjects were instructed to attend to uncued locations prompted by peripheral cues (i.e. attend to locations opposite of the cue location) before the target onset. This condition resulted in longer CTOAs (500 and 1000 ms). The reason for longer CTOAs was that peripheral cues would enable subjects to have enough time to overcome the IOR effect which occurred relatively early in the process (Wright & Richard, 2000). Other researchers further suggested that use of peripheral cues in visual attention task would elicit an initial exogenous driven capture of information followed by an endogenous driven maintenance of this information (Warner, Juola, & Koshino, 1990). Peripheral cues henceforth would induce an automatic followed by a voluntary. This study used peripheral cues to elicit subsequent attentional responses.

Visual Attention - Overt and covert orienting processes

Overt Orienting

Orienting is the first step of the attention process which can improve efficiency of processing targets and resulting in response more rapidly (Posner & Petersen, 1990).

Selective visual attention can be modulated by eye and/or head movements. Foveation resulting in better acuity visual inputs can be achieved by these body movements (Rybak et al., 1998). Overt orienting refers to the attentional processes which involve movements of the eye and hence obtains higher resolution of the visual image formed from the stimulus. Both overt and covert orienting would activate similar neural networks involving the occipital, temporal and parietal lobes. However, the frontal eye field was found to be unique to overt orienting in task involving saccadic eye movements to visual stimuli (Nobre et al., 2000).

Covert Orienting

Attentional processes achieved without any overt eye or head movement is known as covert orienting. Posner and his colleagues conceptualized three distinct processes associated with covert orienting (Posner et al., 1988). The processes involve: 1) disengage the attentional focus from the location of the currently attended stimulus; 2) shift the focus to a new location where another stimulus exists, and 3) engage the focus on the new stimulus (Posner & Dehaene, 1994; Posner & Petersen, 1990). The posterior parietal cortex was revealed to mediate the disengagement process (Posner et al., 1984, 1987), while the shifting of focus was mediated by the superior colliculus (Posner & Driver, 1992; Robinson & Kertzman, 1995), and reengagement of focus was mediated by lateral pulvinar of the thalamus (Petersen et al., 1987; Posner & Driver, 1992). Some other neural substrates such as anterior cingulated, lateral frontal cortex and basal ganglia were also found to be involved in target detection and response

preparation (Posner & Driver, 1992). The role of the parietal cortex in disengagement during covert orienting is supported by some lesion studies in which all neglect patients were found to have lesions at the right parietal lobe, or to its ipsilateral prefrontal cortex (Bourgeois et al., 2012; Losier & Klein, 2001).

Covert orienting is an important function for improving the efficiency on locating visual targets because it could facilitate visual task performances without eye movements (Deubel & Schneider, 1996; Kowler et al., 1995). Some behavioural studies have demonstrated that attentional shift towards the visual object occurred before the actual saccade movements of the eye (Hoffman & Subramaniam, 1995; Irwin & Gordon, 1998). Besides, it was found to affect trajectories of eye movement (Sheliga et al., 1995) and guide the eyes to an appropriate area of visual field for producing an efficient gaze (Kowler et al., 1995; Motter & Simoni, 2008). The visual experimental task used in this study involved covert orienting elicited by peripheral cues.

Visual Attention - Egocentric and Allocentric Encoding Processing

Another factor that modulates visual attention is the frame of reference which individual takes when perceiving visual stimuli. It acts on the ways which individual encodes the incoming visual information. The selection of different objects or events to encode in orienting attentional process can be modulated by how an individual relates oneself to the environment (Goodale & Haffenden, 1998; Hasselbach-Heitzeg & Reuter-Lorenz, 2002). The spatial frames of

reference (or coordinates) can largely be classified into egocentric (viewer-based) and allocentric (object-based) (Behrmann, 2000). Previous studies suggested that visual attention largely tap on both egocentric and allocentric encoding processes (Behrmann, 2000; Fink et al., 1997; Marshall & Halligan, 1993).

Egocentric Frame of Reference

For egocentric processes, positions of objects are identified and located with reference to the observer (Figure 2.1a). That is, locations or objects are represented in the viewer-centred coordinate system. Hence the relationship between the object and the viewer is the key of egocentric encoding. Previous studies indicated that specific body parts were used as the frame of reference when external visual stimuli were encoded, such as the eyes, head, trunk and even the hand (Bisiach, 1996; Karnath, 1994). Egocentric encoding is found to be crucial for defining the position of the body in space as well as localizing and reaching objects in space (Batista et al, 1999; Karnath et al., 1997). Besides, it is available early in life (Lehnung et al., 2003). This encoding frame gives us an automatic and implicit way for locating objects visually (Chua & Chun, 2003; Waller, 2006).

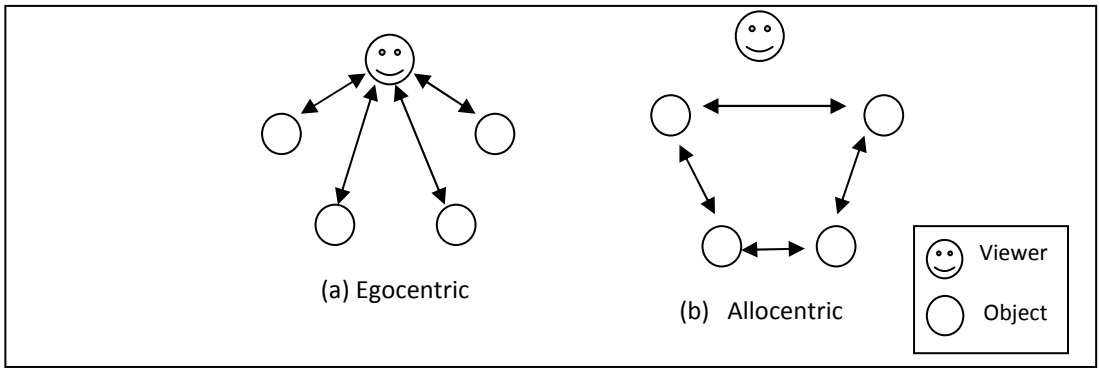


Figure 2.1. Frame of reference of allocentric and egocentric encoding processes

(Adopted from Vogeley & Fink, 2003)

Allocentric Frame of Reference

Allocentric encoding is also known as exocentric or object-based spatial encoding. In contrast to egocentric encoding, an object is located with reference to the other objects in the environment in an allocentric reference frame (Figure 2.1b). In other words, the properties of the objects become the key of allocentric encoding and therefore it is not affected by the viewer's positions (Behrmann, 2000; Vogeley & Fink, 2003). Previous studies found that the spatial information would remain unchanged in different perceptual encoding positions or situations by allocentric encoding. That means allocentric encoding is more robust than egocentric encoding (Burgess, 2006; Farah, 2000). While egocentric encoding develops early in life (Lehnung et al., 2003), allocentric encoding developed later in life. It is suggested that it develops in adolescent age when the temporoparietal cortex becomes more mature (Pine et al., 2002).

Neural Correlates of Egocentric and Allocentric Processing

Egocentric and allocentric encoding processes are thought to be mediated by different neural circuits. The two encoding processes were found to activate dorsal occipitoparietal and ventral occipitotemporal pathways respectively (Grimsen, Hildebrandt, & Fahle, 2008; Zaehle et al., 2007). The dorsal pathway subserves goal-directed actions. In contrast, the ventral pathway subserves object perception (Goodale & Milner, 1992; Milner & Goodale, 1995). Single cell recordings in monkeys and functional imaging of the human brains support such dissociation with the parietal (Carey, 2000; Medendrop et al., 2005) and pre-motor cortices (Cisek & Kalaska, 2002) in egocentric but not allocentric encoding of visuospatial information. Other neuroimaging studies further suggested that the frontal cortex was important in egocentric but less in allocentric encoding (Galati et al., 2000; Vallar et al., 1999). In the study conducted by Galati et al., the subjects had to report the left–right position of the vertical bar relative either to the body mid-sagittal plane (body-centered task) or to the midpoint of the horizontal line (object-centered task) (Figure 2.2). The findings suggested that the bilateral and mainly the right frontoparietal networks appeared to mediate the egocentric encoding. These networks are also known as the dorsal attentional networks.

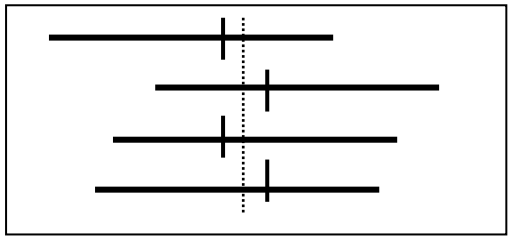


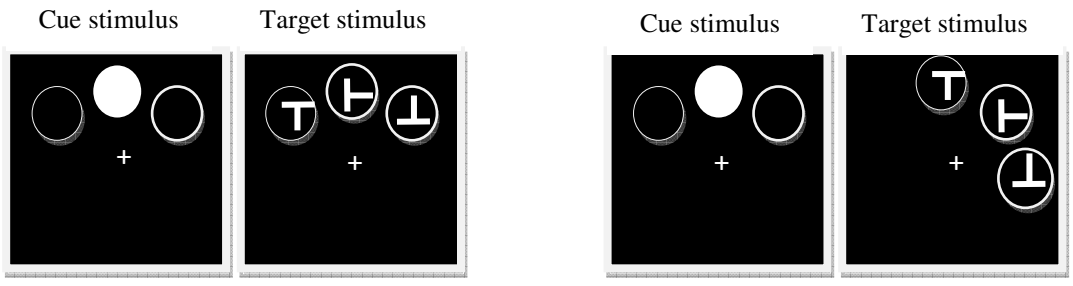
Figure 2.2. Experimental designed by Galati and colleagues

Committeri and colleagues (2004) used a different paradigm to demonstrate the neural processes associated with egocentric versus allocentric encoding. The task involved the subjects to judge the positions of target objects within a 3-D virtual environment. The virtual environment was a square arena in a park. In each trial, subjects were shown three objects: a red ball as the reference object, and a big green and a small blue garbage can as the target objects. In the egocentric condition, subjects were instructed to respond as quickly as possible by pressing the button corresponding to the garbage can that was closer to their current position. In the allocentric condition, subjects were instructed to choose the garbage can that was closer to the reference object (red ball). In the control task, the subjects were to choose the can which was lying on the ground. The results showed that the premotor and the posterior parietal cortices were activated in both the allocentric conditions. The increases in signals in the left inferior frontal cortices and right superior frontal were greater in the egocentric than the allocentric condition. The allocentric condition showed greater signals increased in the bilateral lateral occipitotemporal cortex than egocentric condition. It shows that allocentric and egocentric condition are subserved by ventral and dorsal network respectively.

In another study, both egocentric and allocentric conditions were found to activate the bilateral posterior parietal cortex and premotor cortex (Galati et al., 2000). Despite most of these neural substrates were found to be common to both encoding processes, activations of the bilateral hippocampal formation was only found in the allocentric but not egocentric condition (Galati et al., 2000). The cognitive map theory was proposed based on the hippocampal function (O'keefe & Nade, 1978). Recent studies also supported that the hippocampus mediated the development of representations of the objects' locations in the environment. These representations of locations would provide the basis for navigation relying on visuospatial memory (Bohbot et al., 2004; Burgess et al., 2002; Nadel & Hardt, 2004). Galati and colleagues revealed that subjects' performance on the line bisection task, commonly used for assessing allocentric neglect, had stronger activations in the right hippocampal in the allocentric than the egocentric condition.

Egocentric and allocentric are the two commonly used frames of reference in our daily life for modulating the allocation of visual attention (Behrmann, 2000; Fink et al., 1997; Marshall & Halligan, 1993). However, studies on the effects of the two reference frames on influencing visual attention are limited. A behavioural study conducted by Barrett and colleagues (2001) employed a triad-circle localization design task. The cue indicated the probable location of the target appearing as an illumined circle among the triad-circle figure. After 150ms of the cue offset, the target appeared which was defined by the circle marked with a $\pm 90^0$ rotated "T" (Figure 2.3). The circles marked with erected "T" or

upside down "T" were the distracters. The rules set for a valid cue-to-target trial were different for the egocentric and allocentric conditions. For the egocentric condition, a valid cue-to-target trial was that the position of the target circle in the triad-circle figure marked by a ±90º "T" located at the exact location of the illuminated circle in the triad-circle cue (Figure 2.3a). For the allocentric condition, a valid cue-to-task trial was that the position of the target located at the same relative location of the cue (Figure 2.3b). The skeleton of the experimental task was based on four basic cue to target spatial relationships: (1) valid in both egocentric and allocentric frameworks (Figure 2.4a), (2) valid in egocentric coordinates only (Figure 2.4b), (3) valid in allocentric coordinates only (Figure 2.4c), and (4) not valid in either framework (Figure 2.4d). The advantage of this task design was that appearance of the cues and targets were the same for both the egocentric and allocentric conditions. This design enables direct between-condition comparisons which is particularly useful in capturing event-related potentials which was the case in this study



(a) Valid egocentric

(b)Valid allocentric

Figure 2.3. Examples of valid egocentric and allocentric cued conditions (Barrett and colleagues, 2001)

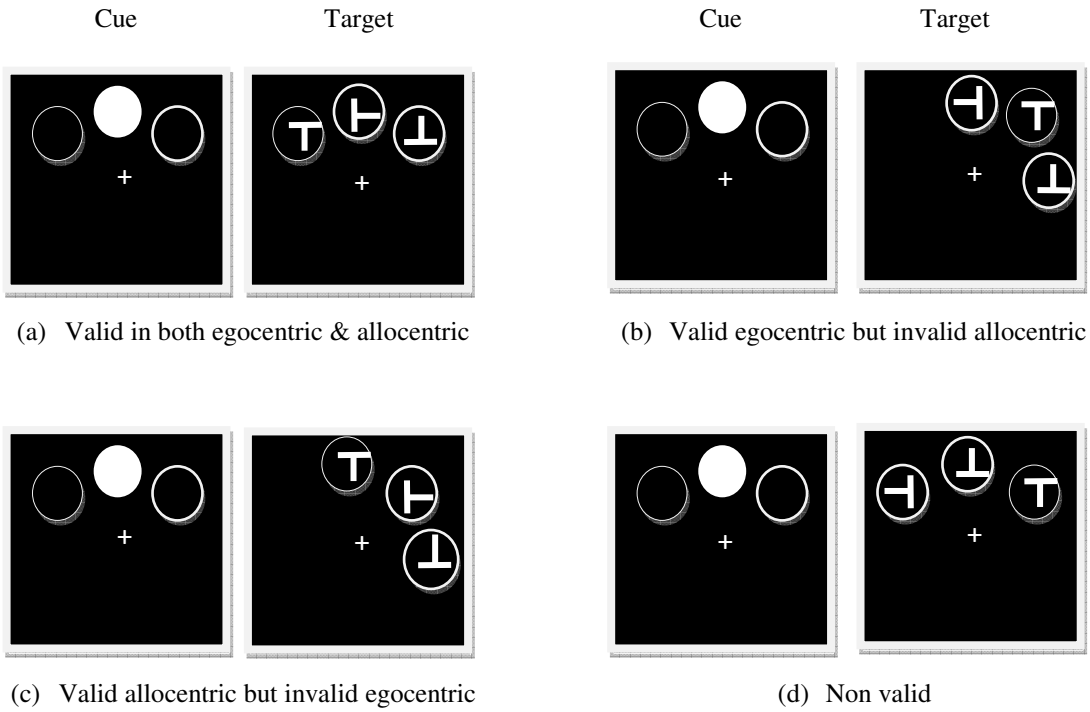


Figure 2.4. Illustration of four different kinds of cue-to-target spatial relationships used in the task design (Barrett and colleagues, 2001)

The Effect of Aging on Visual Attention

Although age-related changes in visual attention have been well investigated (Kok, 2000), the underlying cognitive processes being involved are still not fully understood. Some studies found that the effect of aging on visual attention may involve decline in the early processing, such as sensory processing of visual stimuli (Grady et al., 1994; Plomp, Kunchulia, & Herzog, 2012) or problems in modulating visual sensory processing in a top-down manner (Curran et al., 2001). Most of the previous studies that explored the effects of aging on visual attention mainly required subjects to adopt an egocentric frame of reference (Posner, 1980; Wang et al., 2012). The typical task used in previous

studies was to identify the cued target on the left or right side with reference to the body or self of subjects. Previous studies also did not focus on the possible dissociation of the egocentric and allocentric orienting processes in older people, particularly using event-related potential (ERP). There were few studies published on this topic. The first study compared the performances of younger and older subjects on seven visuospatial tasks (Chen, Myerson, & Hale, 2002). Three of the tasks assessed the ventral visual-pathway related functions with unnameable shapes, puzzle pieces and abstract matching. The other four tasks assessed the dorsal visual-pathway related functions with curve tracing, dot location, two-dimensional mental rotation and three-dimensional mental rotation. The findings showed that older subjects had much weaker correlations among the tasks tapping on the similar visual-pathways than those from the younger subjects group. The result suggested that the functional distinction between the ventral and dorsal visual-pathways were decreased in the older but not the younger subjects. A recent brain imaging study revealed that older subjects tended to show more extensive bilateral involvement of the ventral visual-pathway in visual attention task while younger subjects tended to involve unilateral ventral visual-pathway (De Sanctis et al., 2008).

Although previous studies provided insights into the possible age-related changes in egocentric and allocentric visual attention, the specific neural processes contributing to the observable differences are still not clear. This study was designed to address this question using event-related potentials associated with egocentric and allocentric encoding of visual cues.

Most of the previous studies that investigated the effect of aging on visual attention adopted a central cue paradigm (Curran et al., 2001; Greenwood, Parasuraman, & Haxby, 1993; Yamaguchi, Tsuchiya, & Kobayashi, 1995). These tasks involved older subjects' foveal vision. The functionality of foveal vision was found not as essential as peripheral vision among older subjects as the latter was deemed more crucial for facilitating escape swiftly from danger (Crundall, Unerwood, & Chapman, 2002). A recent study revealed that peripheral vision was crucial for localizing obstacles in fall prevention among older subjects (Freeman et al., 2007). With this in mind, the experimental design used in this study adopted peripheral visual cues for prompting egocentric or allocentric-based encoding for localizing subsequent targets.

Event-related Potential (ERP) and Visual Attention

Changes in electrical field potential and time-locked with motor, sensory or cognitive events are known as event-related potentials (ERPs). It consists of voltage deflections that represent the neuronal activity against time. The time course has high resolution in the order of milliseconds. As neural processing associated with visual attention occurred within a relatively short period of time, ERPs can reveal the neural processes in terms of latency and amplitudes of different components elicited from different location on the scalp of the brain (Mangun et al., 2001).

Early Components

Individual's attentional state can modulate one's expectation and hence the subsequent stimulus-locked responses (Chawla, Rees, & Friston, 1999; Kastner, 1999). For visual stimuli, the neural activities associated with expectation of stimuli were found in the visual cortex (Kastner, De Weerd, & Ungerleider, 2000). These activities were revealed to contribute to enhancement of processing of the stimulus (Sylvester et al., 2009). The early neural processes were previously found to be reflected from enhanced amplitude of posteriorly distributed C1 (Fu et al., 2009; Rauss et al., 2009; Rauss et al., 2011; Wang et al., 2012), P1 and N1 over the occipital and occipitoparietal areas (Luck, 2005).

The C1 was found to reflect the initial response to visual information in V1. Although it is still controversial, some studies found that it was the first ERP component to be modulated by attention and perceptual load (Fu et al., 2009; Wang et al., 2012).

The P1 component had a latency of about 80 ms after the onset of visual stimulus elicited from the contralateral extrastriate visual cortex (Mangun et al., 1997). The amplitude and latency of the P1 was reported to associate with the processes of visuospatial selective attention (Fu et al., 2001) and non-spatial perceptual processing of attended stimuli (Doallo et al., 2004). The P1 would be modulated by external cues presented prior to the visual stimulus. For instance, prior cue of object's location was reported to result in a relatively shorter latency and more positive P1 (Fu et al., 2001), which perhaps was due to the external cue activating larger number of neurons hence producing larger bioelectrical

potentials of P1 (Proverbio & Zani, 2003). The P1 may be a useful marker for reflecting active attention and possible cueing effects. Endogenous spatial orienting has been found to be involved in linking areas in the posterior parietal and dorsal frontal areas. Interaction between this frontoparietal network with extrastriate regions of the visual system results in enhancing visual processing (Corbetta, 1998). They are the early process involved in the attentional control of sensory processing and are the common markers for comparing between the young and aged group.

The N1, which follows the posterior P1, reflects processing of visual stimuli at the attended location (Luck et al., 1994). Researchers further demonstrated that its amplitude was modulated by stimulus characteristics and spatial attention (Hillyard & Anllo-Vento, 1998; Luck and Ford, 1998; Mangun, 1995; Natale et al., 2006). Similar to P1, visual stimuli that fell onto an attended location elicit more negative-going N1 at the posterior electrode locations than did stimuli fall onto the same location but not attended to. These early effects indicate that attention can modulate processing even at an early sensory stage.

Late Components

If earlier components such as P1 and N1 are related to responses to the physical properties of stimulus, later components in the waveform are likely to reflect the cognitive processes associated with processing of the stimulus (Koivisto & Revonsuo, 2010). Literature suggests that late components of the N2, P3 and the posteriorly distributed contralateral delay activity (CDA) are useful

markers for reflecting attentional control and its related visual working memory (VWM).

The negative-going N2 component peaks at about 250-300 ms. Three subcomponents of the N2, which included the posterior and anterior N2, were found to be elicited in attending to a visual stimuli. The posterior N2 was considered to involve in the selective processing which was modulated by the degree of discrimination process involved for the attended visual stimuli (Tachibana, Aragane, & Sugita, 1996). Two anterior subcomponents were proposed in which one of them involved cognitive control for response inhibition, response conflict and error monitoring. Another anterior subcomponent was found to relate in the post-selection processes of further task-directed processing the relevant stimuli (Foltstein & Patten, 2008; Kenemans, Smulders, & Kok, 1995; Smid, Jakob, & Heinze, 2003).

The P3 component followed N2 has a latency of around 300-600 ms after the onset of the stimulus. It is predominantly elicited in the frontal regions and was found to be associated with orienting and responding to unexpected stimuli such as in an odd ball paradigm (Polich & Criado, 2006) and the invalid cued condition (Martens et al., 2006). The P3 was found to be sensitive in aging in previous studies (Kutas, Iragui, & Hillyard, 1994; Polich, 1997). The P3 component has been extensively studied and proposed to relate the resource allocation for a relevant stimulus (Polich & Criado, 2006).

In an odd ball paradigm, target stimuli are presented infrequently when compared to the distractor stimuli which are presented more frequently. For an uncued condition, the target stimuli are presented in locations that are not indicated by the cue. The P3 component was found elicited when subjects detected the unexpected target, which was explained as effortful allocation of attention resource to a task (Isreal et al., 1980). Besides, P3 component was also found to reflect brain activities associated with the mental representation generated by incoming stimuli (Donchin, 1981). The onset latency of P3 is regarded as the speed of stimulus evaluation (Magliero et al., 1984). A short P3 onset latency is related to faster processing speed that reflects advanced cognitive performance (O'Donnell et al., 1992).

CDA is also known as sustained posterior contralateral negativity (SPCN) which has been used as a marker of activities related to visual working memory (VWM) before target onset (Jolicoeu, Brisson, & Robitaille, 2008; Vogel & Machizawa, 2004). Its peak latency was found to be around 450 ms appearing as a more negative-going component elicited at the parieto-occipital and parietal regions. The CDA is a difference waveform by subtracting the ipsilateral from the contralateral sides of brain. Recent studies found that the CDA amplitude was enhanced by increasing the load of the VWM (Gao, 2011; Jolicoeu, Brisson, & Robitaille, 2008; McCollough, Machizawa, & Vogel, 2007). All these studies commonly required the subjects to hold the visual information in mind during the retention interval. Then, they had to make a response to the test stimuli to indicate whether it had been displayed before or not. The mean amplitude of

CDA was found to be increased with memory load e.g. increased number of items or the complexity of features to be retained. These findings suggested that the CDA amplitude was modulated by the degree of top-down control required by the task. However, there is a limit for such amplitude enhancement. That is, despite continued increase in memory load, CDA amplitude did not increase when it reached to the subject's maximum working memory capacity (Veronica, Perez, & Vogel, 2012). Given that working memory varies among different age groups, CDA was therefore suggested to be a useful indicator for studying age differences in working memory function (Sander, Werkle-Bergner, & Lindenberger, 2011).

Walter and his colleagues (1964) discovered the contingent negativity variation (CNV) and its properties were investigated extensively (Cui et al., 2000; Gomez et al., 2001; 2003; 2007; Nagai et at., 2004). It is a sustained negative slow potential which is generated for preparing an imperative stimulus (S2) with a predictable delay after a warning stimulus (S1) (Walter et al., 1964). This ERP component is postulated to have early and late phases.

An early phase is activated at about 400 to 500 ms after the warning signal (Gomez et al., 2003; 2007; Gonzalez-Rosa et al., 2011). It is related to orientation to the warning stimulus (Weerts & Lang, 1973), anticipatory process (Bender et al., 2004; Brunia & Damen, 1988; Ruchkin et al., 1986) and executive function (Segalowitz et al., 1992). Anticipatory processes and executive function are thought to be carried out by frontal lobes (Fuster, 2000).

The late phase relates to the motor preparation for the response (Cui and Deecke, 1999; Cui et al., 2000). It is activated at about 300 to 500 ms preceding the imperative stimulus (Bennett et al., 2004; Gonzalez-Rosa et al., 2011). The possible origin of this late phase process related to motor preparation was suggested to be in the primary motor cortex (M1) (Gomez et al., 2001; Vidal et al., 1995).

Aims of the Present Study

Not much is known about the underlying cognitive processes that mediate the egocentric and allocentric visual attention despite dissociations have been found between the two encoding mechanisms (Galati et al., 2000; Vallar et al., 1999). As dissociation in pathways between allocentric and egocentric visual attention was reported in a few lesion studies (Behrmann & Geng, 2002; Ota et al., 2001), different processes may be involved in these two types of visual attention. Along a separate line, there were few previous studies that investigated how aging affect egocentric and allocentric visual attention. The need of exploring how aging affecting cognitive processes in egocentric and allocentric visual attention using ERPs henceforth is obvious. The results obtained from normal healthy subjects can serve the basis for studying patients who have deficits in visuospatial attention.

Specific Research Questions

The following questions were asked in this study:

1. Do the early sensory processes in visuospatial attention differ between egocentric and allocentric conditions?
2. Do the late cognitive processes in visuospatial attention differ between egocentric and allocentric cued conditions?
3. Does aging affect the early or later cognitive processes of visual attention differently between egocentric and allocentric frames of reference?

CHAPTER THREE

METHODS OF STUDY ONE AND TWO

This chapter covers the methods of Study One and Study Two. It describes the experimental design, measures, procedure and statistical analysis used in these two studies. The aim of Study One was to investigate the cognitive processes of covert visual attention which was modulated by egocentric and allocentric frames of reference in a group of young adults. The results would provide the foundation and paved the way for comparing the effect of aging in Study Two in which the participants were older adults. The procedures and measures used were similar in these two studies.

METHOD OF STUDY ONE:

Modulation of Visual Attention by Egocentric and Allocentric Frames of Reference in the Young Adults

Subjects

Eighteen young individuals (8 female) participated in this study through convenience sampling on a voluntary basis. They were invited to attend the experimental session at Applied Cognitive Neuroscience Laboratory, Department of Rehabilitation Sciences, The Hong Kong Polytechnic University. Informed written consent (Appendix I & II) was obtained from all participants prior to

being tested according to procedures approved by Departmental Research Committee of Department of Rehabilitation Sciences, The Hong Kong Polytechnic University (PolyU) (Appendix III). The purpose and procedure of the experiment were summarized and presented on the information sheet (Appendices IV & V). Data of one participant was excluded from the analysis due to excessive eye movement artifacts. Thus, data from seventeen individuals (7 female) aged 18-23 years (mean $\pm$ SD = 20.8 $\pm$ 1.2 years) were included in the final data analyses. To ensure strong right handedness, the Annett Handedness Questionnaire (Appendix VI) was administered for each participant (mean $\pm$ SD = 12.89 $\pm$ 0.94, a scale of 36, from 36 i.e. extremely left handed, to 12 i.e. extremely right handed) (Annett, 1970). None of the participants reported history of neurological, psychiatric or ophthalmological diseases. All participants had visual acuity of at least 20/25 which was tested by Snellen eye chart. The experimental protocol was approved by the Departmental Research Committee of Department of Rehabilitation Sciences, PolyU.

Materials and procedure

Apparatus and Setup

The experiment was conducted in a sound attenuated, electricity shield and totally darken chamber that contained a 15-inch colour monitor. Participants were seated at a distance of 700mm in front of the monitor. Head and eye height were stabilized by a chin and forehead support. The position of the monitor was adjusted in the vertical and horizontal direction so that the fixation point at the

centre of the screen was at eye level in the centre between two eyes. Viewing was binocular.

No lighting other than the stimuli was produced during the whole experiment. All stimuli, which were generated by the STIM software, were presented on a 15-inch colour monitor with 1280 x1024 mode and refresh rate of 60 Hz. Luminances of the displays of cue and target were 0.50 lux and 0.60 lux respectively.

Paradigm Design

The paradigm of this study was modified from the Barrett's (2001) design. The presentation schedule of the cueing and task stimuli is summarized in Figure 3.1. Each trial began with a fixation cross "+" at the centre of the screen that was presented randomly for the duration between 800 and 1000 ms. The variation in the exposure time of this fixation cross was used to minimize the slow anticipatory potentials that would be generated when a constant exposure time were used (McDonald & Green, 2008). The fixation cross would maintained on the screen until the target offset. Thereafter, a cue stimulus composed of 3 circles appeared and these were displayed for 100 ms. After the re-fixation period for 1200 ms, the group-of-three "T" object target (a "T" with $\pm 90^0$ orientation) and two distracters ("T" in upright (0^0) or 180^0 orientation) were presented for 300 ms. After the onset of the group-of-three "T" object target, the participant was given 1,500 ms to give the response by pressing the left or right button of a keypad for the target "T" with 90^0 orientation to left and right respectively,

which laid on top of a cushion supported on the participant's laps, with left or right thumb respectively. A blank screen was then displayed for 500 ms before the next trial began, no matter the participant had made a response or not. Summary of schedule of stimuli presentation in one typical trial is illustrated in Figure 3.1.

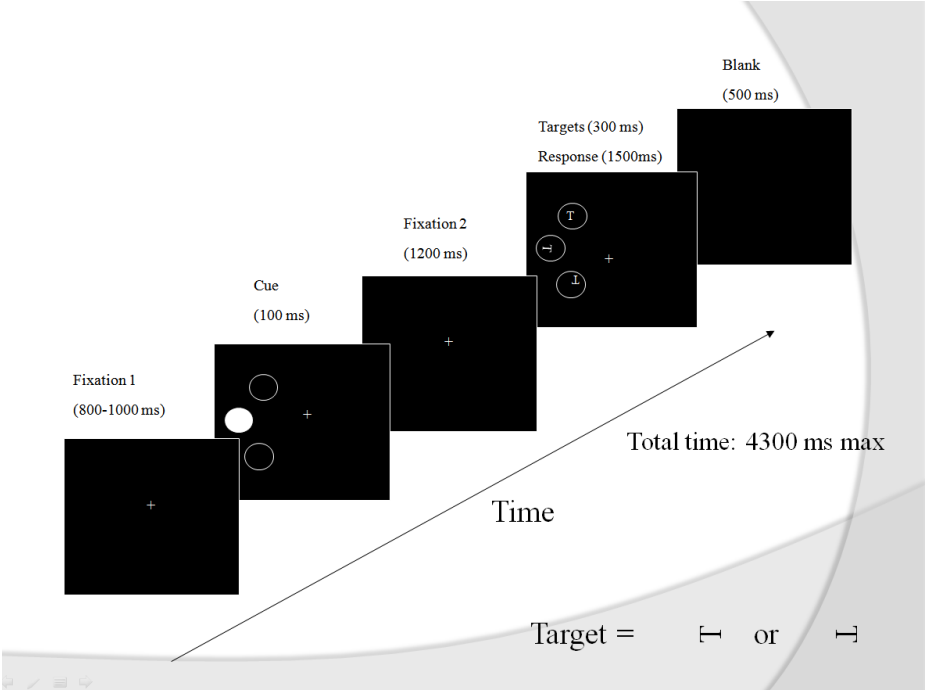


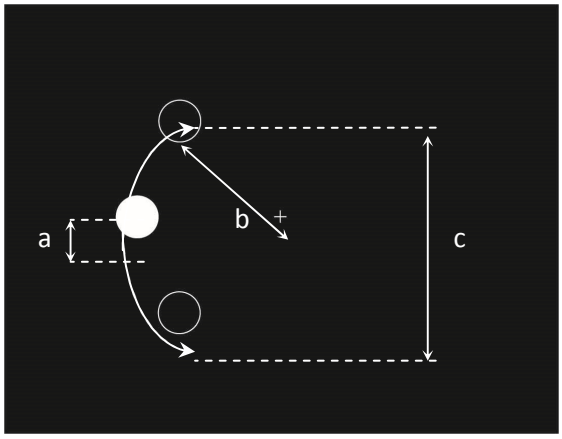
Figure 3.1. Illustration of the sequence of events for each trial

The sequence of trials was randomized in each block by a computer program while the blocks of presentation were counterbalanced by Latin square design (Appendix VII). There were 44 trials in each block, a total of ten blocks in each of the egocentric and allocentric tasks. It gave total of 20 task blocks for the entire experiment. It took about 3.2 minutes to complete one task block. About one minute of break was provided between blocks and additional time for rest

was arranged upon requested by subjects. Altogether, it took about 2 to 3 hours to complete the entire experiment.

Cue Stimuli

The function of the cue was to guide the participant to attend to the likely location of a subsequently presented target with a particular frame of reference. The cueing stimulus was in group-of-three circles drawn with white lines in a black background in the computer screen. One of these circles was illuminated to indicate the likely location of a subsequent target. This illuminated circle could be either on the upper, middle or the lower of the group-of-three circles as shown in Appendices IX. The cue appeared on the left or right side of the fixation cross randomly. There was no illuminated circle on midline, i.e. top or bottom of the screen. Each circle subtended 1.76^0 with their centres at an eccentricity of 7.75^0 from participant's eye fixation. The array of the three circles subtended 9.2^0 (Figure 3.2).



a: 1.76^0

b: 7.75^0

c: 9.2^0

Figure 3.2 . Visual angles of cue stimulus

Same sets of cue stimuli were used for both egocentric and allocentric conditions. Therefore the physical appearance of the cues for egocentric and allocentric tasks were the same. The difference was the rules which governed the interpretations between the two tasks. For the egocentric task, the absolute location of the illuminated circle was attended as the subsequent target "T" would be very likely present in that location. For the allocentric task, the participant had to attend to the relative location of the illuminated circle with reference to the other 2 circles until the presence of target stimulus. With clear demonstration and practice, all subjects were ensured to understand the instruction before the task set begun.

Altogether, there were 22 cues in each hemi-field per block among which 16 were assigned to be valid, i.e. 72.73%. The definition of valid and invalid cues in egocentric and allocentric conditions will be given later in the Task Section. Both hemi-fields shared the same designs of cue but in a mirror-image manner (Appendices IX).

Target Stimuli

The function of the target was to test the effects of the cues in egocentric and allocentric conditions in terms of reaction time and accuracy rate. Target stimuli would appear at the same hemi-field as the cues. Each stimulus was composed of one target and two distracters which were presented as a group-of-three white "T" objects arranged in various orientations on the screen (Figure

3.3). The visual angles of target triad were the same as cue triad. The locations of target and its distracters were randomly assigned within the group-of-three cluster position. A target was a "T" with $\pm 90^0$ orientation while the distracters can be in upright (0^0) or 180^0 orientation. The target and distracter "T" objects subtended the same angle and eccentricity as the cues. The stimuli used for the egocentric and allocentric tasks were the same.

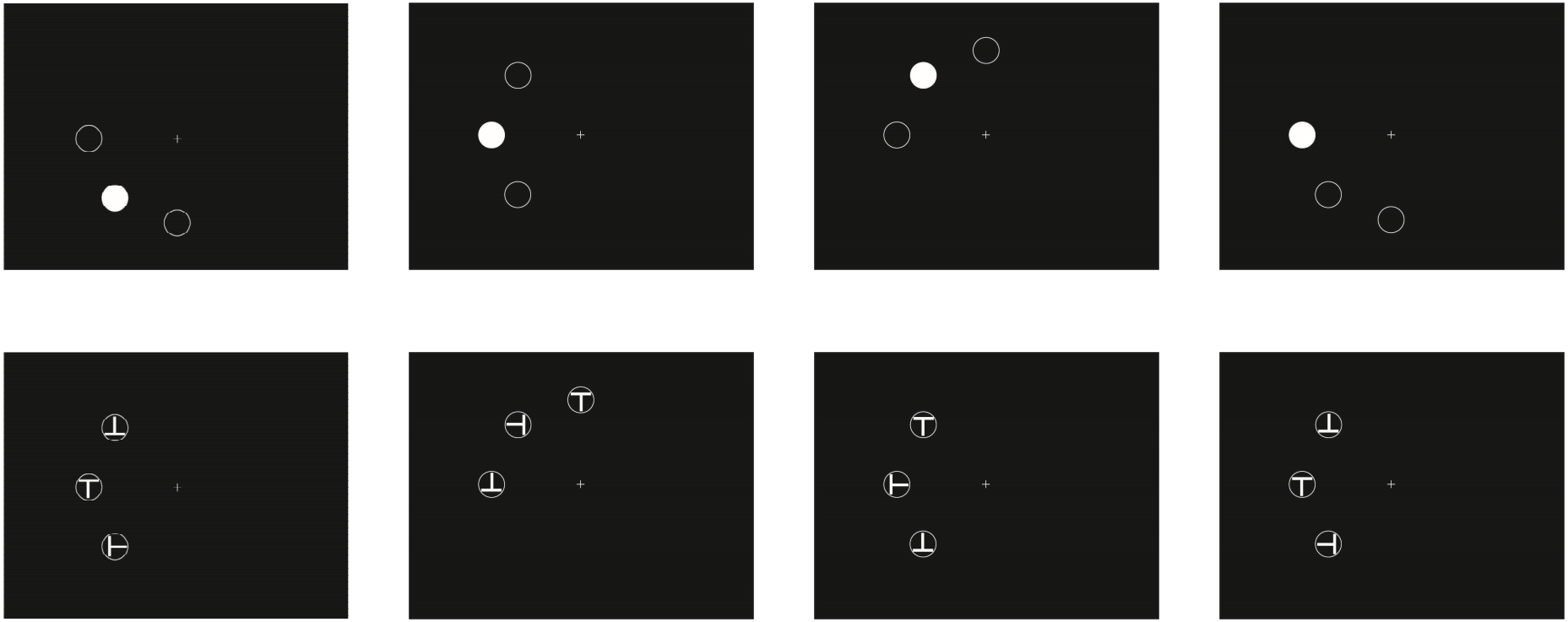
Figure 3.3

Example of the group-of three "T" objects presented in stimuli; the group-of-three stimulus has one target object (circled with dashed line which was for illustration only but not present in the experiment) and two distracter objects.

The Task

The cue stimulus was regarded as valid when the subsequent target ("T" with $\pm 90^0$ orientation) appeared at the cued location. The rules set for the valid cued location between the egocentric and allocentric tasks were differed. For the egocentric task, a valid trial was that the position of the illuminated circle which was the cue shared the same exact location as that of the target "T" object (Figure 3.4 & 3.5). For the allocentric task, a valid trial was that the position of the illuminated circle which was the cue occupied the same relative position among that in the group-of-three positions as the target "T" (Figure 3.4 & 3.5).

Invalid trial was that the location of the illuminated circle which was the cue different from those stipulated by the rules for defining the valid trials for both tasks (Figure 3.4 & 3.5).



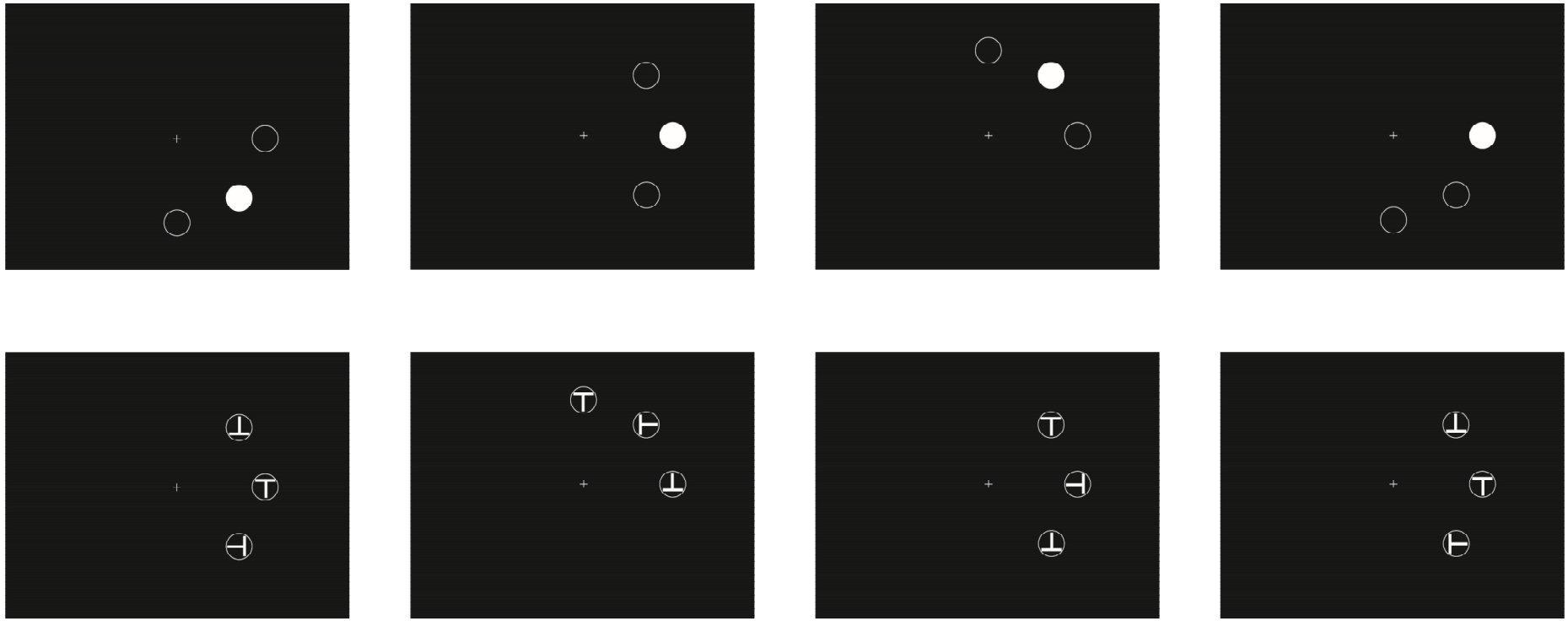
Example of valid trial in egocentric condition: Illuminated circle and target T ($\pm 90^0$ rotated) shared the same absolute location

Example of invalid trial in egocentric condition: cue and target T ($\pm 90^0$ rotated) were not in the same absolute location

Example of valid trial in allocentric condition: position of the illuminated circle occupied the same relative position among that in the group-of-three positions as the target "T" (i.e. middle in this example)

Example of invalid trial in allocentric condition: relative position of the illuminated circle in relation to the other 2 circles differed from the relative position of target T with reference to the distracters

Figure 3.4. Illustration of valid and invalid trial with cue present in left visual field



Example of valid trial in egocentric condition: Illuminated circle and target T ($\pm 90^0$ rotated) shared the same absolute location	Example of invalid trial in egocentric condition: cue and target T ($\pm 90^0$ rotated) were not in the same absolute location	Example of valid trial in allocentric condition: position of the illuminated circle occupied the same relative position among that in the group-of-three positions as the target "T" (i.e. middle in this example)	Example of invalid trial in allocentric condition: relative position of the illuminated circle in relation to the other 2 circles differed from the relative position of target T with reference to the distracters

Figure 3.5. Illustration of valid and invalid trial with cue present in right visual field

Procedures

1. Training Session

Before commencing the actual experiment, the subjects had to attend a training session which was about 1-2 hours for learning of keeping the eyes fixating on the centre of screen throughout the trial and the two spatial coding strategies to be used in the task. Eye movement was monitored by a camera with computer program called Eye Tracker. In order to ensure the subject had learnt the strategies, s/he was to achieve at least 80% of accuracy rate without any excessive eye movements.

In fact, to ensure the subjects having normal visual field, this session also served as visual field testing of the subjects by Eye Tracker during the calibration process. During this process, it required the subjects to fixate their eyes without head movement on four spots which presented one by one in a row with equal distance on the screen. Altogether there were four rows (i.e. 16 spots in total) which ultimately covered the whole screen's area. Subsequent training session could be allowed by the Eye Tracker program only if this calibration process was successfully completed which in turn was determined by detecting all these spots and then fixating on them with eyes correctly. The visual angle of the spot presented at the end range was 13.0^0 which far exceeded the visual angle of visual stimuli presented in the experiment (7.75^0). In other words, all subjects who could complete the calibration process before the training session should be able to see the visual stimuli presented on the screen during the experimental session.

2. Experimental Session

The experimental session was conduct on the same day as the training session. It was about 3 hours for capturing the ERPs when performing on the task. After about an hour for cap setup in the chamber, the subject had to be re-tested on each coding strategy before data collection in order to ensure s/he still maintained the level of performance on the experimental task.

The subject sat comfortably on an arm chair and his /her head was supported on a chin rest in order to keep it from moving. Hands were rested comfortably on the cushion which was on his /her laps. Thumbs were rest on the buttons while the other fingers hold the keypad comfortably. S/he was instructed to make a speeded button-press response to the keypad with their right thumb if the target "T" was rotated to the right ($+90^0$), or with left thumb if the target "T" was rotated to the left (-90^0). S/he was reminded not moving the eyes or body parts other than responding thumbs before each experimental block.

The subject was also reminded to keep their eyes fixate on the centre without any eye movement before each block. Throughout the task, the subject was to fixate the eyes on the "+" sign appeared in the centre of the screen. After being instructed to use a particular coding strategy (i.e. egocentric or allocentric) for the cue stimuli, a corresponding block of experiment would be conducted. Based on using the instructed strategy, the subject was to detect the illuminated circle which was supposed to cue the likely location of the subsequent target stimulus. Once when the target stimulus was displayed, the subject was to locate the target at the cued position, detect the orientation of the "T" object, and make response as soon

as possible whether the target object "T" was in a $+90^0$ (pointing to the right) or to the -90^0 (pointing to the left) orientation within 1,500ms by pressing on the corresponding key of the keypad as quickly as possible.

The sequence of egocentric and allocentric tasks were arranged in accordance with Latin square design (Appendix VII) so that the block effect could be minimized. The subject was instructed to use a particular frame of reference for coding before each experimental block. A short block with 10 trials was designed to let the subjects to accommodate the switch to another frame of reference for coding in the subsequent block.

Electrophysiological recordings

The STIM was used to present the stimuli and the SCAN systems (NeuroScan) was used to record and analyse the electroencephalogram (EEG). 128 channels of EEG and EOG were recorded from the scalp with impedance maintained not more than 5kΩ at all locations. Horizontal eye-movements (HEOG) were monitored with two electrodes placed lateral to the left and right orbits. Eye-blinks and vertical eye-movements (VEOG) were measured by means of the electrodes located 1.5 cm above and below the left eye. The ground was located halfway between Fz and the midpoint of Fp1 and Fp2. EEG from both left and right mastoids (RM) were recorded. All the electrodes, except VEOG and HEOG, were physically referenced to left mastoid (LM). The ERPs were re-referenced to the algebraic mean of LM and RM during data processing. The EEG from each electrode site was digitized at 1000 Hz and was filtered with a band-pass between

0.1 and 30 Hz (48 d/oct). A 1300ms epoch of EEG in cue-to-target interval with 200ms pre-stimulus baseline was used for analyses.

Data analysis

Behavioral Analysis

Reaction time (RT) and accuracy (AR) validity effects were analyzed separately for egocentric and allocentric conditions using a three-way repeated measures analysis of variance (ANOVA). The three experimental factors manipulated within subjects included: Frame of Reference (two: egocentric, allocentric), Cue Position (two: left, right hemi-field) and Cue Validity (two: valid, invalid).

ERP Analysis

Prior to averaging the EEG signals, artefact rejection was carried out to remove epochs in which blinks, muscle activity, body movements, or amplifier blocking occurred. The rejection criterion was $\pm$ 50 μV for all channels. As eye movement within 2^0 is commonly acceptable in visual attention study (Gitelman et al., 1999) and 1^0 of eye movement will induce about 16 μV in EEG signal (Lins, Picton, Berg, & Scherg, 1993), an additional rejection criterion for HEOG with $\pm$ 32 μV (i.e. 2^0 of eye movement) was introduced in order to minimize the eye movement effect. Trials with incorrect behavioural responses were also excluded from the average.

Modulation of the C1, P1, N1, N2, P3, contralateral delay activity (CDA) and early contingent negative variation (CNV) by peripheral cue before target onset

were analyzed. With the exception of the C1 component, all these ERP components were identified from visual inspection on the grand averaged waveforms. Their corresponding time windows were found with reference to literature and objectively supported by the subsequent Independent Component Analysis (ICA): P1: 31-96 ms, N1: 92-142 ms, N2: 230-360 ms, P3: 300-480 ms, CDA: 350-800 ms, and CNV: 400-600 ms. Mean voltages within these windows were used as dependent variables. As it was probably the first study on investigating the aging effect on the frames of reference in visual attention, a full scalp model would be used in order to capture possible changes in different components across all electrode sites of the brain.

Mean Amplitude of ERP components

P1, N1, N2 and P3

The latency window between 0 and 1300 ms relative to cue onset was analyzed. Mean voltages were used as dependent variables in five lateral and four midline regional analyses in order to test the priori assumption, i.e. pronounced P1, N1, N2 and P3 would be found in the posterior sites while N1, N2 and P3 would also be identified in the anterior sites. The five lateral regions consisted of frontal (F3, F4), central (C3, C4), parietal (P3, P4), parieto-occipital (PO3, PO4) and temporal (T7, T/8) sites while the four midline regions included frontal (Fz), central (Cz), parietal (Pz) and parieto-occipital (POz). To examine how the visual attention modulated by two different frames of reference, separate analyses were made for each ERP component. For the lateral regional analyses, repeated measures analyses of variance (ANOVA) were performed on mean amplitude with

the within-subject factors which included Condition (Egocentric vs. Allocentric), Hemisphere (Left vs. Right), Laterality (visual stimuli in the contralateral vs. ipsilateral visual field relative to the electrode site) and Sites (F3/4, C3/4, P3/4, PO3/4, T7/8). For the midline regional analyses, repeated measures analyses of variance (ANOVA) were performed on mean amplitude with the within-subject factors which included Condition (Egocentric vs. Allocentric), Hemi-field (Left vs. Right), and Sites (Fz, Cz, Pz, POz). According to the literature findings, mean voltage of the expected site for a particular ERP component was expected the highest in the corresponding polarity and its amplitude was used for further analyses.

Late components:

CDA

CDA is a difference waveform with negative polarity and its amplitude was obtained by subtracting the ipsilateral from contralateral activity in the posterior sites (Vogel & Machizawa, 2004). To test for its site effect, the same five lateral brain regions were used for analysis which included bilateral hemispheres of, frontal (F3, F4), central (C3, C4), parietal (P3, P4), parieto-occipital (PO3, PO4) and temporal (T7, T8) sites. Two-way repeated measures ANOVA with Condition (Egocentric vs. Allocentric) x Homologous pair of electrode (F3/4, C3/4, P3/4, PO3/4 and T7/8) were used for analyses.

Early CNV

CNV is a slow negative waveform which is usually captured by the midline electrodes from anterior to posterior regions (Kleine & Van der Lubbe, 2011; Nagai et al., 2004; Wright et al., 1995). Only early but not later phase of CNV was captured for analysis, because the late CNV, related to preparatory process of motor response to stimulus, was not the aim of the present study. Four midline regions included frontal (Fz), central (Cz), parietal (Pz) and parieto-occipital (POz) were used for analyses. Two-way repeated measures ANOVA with Condition (Egocentric vs. Allocentric) x Midline site with averaged signal from left & right hemi-fields (Fz, Cz, Pz, POz) were performed.

Latency of ERP components

Similar to mean amplitude, same latency window between 0 and 1300 ms relative to cue onset was analyzed. Repeated measures analyses of variance (ANOVA) were performed on peak latency with the within-subject factors in the lateral brain regional analyses which included Condition (Egocentric vs. Allocentric), Hemisphere (Left vs. Right), Laterality (visual stimuli in the contralateral vs. ipsilateral visual field relative to the electrode site) and Sites (F3/4, C3/4, P3/4, PO3/4, T7/8). For the midline regional analyses, repeated measures analyses of variance (ANOVA) were performed on latency with the within-subject factors which included Condition (Egocentric vs. Allocentric), Hemi-field (Left vs. Right), and Sites (Fz, Cz, Pz, POz).

In all analyses for mean amplitude and latency, the Greenhouse-Geisser epsilon correction factor was used to compensate for any possible effects of nonsphericity. An alpha level of .05 was maintained for all statistical tests.

METHOD OF STUDY TWO:

Modulation of Visual Attention by Egocentric and Allocentric Frames of Reference in the Healthy Older Adults

Subjects

The inclusion criteria for older subjects were:

1. Aged 60 or above
2. Primary six or above education level
3. Right handed
4. Normal or corrected to normal vision
5. Normal upper limb function
6. Sitting tolerance with more than 2 hours

The exclusion criteria were:

1. Presence of any psychiatric, neurological or ophthalmological diseases
2. Unable to meet the passing criteria in the training session

Twenty one older subjects (10 females) were recruited in this study. Informed written consent (Appendix I & II) was obtained from all participants prior to being tested according to procedures approved by the Hong Kong Polytechnic University (HKPU) (Appendix III). The whole experiment was described with the information sheet (Appendix IV & V). One subject was not able to complete the experiment while another one quitted during the training session. Data from other three subjects were excluded from the analysis due to excessive eye movement artifacts.

Thus, data from sixteen older subjects (9 female) aged 60-66 years (mean ± SD = 62.75 ± 1.57 years) were included in the final data analyses. To ensure strong right handedness, the Annett Handedness Questionnaire (Appendix VI) was administered for each subject (mean ± SD = 12.33 ± 0.58, a scale of 36, from 36 i.e. extremely left handed, to 12 i.e. extremely right handed) (Annett, 1970). None of the subjects reported history of neurological, psychiatric illnesses or ophthalmological diseases. All subjects had visual acuity of at least 20/25 which was tested by Snellen eye chart. To ensure all older adults were cognitively intact, all of them were assessed by Chinese Mini Mental Status Examination (C-MMSE) (Appendix VIII) with score from 0 (poorest) to 30 (best) (mean ± SD = 29.19 ± 0.98).

Materials and procedure

The experimental design, procedures and equipment setup in the second part of the main study was the same as the Study One described in the previous session (pp.31 - 40).

EEG Recording and Data Processing

The procedure, specification of EEG processing and behavioral as well as ERP analyses were basically the same as in Study One. The time windows were identified according to visual inspection from the grand averaged waveforms and supported by the follow-up ICA findings: P1: 30-95 ms, N1: 100-150 ms; N2: 220-350 ms; P3: 330-510 ms; CDA: 350-800 ms; and CNV: 450-650 ms. Same as Study One, mean voltages within these windows were used as dependent variables.

CHAPTER FOUR

RESULTS

This chapter reports the results of two studies. The aim of the first study was to find out the effects on visual attention by the modulation of egocentric and allocentric frames of reference in the young adult. The results would be used for comparing the results in the second study. The second study used the similar methodology but the participants were the healthy older adults. The aim was to investigate the effect of aging on the allocation of visual attention by manipulating the frames of reference.

RESULTS OF STUDY ONE: MODULATION OF VISUAL ATTENTION BY EGOCENTRIC AND ALLOCENTRIC FRAMES OF REFERENCE IN YOUNG ADULTS

Demographic Data

Eighteen young healthy individuals (8 female) participated in this study but one of them was excluded from the analysis due to excessive eye movement artifacts. Thus, data from seventeen individuals (7 female and 10 male) aged 18-23 years (mean $\pm$ SD = 20.82 $\pm$ 1.19 years) were included in the final data analyses. All young subjects were extremely right handed (12.89 $\pm$ 0.94) as indicated by the Annett Handedness Questionnaire (Appendix VI) (Annett, 1970). All of them were

university students and had received an average 14.41±0.80 (range 13 to 15) years of education (Appendix X a).

Behavioral Results

The results of reaction time (RT) and accuracy rate (AC) of both egocentric and allocentric task conditions recorded (Appendix XI & XII) during the experiment are shown in Table 4.1. RT and AC were the dependent variables which were analyzed separately by three-way repeated measures ANOVA using SPSS (version 20) (SPSS Inc.). The within-subject factors included two conditions (egocentric vs. allocentric conditions), two hemi-fields (left vs. right) and validity (valid vs. invalid).

Table 4.1
Reaction time and accuracy rate in egocentric and allocentric conditions in young adults

			Reaction Time (ms)		Accuracy Rate (%)	
Condition	**Validity**	**Hemi-field**	**Mean**	**SD**	**Mean**	**SD**
Egocentric	Valid	Left	573.03	94.09	95.14	5.30
		Right	551.35	86.38	96.48	3.84
	Invalid	Left	776.23	136.81	89.88	8.25
		Right	732.23	139.25	91.04	10.92
Allocentric	Valid	Left	612.84	86.76	94.22	5.75
		Right	574.30	87.94	94.59	6.48
	Invalid	Left	794.86	176.66	90.43	7.20
		Right	749.14	168.08	91.40	9.63

Egocentric condition: attend to the absolute location of the illuminated circle within a triad
Allocentric condition: attend to the relative location of the illuminated circle with reference to the other circles within a triad
Valid in egocentric condition: the illuminated circle shared the same exact location as the target
Valid in allocentric condition: the illuminated circle occupied the same relative position as that of the target with reference to the distracters
Invalid in egocentric/ allocentric conditions: the location of the illuminated circle different from those stipulated by the rules for defining the valid trials for that tasks
Hemi-field: the space that the visual stimuli of cues and targets presented
Reaction time: Time required to make response by participants after the onset of target stimuli
Accuracy rate: Percentage of correct response from the total trials

Reaction Time (RT)

The results showed that there were significant effects on Conditions, $F(1, 16)=4.72$, $p=0.045$, Validity, $F(1, 16)=44.44$, $p<0.001$ and Hemi-field, $F(1, 16)=18.39$, $p=0.001$. No interaction was found among these factors (Appendix XIII (a)). The results showed that the young subjects responded faster in the egocentric (658.21$\pm$24.39 ms) than allocentric condition (682.79$\pm$28.90 ms). The subjects responded faster when the presented stimuli were valid (577.88$\pm$20.32 ms) than when the stimuli were invalid (763.12$\pm$36.59 ms) and when the stimuli were presented to their right (651.75$\pm$25.86 ms) compared to their left (689.24$\pm$27.12 ms) visual hemi-fields. Further analyses found that reaction time to right hemi-field was faster no matter when the stimuli were presented as valid or invalid after Bonferroni correction. We also found a marginal significant difference at $p=0.052$ between valid and invalid trials in the egocentric condition (Appendix XIII (b)).

Accuracy Rate (AC)

In contrast to RT, results of accuracy rate showed that there was effect only on Validity, $F(1, 16)=19.80$, $p<0.001$. No significant interaction was found among factors (Appendix XIII (c)). The results showed that the subjects responded more accurately in valid (95.11$\pm$1.25%) than invalid trial (90.67$\pm$2.02%).

To ensure that the observations were not due to the factor of gender, four-way repeated measures ANOVA with a model of Condition (Egocentric vs. Allocentric) x Hemi-field (Left vs. Right) x Cue-validity (Valid vs. Invalid) x Groups (Male vs. Female) as a between-subject factor was conducted separately on

RT and AC. For RT, no any between-subject effect of Gender, F(1, 15)=1.51, p=0.238 or any interaction effect was found between Gender and Condition, F(1.00, 15.00)=0.01, p=0.911, between Gender and Validity, F(1.00, 15.00)<0.00, p=0.988, between Gender and Hemi-field, F(1.00, 15.00)= 0.69, p=0.420, between Gender, Condition and Validity, F(1.00, 15.00)=0.29, p=0.600, between Gender, Condition and Hemi-field, F(1.00, 15.00)=3.146, p=0.096, between Gender, Validity and Hemi-field, F(1.00, 15.00)=2.17, p=0. 162, or between Gender, Condition, Validity and Hemi-field, F(1.00, 15.00)=0.21, p=0.654. Similarly, there was no any between-subject effect of Gender was found in AC, F(1.00, 15.00)=0.46, p=0.510, or any interaction effect was found between Gender and Condition, F(1.00, 15.00)=0.62, p=0.444, between Gender and Validity, F(1.00, 15.00)=2.01, p=0.177, between Gender and Hemi-field, F(1.00, 15.00)=1.95, p=0.183, between Gender, Condition and Validity, F(1.00, 15.00)=0.06, p=0.805, between Gender, Condition and Hemi-field, F(1.00, 15.00)=0.12, p=0.739, between Gender, Validity and Hemi-field, F(1.00, 15.00)=0.88, p=0. 364, or between Gender, Condition, Validity and Hemi-field, F(1.00, 15.00)=2.66, p=0.124.

ERP measures

Except C1, all the other six ERP components between cue and target interval were identified by visual inspection from the grand averaged waveforms. Their time windows were found with reference to the literature and objectively supported by the subsequent ICA: P1: 31-96 ms, N1: 92-142 ms, N2: 230-360 ms, P3: 300-480 ms, CDA: 350-800 ms, and CNV: 400-600 ms.

ERP components between cue and target interval were analyzed by two models which include the model using the lateral sites and another model using the midline sites. For the model using lateral sites, a four-way repeated measures ANOVA with Condition (Egocentric vs. Allocentric) x Hemisphere (Left vs. Right) x Laterality (Contralateral vs. Ipsilateral signal relative to the visual stimuli) x Lateral electrode site (F3, F4, C3, C4, P3, P4, PO3, PO4, T7, T8) were used to test the effects of the P1, N1, N2 and P3 components. The sites for the left hemisphere were: F3, C3, P3, PO3 and T7; those on the right hemisphere were F4, C4, P4, PO4 and T8. A three-way repeated measures ANOVA with Condition (Egocentric vs. Allocentric) x Hemi-field (Left vs. Right) x Midline site (Fz, Cz, Pz, POz) were used to test the effects of the P1, N1, N2 and P3 components in the midline model. The same models were used for testing the peak latency of each identified component.

CDA was a differential waveform which was obtained by computing the differences of the contralateral and ipsilateral activities. It was analyzed by two-way repeated measures ANOVA with Condition (Egocentric vs. Allocentric) x Homologous pair of electrode (F3/4, C3/4, P3/4, PO3/4 and T7/8).

CNV was analyzed from four midline regions which included frontal (Fz), central (Cz), parietal (Pz) and parieto-occipital (POz). Two-way repeated measures ANOVA with Condition (Egocentric vs. Allocentric) x Midline site with averaged signal from left & right hemi-fields (Fz, Cz, Pz, POz) were performed.

The mean amplitudes of the P1, N1, N2 and P3 components recorded from which cortical areas contralateral and ipsilateral to the visual stimuli at lateral sites in both egocentric and allocentric conditions were shown in Appendix XIII (d) while the mean amplitudes of these components recorded in midline sites were shown in Appendix XIII (e).

P1 Component

Mean Amplitude

No condition effect but main effect in Laterality, $F(1.00,16.00)= 12.33$, $p=0.003$ and Site, $F(1.39, 22.25)= 5.41$, $p=0.020$ were found by the lateral site model (Appendix XIII (f)). Mean amplitude was greater in contralateral ($0.08\pm0.14\mu V$) than ipsilateral signals ($-0.27\pm0.15\mu V$). Pairwise comparisons of the means obtained from the contralateral and ipsilateral signals among the five paired sites (i.e. F3/4, C3/4, P3/4, PO3/4 and T7/8) indicated that the mean amplitude of the P1 component in young subjects was highest at PO3/4 in both egocentric ($0.33\pm0.17\mu V$) and allocentric conditions ($0.28\pm0.18\mu V$) ($p<0.05$) (Figure 4.1). No condition effect was found at PO3/4, $F(1.00, 16.00)=0.34$, $p=0.567$ by a three-way repeated measures ANOVA with Condition (Egocentric vs. Allocentric) x Hemisphere (Left vs. Right) x Laterality (Contralateral vs. Ipsilateral signal relative to visual stimuli). Interaction effects were found between Hemisphere and Laterality, $F(1.00, 16.00)=30.13$, $p<0.001$ and between Laterality and Site, $F(1.63, 26.14)=7.45$, $p=0.004$. Separate post-hoc tests by three-way repeated measures ANOVA in each hemisphere with Condition (Egocentric vs.

Allocentric) x Laterality (Contralateral vs. Ipsilateral signal relative to visual stimuli) x Lateral site (F3, F4, C3, C4, P3, P4, PO3, PO4, T7, T8) found main effect of Laterality only in left hemisphere $F(1.00, 16.00)=46.46$, $p<0.001$ but not in right hemisphere, $F(1.00, 16.00)=2.60$, $p=0.126$. Separate post-hoc tests by three-way repeated measures ANOVA with Condition (Egocentric vs. Allocentric) x Hemisphere (Left vs. Right) x Laterality (Contralateral vs. Ipsilateral signal relative to visual stimuli) in each paired lateral site found main effect of Laterality at C3/4, $F(1.00, 16.00)=11.27$, $p=0.004$, P3/4, $F(1.00, 16.00)=11.35$, $p=0.004$, PO3/4, $F(1.00, 16.00)=11.66$, $p=0.004$, T7/8, $F(1.00, 16.00)=11.81$, $p=0.003$ but not at F3/4, $F(1.00, 16.00)=1.31$, $p=0.269$. That means with the exception of F3/4, the mean amplitudes of contralateral signals in lateral sites were greater than ipsilateral signals ($p<0.05$).

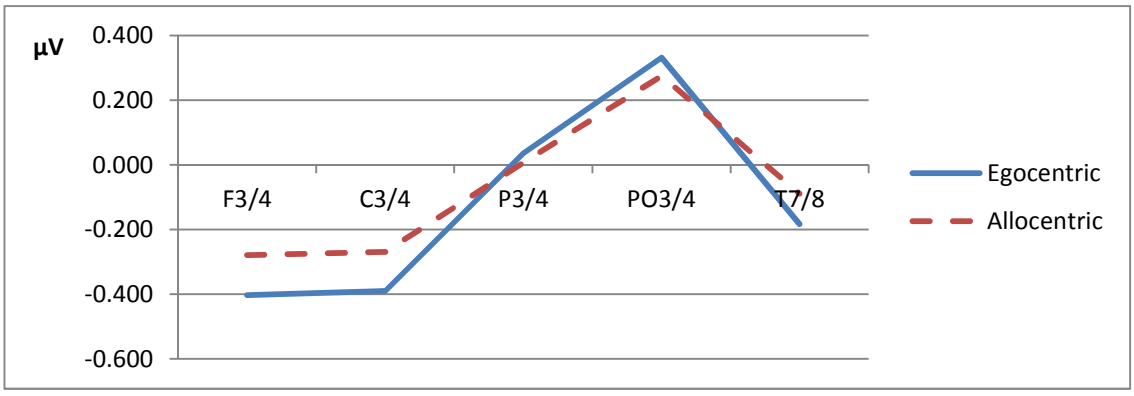


Figure 4.1 Mean amplitudes (in µV) of five paired electrode sites (i.e. F3/4, C3/4, P3/4 and PO3/4, T7/8) of the P1 component in Egocentric and Allocentric conditions in young adults

The midline site model showed main effect of Hemi-field, $F(1.00, 16.00)=38.50$, $p<0.001$ by three-way repeated measures ANOVA in which the

within-subject factors were Condition (Egocentric vs. Allocentric) x Hemi-field (Left vs. Right) x Midline site (Fz, Cz, Pz, POz). Mean amplitude of the P1 was larger for the visual stimuli presented at right hemi-field (0.07 $\pm$ 0.20μV) than left hemi-field (-0.80 $\pm$0.24μV). No any interaction effect was found ((Appendix XIII (g)).

Peak Latency

Similar as mean amplitude, the lateral site model did not find condition effect but main effect of Laterality and Lateral site (Appendix XIII (h)). It showed that peak latency in contralateral signal (57.96$\pm$1.82 ms) was shorter than ipsilateral signal (62.54$\pm$2.41 ms). Peak latency at PO3/4 (69.62$\pm$2.51 ms) were the longest when compared to F3/4 (50.96$\pm$2.20 ms), C3/4 (58.06$\pm$2.37 ms), P3/4 (63.82$\pm$2.35 ms) and T7/8 (58.79$\pm$2.64 ms) in pairwise comparisons ($p<0.05$). No condition effect was found at PO3/4, $F(1.00, 16.00)=2.23$, $p=0.154$ by a three-way repeated measures ANOVA with Condition (Egocentric vs. Allocentric) x Hemisphere (Left vs. Right) x Laterality (Contralateral vs. Ipsilateral signal relative to visual stimuli). Interaction effects were found between Laterality and Site, $F(4, 64)=3.60$, $p=0.010$. Separate post-hoc test by a three-way repeated measures ANOVA with Condition (Egocentric vs. Allocentric) x Hemisphere (Left vs. Right) x Laterality (Contralateral vs. Ipsilateral signal relative to visual stimuli) in each paired lateral site found main effect of Laterality at P3/4, $F(1.00, 16.00)=6.38$, $p=0.022$; PO3/4, $F(1.00, 16.00)=8.51$, $p=0.010$ and marginal at T7/8, $F(1.00, 16.00)=4.41$, $p=0.052$ but not at F3/4, $F(1.00, 16.00)=0.01$, $p=0.906$; C3/4, $F(1.00, 16.00)=1.60$, $p=0.223$. That means the peak latency of contralateral signals

recorded at posterior sites (P3/4 and PO3/4) were significantly shorter than their ipsilateral signals.

The midline site model showed main effect of Site, $F(1.67, 26.72)=12.12$, $p<0.001$ by a three-way repeated measured ANOVA in which the within-subject factors were Condition (Egocentric vs. Allocentric) x Hemi-field (Left vs. Right) x Midline site (Fz, Cz, Pz, POz). Peak latencies at Pz (61.66$\pm$2.56 ms) and POz (63.60$\pm$2.54 ms) were significantly longer than Fz (50.52$\pm$2.29 ms) and Cz (54.91$\pm$2.63 ms) ($p<0.05$). Interaction effect between Condition and Site was found, $F(1.77, 28.250)=12.12$, $p=0.032$ (Appendix XIII (i)). Separate post-hoc tests by a two-way repeated measures ANOVA with Hemi-field (Left vs. Right) x Midline site (Fz, Cz, Pz, POz) in each condition found main effect of Site only in egocentric condition, $F(1.87, 29.94)=10.72$, $p<0.001$ but not in allocentric condition, $F(1.58, 25.26)=2.22$, $p=0.138$. In egocentric condition, peak latencies at Pz (65.91$\pm$3.66 ms) and POz (68.88$\pm$4.00 ms) were significantly longer than Fz (49.06$\pm$3.15 ms) and Cz (54.09$\pm$4.13 ms) by pairwise comparisons ($p<0.05$). No condition effect was found at Pz and POz, $F(1.00, 16.00)=3.39$, $p=0.084$ by a three-way repeated measures ANOVA with Condition (Egocentric vs. Allocentric) x Hemi-field (Left vs. Right) x Midline sites (Pz vs. POz).

To summarize, the mean amplitude of the P1 in the young subject did not have condition effect but lateralized effect at all sites with the exception of F3/4 in the lateral site model. However, such lateralized effect was only found in the left hemisphere. PO3/4 was the site with the greatest mean amplitude. Mean amplitude

of the P1 was larger for the visual stimuli presented at the right hemi-field than the left hemi-field in the midline site model. For the peak latency, no condition effect was found but lateralized effect was found mainly at the posterior sites: P3/4, PO3/4 and marginal at T7/8. Among the sites with lateralized effect, the sites with shorter contralateral than the ipsilateral signal were only found at P3/4 and PO3/4. The posterior sites (P3/4, PO3/4, Pz, POz) were found to have longer latency than the other sites.

N1 Component

Mean Amplitude

The N1 was found to have significant main effects in Hemisphere, F(1.00, 16.00)=12.21, p=0.003, Laterality, F(1.00, 16.00)=7.58, p=0.01 and Lateral site, F(2.09, 33.49)=4.50, p=0.017 (Appendix XIII (j)). Mean amplitude of the N1 component was more negative in left (-1.53$\pm$0.25μV) than right hemisphere (-1.16 $\pm$0.22μV) and contralateral (-1.52$\pm$0.26μV) than ipsilateral signal (-1.18 $\pm$0.22μV). Pairwise comparisons also found that P3/4 (-1.79$\pm$0.32μV) was significantly more negative than F3/4 (-1.02$\pm$0.26μV), PO3/4 (-1.03$\pm$0.19μV) and T7/8 (-1.36$\pm$0.25μV) ($p<0.05$) (Figure 4.2). Interaction effects were found between Condition and Hemisphere, F(1.00, 16.00)=10.96, p=0.004, Condition and Laterality, F(1.00, 16.00)=1.00, p=0.006, Hemisphere and Site, F(1.92, 30.66)=4.50, p=0.021, Laterality and Site, F(2.57, 41.05)=7.20, p=0.001, Condition, Hemisphere and Site, F(1.86, 29.78)=6.40, p=0.006, Condition, Laterality and Site, F(1.78, 28.50)=6.42, p=0.006. Separate post-hoc tests by a three-way repeated measures ANOVA with Hemisphere (Left vs. Right) x

Laterality (Contralateral vs. Ipsilateral signal relative to visual stimuli) x Lateral sites (F3, F4, C3, C4, P3, P4, PO3, PO4, T7, T8) in each condition found that effect of Hemisphere was only found in egocentric, F(1.00, 16.00)=16.25, p=0.001 where the mean amplitude in the left (-1.80±0.27μV) was more negative than the right hemispheres (-0.95±0.24μV). However, there was no such effect in allocentric condition, F(1.00, 16.00)=0.62, p=0.44. On the other hand, laterality effect was only found in allocentric condition, F(1.00, 16.00)=14.49, p=0.002 but not in egocentric condition, F(1.00, 16.00)=0.50, p=0.490. That means the mean amplitude was found more negative in the contralateral (-1.72 +0.28μV) than ipsilateral signal (-0.92+0.24μV) but it only occurred in allocentric condition.

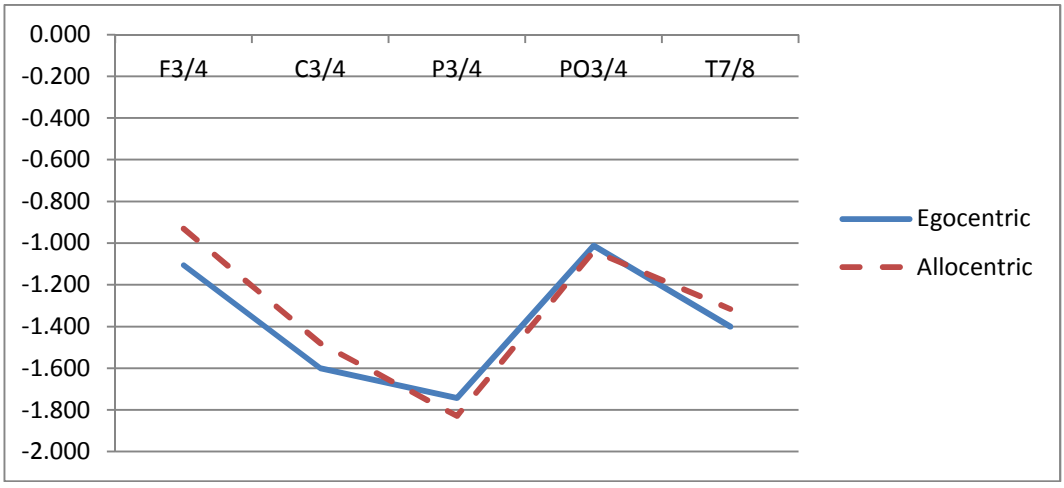


Figure 4.2 Mean amplitudes (in μV) of five paired electrode sites (i.e. F3/4, C3/4, P3/4 and PO3/4, T7/8) of the N1 component in Egocentric and Allocentric conditions in young adults

The midline site model did not find any main effect but interaction effect between Condition and Site, F(1.26, 20.11)=5.64, p=0.022 (Appendix XIII (k)). Separate post-hoc tests by two-way repeated measures ANOVA with Hemi-field

(Left vs. Right) x Midline site (Fz, Cz, Pz, POz) in each condition did not find any site effect in egocentric, $F(1.39, 22.25)=1.26$, $p=0.29$ or allocentric condition, $F(1.41, 22.56)=2.46$, $p=0.121$. Similarly, no condition effect was found in any midline site ($p>0.05$) by a two-way repeated measures ANOVA with Condition (Egocentric vs. Allocentric) x Hemi-field (Left vs. Right) in each midline site separately.

Peak Latency

Similar as mean amplitude, no condition effect, $F(1.00, 16.00)=3.38$, $p=0.084$ but main effects in Hemisphere, $F(1.00, 16.00)=7.83$, $p=0.013$, Laterality, $F(1.00,16.00)=8.42$, $p=0.010$ and Lateral site, $F(1.87, 29.84)=36.33$, $p<0.001$ were found in peak latency of the N1 component in the lateral site model (Appendix XIII (l)). Peak latency was found shorter in the left hemisphere (116.79$\pm$1.90 ms) than right hemisphere (119.76$\pm$1.72 ms). Shorter peak latency was also found in contralateral (116.49$\pm$1.80 ms) than ipsilateral (120.06$\pm$1.88 ms) signals. Pairwise comparisons showed that each pair of lateral site was significantly different from each other ($p<0.01$). The shortest peak latency was found at F3/4 (108.57$\pm$1.78 ms) while the longest was at PO3/4 (126.91$\pm$2.27 ms) (Appendix XIII (m)). Interaction effect between Hemisphere and Laterality, $F(1.00, 16.00)=5.82$, $p=0.028$ and between Laterality and Site, $F(2.21, 35.31)= 3.55$, $p=0.035$ were found. Separate post-hoc analyses by a two-way repeated measures ANOVA with Condition (Egocentric vs. Allocentric) x Laterality (Contralateral vs. Ipsilateral signal relative to visual stimuli) in each hemisphere showed effects in laterality in the right

hemisphere, F(1.00, 16.00)=13.19, p=0.002 but not left hemisphere, F(1.00, 16.00)=0.23, p=0.640. That means the peak latency was found significantly shorter in the contralateral signal than ipsilateral signal but it was only found in the right hemisphere. Separate post-hoc test by three-way repeated measures ANOVA with Condition (Egocentric vs. Allocentric) x Hemisphere (Left vs. Right) x Laterality (Contralateral vs. Ipsilateral signal relative to visual stimuli) in each paired lateral site found main effect of Laterality at P3/4, F(1.00, 16.00)=8.87, p=0.009, PO3/4, F(1.00, 16.00)=7.96, p=0.012 and marginal at T7/8, F(1.00, 16.00)=4.34, p=0.054 but not at F3/4, F(1.00, 16.00)=0.62, p=0.441, C3/4, F(1.00, 16.00)=2.75, p=0.117. Similar to the P1 component, the peak latency of contralateral signals of the N1 recorded at posterior sites (P3/4 and PO3/4) were significantly shorter than their ipsilateral signals.

The midline site model showed main effect of Site, F(1.06, 17.02)=18.49, p<0.001. Peak latencies of POz (119.85$\pm$2.69 ms) and Pz (118.88$\pm$2.52 ms) were significantly longer than Fz (107.85$\pm$2.04 ms) and Cz (109.97$\pm$1.97 ms) by pairwise comparison (p<0.01) (Appendix XIII (n)). No interaction effect was found (p>0.05).

To summarize, the mean amplitude of the N1 did not have condition effect but lateralized main effect of Hemisphere, Laterality and Site. Mean amplitude of the N1 component was more negative in the left than right hemisphere and contralateral than ipsilateral signal. Only the egocentric condition showed that the mean amplitude in the left was more negative than the right hemispheres. On the

other hand, laterality effect was only found in the allocentric condition and P3/4was significantly more negative than the other sites.

Peak latency was found shorter in the left hemisphere. The peak latency was also found significantly shorter in the contralateral signal than ipsilateral signal in the right hemisphere. The shortest peak latency was found at F3/4 while the longest was at PO3/4. Peak latency of N1 showed lateralized effect at posterior sites (P3/4 and PO3/4). Peak latencies of POz and Pz were significantly longer than Fz and Cz.

N2 Component

Mean Amplitude

No any main effect but marginal effect of Site was found in the lateral site model, $F(1.27, 20.37)=3.80$, $p=0.057$ (Appendix XIII (o)). Interaction effect between Laterality and Site, $F(2.51, 40.12)=3.70$, $p=0.025$, and between Condition, Laterality and Site, $F(4, 64)=3.16$, $p=0.020$. Post-hoc analyses by three-way repeated measures ANOVA with Condition (Egocentric vs. Allocentric) x Hemisphere (Left vs. Right) x Lateral sites (F3, F4, C3, C4, P3, P4, PO3, PO4, T7, T8) were conducted separately in contralateral and ipsilateral signals. Marginal effect of Site was found for the contralateral, $F(1.30, 20.83)=3.93$, $p=0.051$ but not ipsilateral signals, $F(1.29, 20.56)=3.62$, $p=0.062$. Mean amplitude of the contralateral signal of the N2 was found lowest at F3/4 ($0.31\pm0.33\mu V$) by pairwise comparisons to those of C3/4 ($0.91\pm0.35\mu V$), P3/4 ($1.68\pm0.61\mu V$), PO3/4 ($1.55\pm0.48\mu V$) and T7/8 ($1.07\pm0.28\mu V$) ($p<0.05$). No condition effect of the

anterior N2, F(1.00, 16.00)=0.70, p=0.415 was found by a four-way repeated measures ANOVA with Condition (Egocentric vs. Allocentric) x Hemisphere (Left vs. Right) x Laterality (Contralateral vs. ipsilateral signal relative to visual stimuli) x Lateral sites (F3/4 vs. C3/4). Similarly, no condition effect of the posterior N2, F(1.00, 16.00)=1.66, p=0.216 was found by a four-way repeated measures ANOVA with Condition (Egocentric vs. Allocentric) x Hemisphere (Left vs. Right) x Laterality (Contralateral vs. ipsilateral signal relative to visual stimuli) x Lateral sites (P3/4 vs. PO3/4).

Separate post-hoc tests by a three-way repeated measures ANOVA with Hemisphere (Left vs. Right) x Laterality (Contralateral vs. Ipsilateral signal relative to visual stimuli) x Lateral site (F3, F4, C3, C4, P3, P4, PO3, PO4, T7, T8) in each condition found that no site effect was found in egocentric condition, F(1.24, 19.79)=3.57, p=0.066 but marginal in allocentric condition, F(1.33, 21.26)=3.91, p=0.051. That means the mean amplitude of the N2 was found more negative at F3/4 (0.44 $\pm$0.36μV) than other lateral sites ($p<0.05$) but it only occurred in allocentric condition. Both egocentric, F(1.00, 16.00)=0.110, p=0.74 and allocentric condition, F(1.00, 16.00)=1.03, p=0.326 did not have effect of Laterality.

Similar to the lateral site model, the midline site model did not find any main effect but marginal effect of Site, F(1.26, 20.17)=3.85, p=0.056 (Appendix XIII (p)). Fz (0.10$\pm$0.44μV) was more negative than Pz (1.34$\pm$0.64μV). No condition effect of the anterior N2, F(1.00, 16.00)=0.09, p=0.766 was found by a three-way repeated measures ANOVA with Condition (Egocentric vs. Allocentric)

x Hemi-field (Left vs. Right) x Midline site (Fz vs. Cz). Similarly, no condition effect of the posterior N2, F(1.00, 16.00)=0.38, p=0.545 was found by a three-way repeated measures ANOVA with Condition (Egocentric vs. Allocentric) x Hemi-field (Left vs. Right) x Midline site (Pz vs. POz). No any interaction effect between factors was found (p>0.05).

Peak Latency

No any effect on peak latency of the N2 component was found in the lateral site model (p>0.05) (Appendix XIII (q)).

Main effect of Condition was found in the midline model, F(1.00, 16.00)=8.56, p=0.010 (Appendix XIII (r)). Peak latency of the N2 was shorter in egocentric (286.08±7.10 ms) than allocentric condition (298.75±8.68 ms). Condition effect of the anterior N2, F(1.00, 16.00)=6.28, p=0.023 was found by a three-way repeated measures ANOVA with Condition (Egocentric vs. Allocentric) x Hemi-field (Left vs. Right) x Midline site (Fz vs. Cz). Peak latency of the anterior N2 was shorter in the egocentric (288.02±7.36 ms) than allocentric condition (300.53±9.34 ms). Similarly, condition effect of the posterior N2, F(1.00, 16.00)=6.37, p=0.023 was also found by a three-way repeated measures ANOVA with Condition (Egocentric vs. Allocentric) x Hemi-field (Left vs. Right) x Midline site (Pz vs. POz). Peak latency of the posterior N2 was shorter in the egocentric (284.15±10.23 ms) than allocentric condition (296.97±10.36 ms). No any interaction effect was found among factors.

To summarize, the N2 component was found to be more negative in the frontal region (F3/4) particularly in the allocentric condition. It is consistent with the findings obtained from the midline site model that the mean amplitude was more negative at Fz than Pz. Peak latency of the anterior as well as posterior N2 were shorter in egocentric than allocentric condition.

P3 Component

Mean Amplitude

No condition effect, F(1.00, 16.00)=4.01, p=0.063 but main effects on Laterality, F(1.00, 16.00)=9.25, p=0.008 and Site, F(1.36, 21.72)=5.10, p=0.025 were found in the lateral site model (Appendix XIII (s)). In contrast to the previous components, mean amplitude of the P3 of contralateral signal (0.98$\pm$0.34μV) was less than ipsilateral signal (1.22$\pm$0.35μV). Pairwise comparisons indicated that the mean amplitude at F3/4 (0.29$\pm$0.36μV) was the smallest among the lateral electrode sites ($p<0.05$) (Figure 4.3). No condition effect of the anterior P3, F(1.00, 16.00)=2.98, p=0.103 was found by a four-way repeated measures ANOVA with Condition (Egocentric vs. Allocentric) x Hemisphere (Left vs. Right) x Laterality (Contralateral vs. ipsilateral signal relative to visual stimuli) x Lateral site (F3/4 vs. C3/4). Similarly, no condition effect of the posterior P3, F(1.00, 16.00)=3.81, p=0.069 was found by a four-way repeated measures ANOVA with Condition (Egocentric vs. Allocentric) x Hemisphere (Left vs. Right) x Laterality (Contralateral vs. ipsilateral signal relative to visual stimuli) x Lateral site (P3/4 vs. PO3/4). Interaction effects were found between Hemisphere and Laterality F(1.00,

16.00)=6.99, p=0.018 , Hemisphere and Site, F(4, 64)=6.06, p<0.001, Laterality and Site, F(1.78, 28.54)=3.97, p=0.034, and between Condition, Laterality and Site, F(1.78, 28.49)=0.65, p=0.514. Separate post-hoc test for each hemisphere by three-way repeated measures ANOVA with Condition (Egocentric vs. Allocentric) x Laterality (Contralateral vs. Ipsilateral signal relative to visual stimuli) x Lateral sites (F3, F4, C3, C4, P3, P4, PO3, PO4, T7, T8) found main effect of Laterality in the right hemisphere, F(1.00, 16.00)=10.78, p=0.005 but not left hemisphere, F(1.00, 16.00)=0.19, p=0.672. That means the ipsilateral signal (1.44$\pm$0.35μV) was greater than contralateral signal (0.93$\pm$0.37μV) but it was only found in the right hemisphere. Post-hoc tests for contralateral and ipsilateral signals separately by three-way repeated measures ANOVA with Condition (Egocentric vs. Allocentric) x Hemisphere (Left vs. Right) x Lateral site (F3, F4, C3, C4, P3, P4, PO3, PO4, T7, T8) found site effect in ipsilateral signal, F(1.35, 21.53)=7.20, p=0.009 but not contralateral signal, F(1.40, 22.46)=3.29, p=0.70. Pairwise comparisons showed that the ipsilateral signal at F3/4 (0.30$\pm$0.36μV) was the least in mean amplitude among the recording sites (p<0.05) which was consistent with the previous analysis. Separate post-hoc test by a three-way repeated measures ANOVA with Condition (Egocentric vs. Allocentric) x Hemisphere (Left vs. Right) x Laterality (Contralateral vs. Ipsilateral signal relative to visual stimuli) in each paired lateral site found main effect of Laterality at C3/4, F(1.00, 16.00)=7.12, p=0.017, P3/4, F(1.00, 16.00)=10.17, p=0.006 and T7/8, F(1.00, 16.00)=8.98, p=0.009 but not at F3/4, F(1.00, 16.00)=0.15, p=0.701, PO3/4, F(1.00, 16.00)=4.02, p=0.062. The mean amplitudes of ipsilateral signals were found larger than contralateral for those lateral sites having effect of Laterality. Such post-hoc tests also found effect

of Hemisphere at F3/4, F(1.00, 16.00)=13.18 p=0.002 and T7/8, F(1.00, 16.00)=4.94, p=0.041 but not at C3/4, F(1.00, 16.00)=2.58, p=0.128, P3/4, F(1.00, 16.00)=2.29, p=0.15 and PO3/4, F(1.00, 16.00)=1.16, p=0.298. That means the mean amplitudes in right hemisphere were greater than left hemisphere at F3/4 and T7/8.

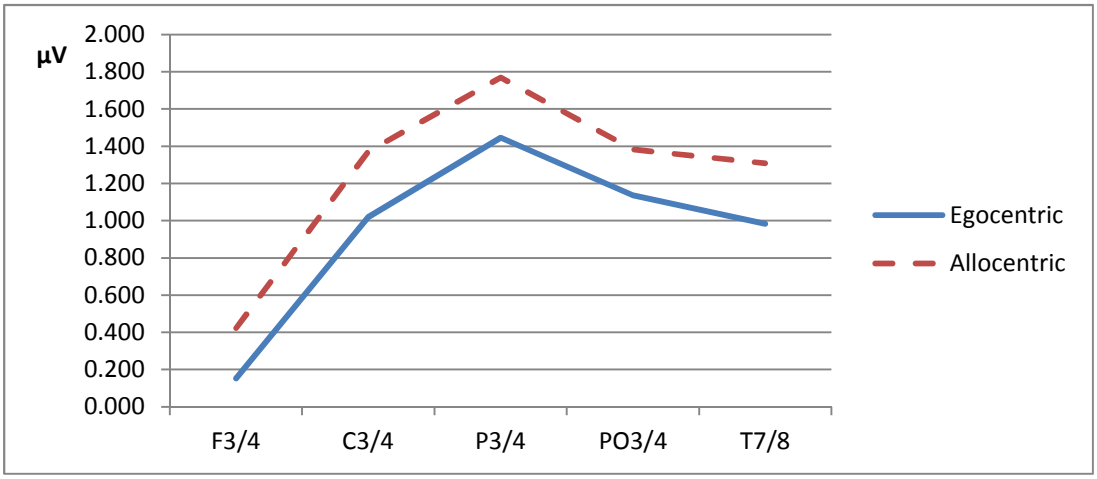


Figure 4.3 Mean amplitudes (in μV) of five paired electrode sites (i.e. F3/4, C3/4, P3/4 and PO3/4, T7/8) of P3 component in Egocentric and Allocentric conditions in young adults

Site effect was also found in the midline site model, F(1.21, 19.38)=6.24, p=0.017 (Appendix XIII (t)). Pairwise comparisons found that the mean amplitude of Fz was significantly smaller than the other midline sites ($p<0.05$) (Appendix XIII (u)). No condition effect of the anterior P3, F(1.00, 16.00)=1.38, p=0.257 was found by a three-way repeated measures ANOVA with Condition (Egocentric vs. Allocentric) x Hemi-field (Left vs. Right) x Midline sites (Fz vs. Cz). Similarly, no condition effect of the posterior P3, F(1.00, 16.00)=1.97, p=0.180 was found by a three-way repeated measures ANOVA with Condition (Egocentric vs. Allocentric)

x Hemi-field (Left vs. Right) x Midline sites (Pz vs. POz). Effect of Hemi-field was marginal, F(1.00, 16.00)=4.17, p=0.058 which revealed that the mean amplitude was marginally larger for the visual stimuli presented at right hemi-field (1.22±0.48μV) than left hemi-field (0.86±0.55μV).

Peak Latency

Similar as mean amplitude, no condition effect, F(1.00, 16.00)=2.74, p=0.117 was found but main effect of Laterality, F(1.00,16.00)=4.80, p=0.044 was identified in the lateral site model (Appendix XIII (v)). The latency of P3 component was shorter in the contralateral (371.19±9.32 ms) than the ipsilateral signals (378.17±10.00 ms) to the visual stimuli. Interaction effect was found between Hemisphere and Site, F(4, 64)=2.72, p=0.037. Separate post-hoc test by three-way repeated measures ANOVA with Condition (Egocentric vs. Allocentric) x Hemisphere (Left vs. Right) x Laterality (Contralateral vs. Ipsilateral signal relative to visual stimuli) in each paired lateral site found main effect of Hemisphere only at F3/4, F(1.00, 16.00)=4.59, p=0.048 but not at C3/4, F(1.00, 16.00)=0.11, p=0.307, P3/4, F(1.00, 16.00)=0.72, p=0.410, PO3/4, F(1.00, 16.00)=2.68, p=0.121 and T7/8, F(1.00, 16.00)=0.00, p=0.976. That means shorter peak latency in the left hemisphere (367.22±13.11 ms) than the right hemisphere (378.25±12.22 ms) was only found at F3/4. There was no any effect in the midline model (p>0.05) (Appendix XIII (w)).

To summarize, the P3 component did not have condition effect. Laterality effect was only found in the right hemisphere. Site effect was also found with the

lowest mean amplitude at F3/4 and Fz. The mean amplitude was marginally larger for the visual stimuli presented at the right than the left hemi-field in the midline site model. Site effect of peak latency was only found at F3/4 which showed that the latency at F3 (left hemisphere) was shorter than at F4 (right hemisphere).

CDA Component

CDA is defined as a negative slow waveform which is obtained by calculating the differences of the contralateral and ipsilateral activities. It was analyzed by two-way repeated measures ANOVA with Condition (Egocentric vs. Allocentric) x Homologous pair of electrode (F3/4, C3/4, P3/4. PO3/4 and T7/8). No condition effect, $F(1.00, 16.00)=0.64$, $p=0.435$ but site effect was found, $F(2.14, 34.28)=8.33$, $p=0.001$ (Appendix XIII (x)). Pairwise comparisons found that the mean amplitude of CDA was the least at F3/4 ($-0.24 \pm 0.05\mu V$) ($p<0.01$) (Figure 4.4).

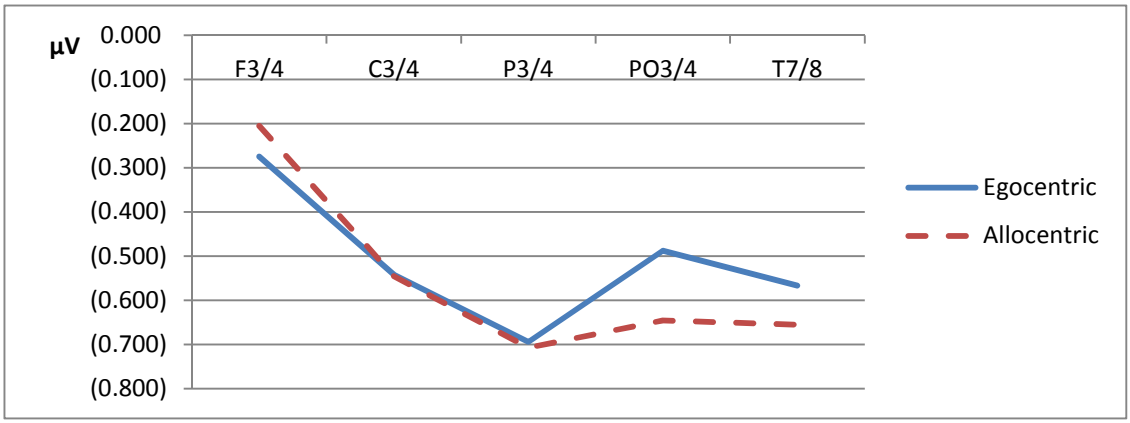


Figure 4.4 Mean amplitudes of differential signals from five paired electrode sites (i.e. F3/4, C3/4, P3/4 and PO3/4, T7/8) of the CDA component in Egocentric and Allocentric conditions in young adults

Early CNV Component

Condition effect was found in which the egocentric condition (-0.01 ± 0.44μV) was more negative-going than the allocentric condition (0.54 ± 0.51μV), F(1.00, 16.00)=8.82, p=0.009 by a two-way repeated measures ANOVA with Condition (Egocentric vs. Allocentric) x Midline site with averaged signal from left & right hemi-fields (Fz, Cz, Pz, POz). Site effect was also shown that Fz was the most negative-going among the four midline sites, F(1.27, 20.35)=6.19, p=0.016 (Figure 4.5).

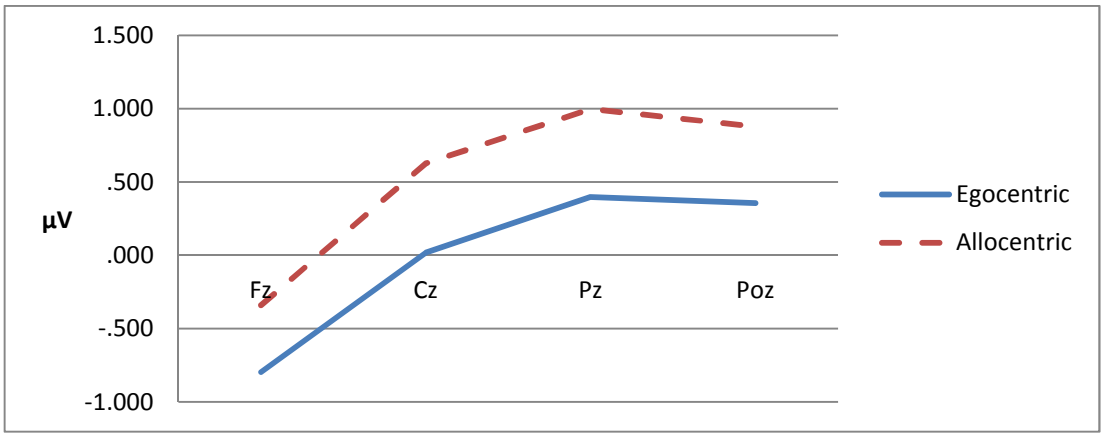


Figure 4.5 Mean amplitudes (in μV) of four midline electrode sites (i.e. Fz, Cz, Pz and POz) of the CNV component in Egocentric and Allocentric conditions in young adults

Figure 4.6 shows the grand average of contralateral ERP signals to visual stimuli collected by five lateral electrodes in egocentric and allocentric conditions. Figure 4.7 shows the ERP signals collected by four midline site electrodes respective to the visual stimuli presented on left and right hemi-fields.

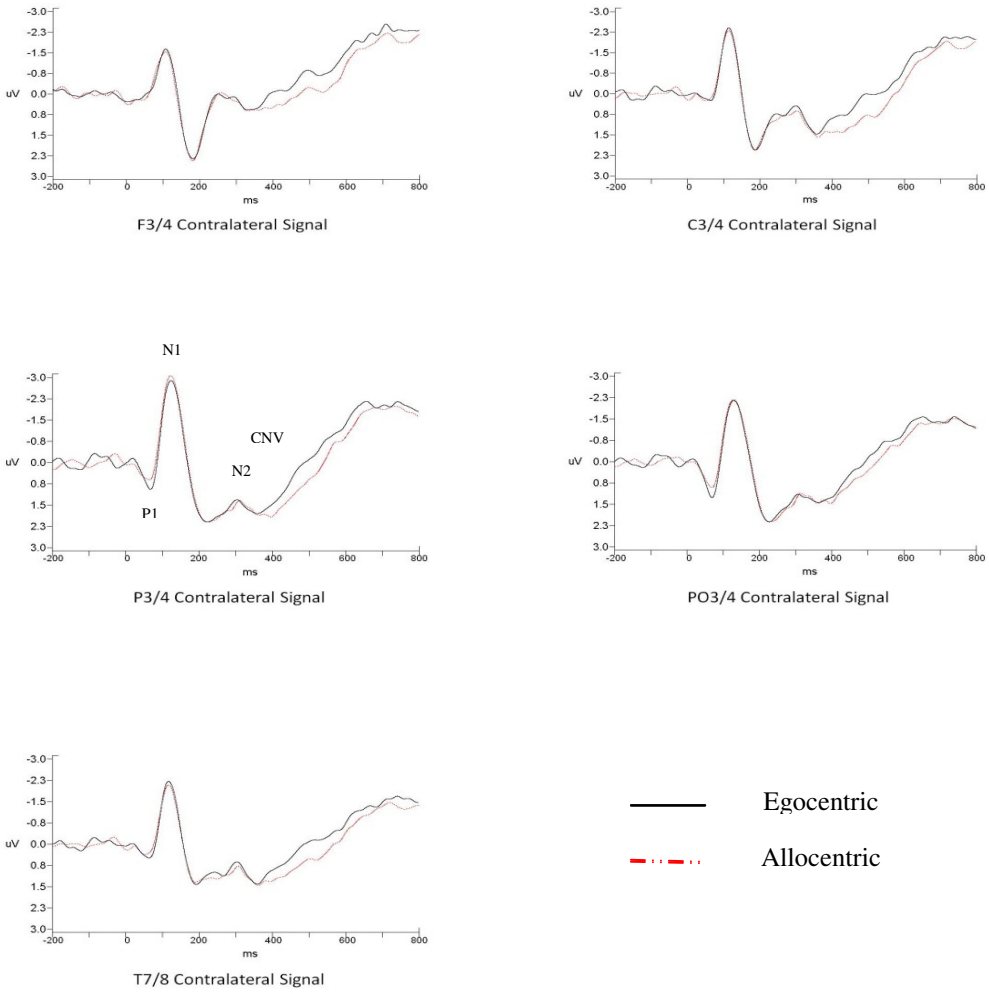


Figure 4.6
The grand average of contralateral signal to visual stimuli recorded from five paired electrodes in egocentric and allocentric conditions in young adults

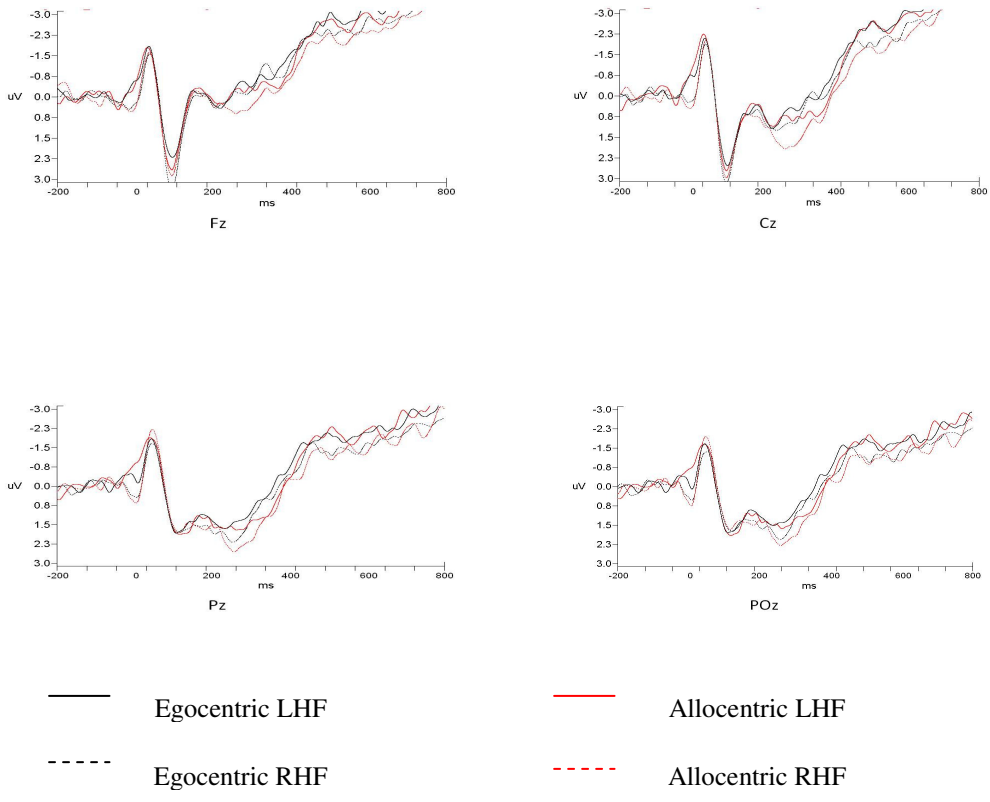


Figure 4.7
The grand average of ERP signals to visual stimuli recorded from four midline electrodes in egocentric and allocentric conditions in young adults
(LHF: visual stimuli presented at left hemi-field, RHF: visual stimuli presented at right hemi-field)

RESULTS OF STUDY TWO: MODULATION OF VISUAL ATTENTION BY EGOCENTRIC AND ALLOCENTRIC FRAMES OF REFERENCE IN OLDER ADULTS

Demographic Data

Twenty one elderly participants (10 females) were recruited in this study. One subject was not able to complete the experiment while another one quitted during the training session. Data from other three participants were excluded from the analysis due to excessive eye movement artifacts. Sixteen older healthy individuals (9 females) aged 60-66 years (mean $\pm$ SD = 62.75 $\pm$ 1.57 years) were studied. They had received an average of 11.56$\pm$2.998 (range 6 to 18) years of education (Appendix X b). All subjects were extremely right handed (mean $\pm$ SD = 12.75 $\pm$ 1.24) as indicated by the Annett Handedness Questionnaire (Appendix VI) (Annett, 1970).

Behavioral Results

Reaction time (RT) and accuracy rate (AC) were recorded (Appendix XIV) during the experiment and results are shown in Appendix XV. This behavioral data was analyzed by three-way repeated measures ANOVA with Condition (Egocentric vs. Allocentric) x Hemi-field (Left vs. Right) x Cue-validity (valid vs. invalid).

Reaction Time

The results showed that there were significant effects on Conditions, $F(1, 15)=17.47$, $p=0.001$ and Validity, $F(1, 15)=89.50$, $p<0.001$. No interaction was found among these factors (Appendix XVI (a)). The subjects responded faster in the egocentric (810.54$\pm$24.99 ms) than allocentric condition (846.31$\pm$26.15 ms) and valid (728.15$\pm$26.24 ms) than invalid trial (928.70$\pm$28.42 ms) (Appendix XVI (b)).

Accuracy Rate

Similar to RT, the results of accuracy rate also showed significant effects on Condition, $F(1, 15)=14.66$, $p=0.002$ and Validity, $F(1, 15)=35.32$, $p<0.001$. No interaction was found among factors (Appendix XVI (c)). The results reflected that the subjects responded more accurately in egocentric (85.64$\pm$1.31%) than allocentric (82.09$\pm$1.64%) and valid (91.22$\pm$0.87%) than invalid trial (76.52$\pm$2.50%).

To confirm that the observations were not due to the factor of gender, four-way repeated measures ANOVA with a model of Condition (Egocentric vs. Allocentric) x Hemi-field (Left vs. Right) x Cue-validity (Valid vs. Invalid) x Group (Male vs. Female) as a between-subject factor was conducted separately on RT and AC. For RT, although between-subject effect of Gender was found, $F(1, 14)=8.24$, $p=0.012$, no interaction effect was found between Gender and Condition, $F(1.00, 14.00)=0.52$, $p=0.484$, between Gender and Validity, $F(1.00, 14.00)=1.87$,

p=0.193, between Gender and Hemi-field, F(1.00, 14.00)= 0.65, p=0.435, between Gender, Condition and Validity, F(1.00, 14.00)=0.06, p=0.808, between Gender, Condition and Hemi-field, F(1.00, 14.00)=0.53, p=0.477, or between Gender, Condition, Validity and Hemi-field, F(1.00, 14.00)=0.78, p=0.393. Marginal effect was found between Gender, Validity and Hemi-field, F(1.00, 14.00)=4.55, p=0. 051. Similarly, there was no any between-subject effect of Gender was found in AC, F(1, 14)=0.04, p=0.848, or interaction effect was found between Gender and Condition, F(1.00, 14.00)=0.23, p=0.642, between Gender and Validity, F(1.00, 14.00)=0.23, p=0.639, between Gender and Hemi-field, F(1.00, 14.00)=0.98, p=0.339, between Gender, Condition and Validity, F(1.00, 14.00)=0.20, p=0.659, between Gender, Condition and Hemi-field, F(1.00, 14.00)<0.00, p=0.970, between Gender, Validity and Hemi-field, F(1.00, 14.00)=0.18, p=0. 678, or between Gender, Condition, Validity and Hemi-field, F(1.00, 14.00)<0.00, p=0.973.

ERP measures

Six ERP components between cue and target interval were identified with reference to the literature, visual inspection from the grand averaged waveforms and objectively supported by the subsequent ICA: P1: 30-95 ms, N1: 100-150 ms, N2: 220-350 ms, P3: 330-510 ms, CDA: 350-800 ms, and CNV: 450-650 ms.

ERP components between cue and target interval were analyzed by two models which included the model using the lateral sites and another model using the midline sites. For the model using lateral sites, a four-way repeated measures

ANOVA with Condition (Egocentric vs. Allocentric) x Hemisphere (Left vs. Right) x Laterality (Contralateral vs. Ipsilateral signal relative to visual stimuli) x Lateral electrode site (F3, F4, C3, C4, P3, P4, PO3, PO4, T7, T8) was used to test the effects of the P1, N1, N2 and P3 components. The sites for the left hemisphere were: F3, C3, P3, PO3 and T7; those on the right hemisphere were F4, C4, P4, PO4 and T8. A three-way repeated measures ANOVA with Condition (Egocentric vs. Allocentric) x Hemi-field (Left vs. Right) x Midline site (Fz, Cz, Pz, POz) was used to test the effects of the P1, N1, N2 and P3 components in the midline model. The same models were used for testing the peak latency of each identified component.

CDA was a differential waveform which was obtained by computing the differences of the contralateral and ipsilateral activities. It was analyzed by two-way repeated measures ANOVA with Condition (Egocentric vs. Allocentric) x Homologous pair of electrode (F3/4, C3/4, P3/4. PO3/4 and T7/8).

CNV was analyzed from four midline regions which included frontal (Fz), central (Cz), parietal (Pz) and parieto-occipital (POz). Two-way repeated measures ANOVA with Condition (Egocentric vs. Allocentric) x Midline site with averaged signal from left & right hemi-fields (Fz, Cz, Pz, POz) were performed.

Appendix XVI (d) shows the mean amplitudes of the P1, N1, N2 and P3 components recorded from which cortical areas contralateral and ipsilateral to the visual stimuli in both egocentric and allocentric conditions.

C1 Component

No clear C1 component was identified from the grand averaged waveform.

P1 Component

Mean Amplitude

Main effect of Laterality, F(1.00, 15.00)=11.90, p=0.004 was found in the lateral site model (Appendix XVI (f)). Mean amplitude of the contralateral signal (0.60±0.17μV) to visual stimuli was larger than ipsilateral signal (0.24±0.17μV). Interaction effect between Laterality and Lateral site was found, F(2.28, 34.13)=8.62, p=0.001. Separate post-hoc tests by three-way repeated measures ANOVA with Condition (Egocentric vs. Allocentric) x Hemisphere (Left vs. Right) x Laterality (Contralateral vs. Ipsilateral signal relative to visual stimuli) in each paired lateral site showed main effect of Laterality at C3/4, F(1.00, 15.00)=9.47, p=0.008, P3/4, F(1.00, 15.00)=11.40, p=0.004, PO3/4, F(1.00, 15.00)=12.48, p=0.003 and T7/8, F(1.00, 15.00)=13.10, p=0.003 and marginal at F3/4, F(1.00, 15.00)=4.27, p=0.057.

The midline site model showed main effect of Hemi-field, F(1.00, 15.00)=4.74, p=0.046 by a three-way repeated measured ANOVA in which the within-subject factors were Condition (Egocentric vs. Allocentric) x Hemi-field (Left vs. Right) x Midline site (Fz, Cz, Pz, POz) (Appendix XVI (g)). The mean amplitude of the P1 was larger for the visual stimuli presented in the right hemi-

field (0.35±0.24μV) than the left hemi-field (0.12±0.19μV). No interaction effect was found (p>0.05).

Peak Latency

There was no any main effect but interaction effect between Condition, Laterality and Lateral site, F(4, 60)=1.30, p=0.030 in the lateral site model (Appendix XVI (h)). Post-hoc tests for each lateral paired site separately by three-way repeated measures ANOVA with Condition (Egocentric vs. Allocentric) x Hemisphere (Left vs. Right) x Laterality (Contralateral vs. Ipsilateral signal relative to visual stimuli) found Laterality effect only at F3/4, F(1.00, 15.00)=9.09, p=0.009 but not at other lateral sites (p>0.05). That means only F3/4 showed shorter peak latency in contralateral signal (68.50±3.22 ms) than ipsilateral signal (72.88±3.89 ms). No any effect was found by the midline site model (Appendix XVI (i)).

To summarize, the mean amplitude of the P1 component was larger for the visual stimuli presented in the right than the left hemi-field. Laterality effect was found in all of the sites but marginal at F3/4. Latency showed laterality but only found at F3/4.

N1 Component

Mean Amplitude

There was no effect of Condition, F(1.00, 15.00)=1.990, p=0.179 but of Laterality, F(1.00, 15.00)=23.79, p<0.001 and Site, F(2.28, 34.12)=7.23, p=0.002 in lateral site model (Appendix XVI (j)). Mean amplitude of the contralateral signal (1.60±0.28μV) was larger than ipsilateral signal (-0.80±0.31μV). Mean amplitude at F3/4 (-0.61±0.31μV) was less negative than C3/4 (-1.58±0.46μV), P3/4 (-1.62±0.36μV) and PO3/4 (-1.41±0.23μV) in pairwise comparisons (p<0.05) (Figure 4.8). Interaction effects were found between Condition and Hemisphere, F(1.00, 15.00)=4.70, p=0.047 and between Laterality and Site, F(2.05, 30.67)=9.05, p=0.001. Separate post-hoc test for each condition by three-way repeated measures ANOVA with Hemisphere (Left vs. Right) x Laterality (Contralateral vs. Ipsilateral signal relative to visual stimuli) x Lateral site (F3, F4, C3, C4, P3, P4, PO3, PO4, T7, T8) did not find main effect of Hemisphere in egocentric, F(1.00, 15.00)=0.59, p=0.453 or allocentric conditions, F(1.00, 15.00)<0.001, p<0.991. Effect of Condition was not found in left hemisphere, F(1.00, 15.00)=3.72, p=0.073 or right hemisphere, F(1.00, 15.00)=0.37, p=0.550 by separate post-hoc test for each hemisphere with three-way repeated measures ANOVA with Condition (Left vs. Right) x Laterality (Contralateral vs. Ipsilateral signal relative to visual stimuli) x Lateral site (F3, F4, C3, C4, P3, P4, PO3, PO4, T7, T8).

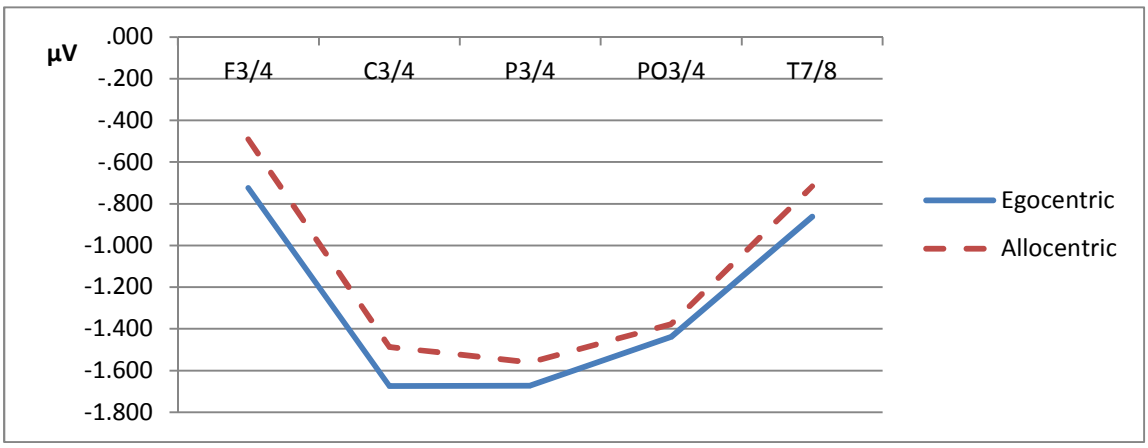


Figure 4.8 Mean amplitudes of five paired electrode sites (F3/4, C3/4, P3/4 and PO3/4, T7/8) of the N1 component in Egocentric and Allocentric conditions in the older adults

Effect of Site was found in the midline site model, F(1.47, 22.01)=3.923, p=0.046 (Appendix XVI (k)). Pairwise comparisons showed that mean amplitude recorded at Fz (-1.166 ±0.43μV) was less than Cz (-1.93 ±0.53μV), Pz (-1.94 ±0.51μV) and Pz (-1.76 ±0.42μV) ($p<0.05$). Interaction effect between Condition and Site, F(1.21, 18.09)=4.35, p=0.045 was found. Separate post-hoc analyses by two-way repeated measures ANOVA in each condition with Hemi-field (Left vs. Right) x Midline site (Fz, Cz, Pz, POz) showed that site effect was only found on allocentric, F(1.48, 22.24)=4.66, p=0.029 but not egocentric condition, F(1.45, 21.72)=3.15, p=0.077. Pairwise comparisons showed that the mean amplitude of Fz (-1.02 ±0.44μV) was significantly less negative than those of Cz (-1.83 ±0.55μV), Pz (-1.90 ±0.53μV) and POz (-1.72 ±0.43μV).

Peak Latency

Main effects were identified on Laterality, F(1.00, 15.00)=11.32, p=0.004 and Site, F(1.46, 21.90)=7.96, p=0.005 in the lateral site model (Appendix XVI (l)). No interaction effect was found (p>0.05). Latency was found shorter in the contralateral (130.68+2.36 ms) than ipsilateral signal (136.07+2.32 ms). Pairwise comparisons showed that peak latency at F3/4 (128.32±2.68 ms) was significantly shorter than C3/4 (132.84±2.53 ms), P3/4 (135.20±2.32 ms), PO3/4 (135.70±2.34 ms) and T7/8 (134.80±2.09 ms). No effect was found in the midline site model (p>0.05)(Appendix XVI (m)).

To summarize, the mean amplitude of the N1 was less negative at F3/4 when compared to C3/4, P3/4 and PO3/4. Similar findings were also found at midline site that Fz was less negative than Cz, Pz and POz. Peak latency at F3/4 was significantly shorter than the other lateral sites.

N2 Component

Mean Amplitude

As shown in Appendix XVI (n), main effect of Laterality was found, F(1.00, 15.00)=22.13, p<0.001 with less mean amplitude in the contralateral (0.59±0.46μV) than ipsilateral signal (1.00±0.42μV) in the lateral site model. Main effect of Site was also found, F(2.43, 33.46)=3.35, p=0.038. Pairwise comparisons showed that the mean amplitude of PO3/4 (0.35±0.40μV) was significantly less than F3/4 (1.27±0.45μV) and T7/8 (0.90±0.37μV) (p<0.05) (Figure 4.9). Interaction effects

were found between Condition and Site, F(2.34, 35.16)=4.01, p=0.022 and between Condition, Laterality and Site, F(3.00, 45.01)=4.81, p=0.005. Separate post-hoc test for each condition by a three-way repeated measures ANOVA with Hemisphere (Left vs. Right) x Laterality (Contralateral vs. Ipsilateral signal relative to visual stimuli) x Lateral site (F3, F4, C3, C4, P3, P4, PO3, PO4, T7, T8) found main effect of site in allocentric, F(2.52, 37.74)=3.82, p=0.023 but not egocentric condition, F(2.35, 35.26)=2.87, p=0.062. Pairwise comparisons showed that the mean amplitude of PO3/4 (0.38±0.41μV) was significantly less than F3/4 (1.40±0.48μV) and T7/8 (0.97±0.39μV) in allocentric condition ($p<0.05$). Effect of Laterality was found in both egocentric, F (1.00, 15.00)=24.95, $p<0.001$and allocentric condition, F (1.00, 15.00)=17.23, p=0.001.

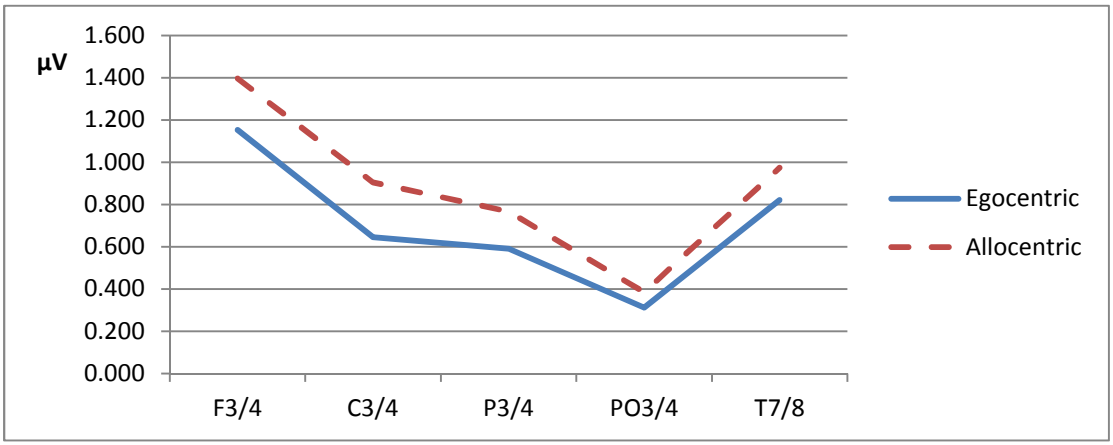


Figure 4.9 Mean amplitudes of five paired electrode sites (i.e. F3/4, C3/4, P3/4 and PO3/4, T7/8) of the N2 component in Egocentric and Allocentric conditions in the older adults

No main effect but interaction effect between Condition and Site was found in the midline site model, F(1.47, 22.03)=5.14, p=0.022 (Appendix XVI (o)). Post-hoc tests by two-way repeated measures ANOVA with Condition (Egocentric vs.

Allocentric) x Hemi-field (Left vs. Right) in each midline site separately found that only Cz showed marginal effect of Condition, $F(1.00, 15.00)=4.34$, $p=0.055$. Mean amplitude of egocentric ($0.14\pm0.66\mu V$) was more negative than allocentric condition ($0.45\pm0.71\mu V$) at Cz.

Peak Latency

No main effect but interaction effect between Condition, Hemisphere and Laterality was found (Appendix XVI (p)). No effect from Condition, Hemisphere or Laterality was found by:

1. Separate post-hoc test ($p>0.05$) for each condition by a three-way repeated measures ANOVA with Hemisphere (Left vs. Right) x 2 Laterality (Contralateral vs. Ipsilateral signal relative to visual stimuli) x Lateral site (F3, F4, C3, C4, P3, P4, PO3, PO4, T7, T8),
2. Separate three-way repeated measures ANOVA with Condition (Egocentric vs. Allocentric) x Hemisphere (Left vs. Right) x Lateral site (F3, F4, C3, C4, P3, P4, PO3, PO4, T7, T8) for testing the effect of Laterality,
3. Separate three-way repeated measures ANOVA with Condition (Egocentric vs. Allocentric) x Laterality (Contralateral vs. Ipsilateral signal relative to visual stimuli) x Lateral site (F3, F4, C3, C4, P3, P4, PO3, PO4, T7, T8) for testing the effect of Hemisphere,
4. Separate two-way repeated measures ANOVA with Hemisphere (Left vs. Right) x Lateral site (F3, F4, C3, C4, P3, P4, PO3, PO4, T7, T8) for testing the effect of Laterality in each condition,

5. Separate two-way repeated measures ANOVA with Laterality (Contralateral vs. Ipsilateral signal relative to visual stimuli) x Lateral site (F3, F4, C3, C4, P3, P4, PO3, PO4, T7, T8) for testing the effect of Hemisphere in each condition.

No any effect was found in the midline site model ($p>0.05$) (Appendix XVI (q)).

To summarize, the mean amplitude of the N2 was significantly less at PO3/4 than F3/4 and T7/8 particularly in the allocentric condition. Cz was the only site which showed condition effect at which the mean amplitude of the egocentric condition was greater than the allocentric condition. No effect was found in the latency.

P3 Component

Mean Amplitude

There was no effect of Condition, $F(1.00, 15.00)=0.04$, $p=0.84$ but on Laterality, $F(1.00, 15.00)=31.61$, $p<0.001$ and Site, $F(2.23, 33.46)=16.23$, $p<0.001$ (Appendix XVI (r)). Pairwise comparisons showed that the mean amplitude was larger at F3/4 ($2.57\pm0.39\mu V$) and C3/4 ($2.16\pm0.43\mu V$) than P3/4 ($1.48\pm0.45\mu V$), PO3/4 ($1.08\pm0.39\mu V$) and T7/8 ($1.82\pm0.32\mu V$). Such differences were found in both conditions (Figure 4.10). In contrast to the identified early components, mean amplitude of the P3 component was larger in ipsilateral ($2.09\pm0.40\mu V$) than contralateral signal ($1.55\pm0.35\mu V$). Interaction effects were found between Hemisphere and Laterality, $F(1.00, 15.00)=10.64$, $p=0.005$ and between Condition,

Laterality and Site, F(2.73, 40.99)=3.13, p=0.040. Separate post-hoc tests for each hemisphere by three-way repeated measures ANOVA with Condition (Egocentric vs. Allocentric) x Laterality (Contralateral vs. Ipsilateral signal relative to visual stimuli) x Lateral site (F3, F4, C3, C4, P3, P4, PO3, PO4, T7, T8) found effect of Laterality in the left hemisphere, F(1.00, 15.00)=23.95, p<0.001 but not right hemisphere, F(1.00, 15.00)=3.89, p=0.067. That means the ipsilateral signal (2.11$\pm$0.47μV) was larger than contralateral signal (1.21$\pm$0.38μV) but only occurred in the left hemisphere. Separate post-hoc tests for each hemisphere in each condition by a two-way repeated measures ANOVA with Laterality (Contralateral vs. Ipsilateral signal relative to visual stimuli) x Lateral site (F3, F4, C3, C4, P3, P4, PO3, PO4, T7, T8) found effect of Laterality in the left hemisphere in egocentric condition, F(1.00, 15.00)=17.26, p=0.001 and allocentric condition, F(1.00, 15.00)=20.81, p<0.001. However, laterality effect in the right hemisphere was only found in egocentric, F(1.00, 15.00)=5.85, p=0.029 but not allocentric condition, F(1.00, 15.00)=0.18, p=0.680. That means the ipsilateral signal recorded in left hemisphere was larger than contralateral signals in both egocentric and allocentric condition. However, ipsilateral signal was greater than contralateral signal in right hemisphere was only found in the egocentric condition (Appendix XVI (s))

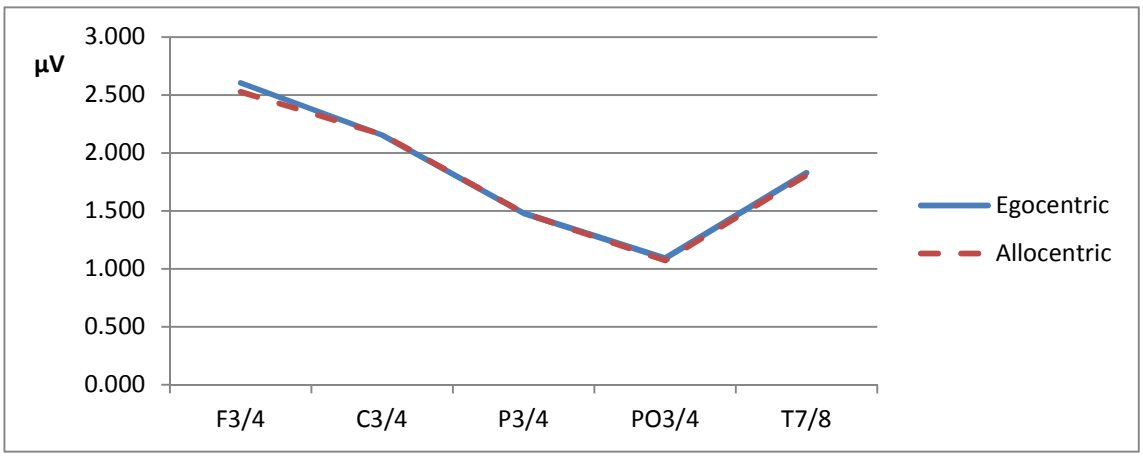


Figure 4.10 Mean amplitudes of five paired electrode sites (i.e. F3/4, C3/4, P3/4 and PO3/4, T7/8) of the P3 component in Egocentric and Allocentric conditions in the older adults

The midline site model showed main effect of Hemi-field, F(1.00, 15.00)=6.45, p=0.023 and Site, (F1.46, 21.84)=7.15, p=0.008 (Appendix XVI (t)). Mean amplitude of the P3 was larger for the visual stimuli presented on the left hemi-field (3.25±0.52μV) than right hemi-field (2.90±0.49μV). Pairwise comparisons showed that the mean amplitude of Fz (3.59±0.45μV) was significantly larger than Pz (2.82±0.56μV) and POz (2.63±0.50μV) ($p<0.05$). Interaction effect between Condition, Hemi-field and Site was found, F(1.82, 27.31)=4.65, p=0.021. Post-hoc analyses for each midline site by a two-way repeated measures ANOVA found that effect of Hemi-field was only found at Fz, F(1.00, 15.00)=6.06, p=0.026 and Cz, F(1.00, 15.00)=9.32, p=0.008 but not Pz, F(1.00, 15.00)=3.14, p=0.097 or POz, F(1.00, 15.00)=2.68, p=0.122. At Fz, the mean amplitude was larger in left hemi-field (3.77±0.45μV) than the right hemi-field (3.42±0.46μV).

Peak Latency

Only effect of Laterality was found in the latency of the P3 component, F(1.00, 15.00)=5.00, p=0.041 (Appendix XVI (u)) with shorter latency in the contralateral (411.91±10.92 ms) than ipsilateral signals (419.91±10.74 ms). No any effect was found in the midline site model (Appendix XVI (v)).

To summarize, the mean amplitude of P3 was larger at F3/4 and C3/4 than the other lateral sites in both conditions. The effects of Laterality in the left hemisphere were found in both egocentric and allocentric condition. However, laterality effect in the right hemisphere was only found in egocentric but not allocentric condition. The mean amplitude of Fz was significantly larger than Pz and POz. Mean amplitude of the P3 was larger for the visual stimuli presented on the left hemi-field than right hemi-field and specifically at Fz and Cz.

CDA Component

Main effect of Condition was found, F(1.00, 15.00)=5.43, p=0.034 (Appendix XVI (w)). Mean amplitude of the CDA was found larger in egocentric (-0.64±0.09μV) than allocentric condition (-0.47±0.07μV). Interaction effect between Condition and Site was also found F(1.64, 24.60)=4.19, p=0.034. Separate post-hoc tests for each condition showed site effect of allocentric, F(2.10, 31.53)=3.98, p=0.027 but not egocentric condition, F(4, 60)=0.38, p=0.820. Pairwise comparisons found that the mean amplitude of CDA was larger at PO3/4

(-0.62±0.090μV) than F3/4 (-0.28±0.111μV) and T7/8 (-0.41±0.115μV) in allocentric condition ($p<0.05$) (Figure 4.11).

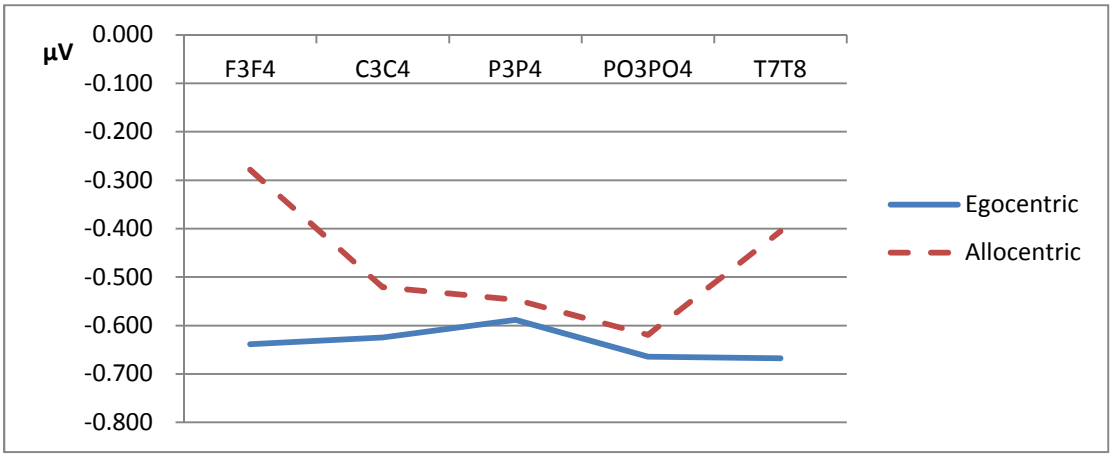


Figure 4.11 Mean amplitudes of difference wave from five homologous paired electrode sites (i.e. F3/4, C3/4, P3/4 and PO3/4, T7/8) of the CDA component in Egocentric and Allocentric conditions in the older adults

Early CNV component

Site effect was found, $F(4.64, 22.18)=4.49$, $p=0.035$ by a two-way repeated measures ANOVA with Condition (Egocentric vs. Allocentric) x Midline site with averaged signal from left & right hemi-fields (Fz, Cz, Pz, POz) . Pairwise comparisons found that the mean amplitude of CNV was larger at POz (0.60±0.46μV) than Fz (1.17±0.48μV) ($P<0.05$) (Figure 4.12).

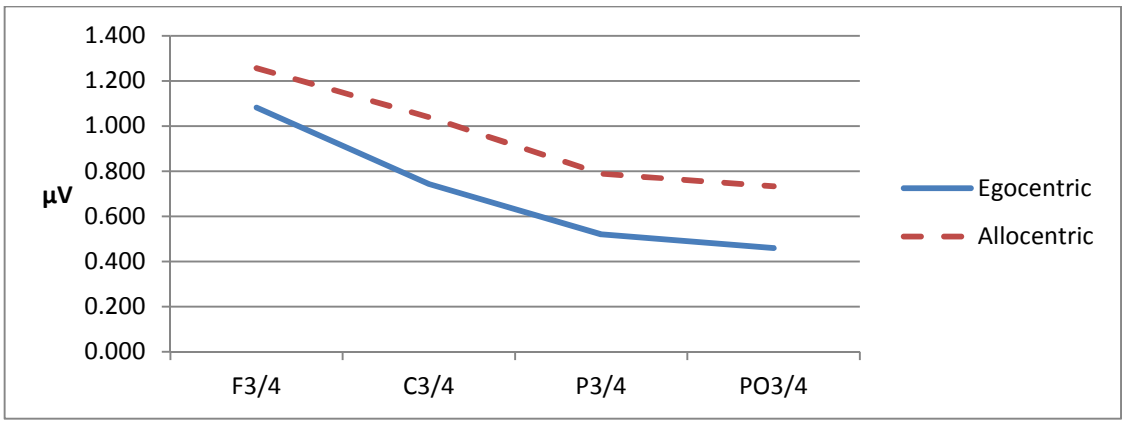


Figure 4.12 Mean amplitudes (in μV) of four midline electrode sites (i.e. Fz, Cz, Pz and POz) of the CNV component in Egocentric and Allocentric conditions in the older adults

Figure 4.13 shows the grand average of contralateral ERP signals to visual stimuli collected by five lateral electrodes in egocentric and allocentric conditions. Figure 4.14 shows the ERP signals collected by four midline site electrodes respective to the visual stimuli presented on left and right hemi-fields.

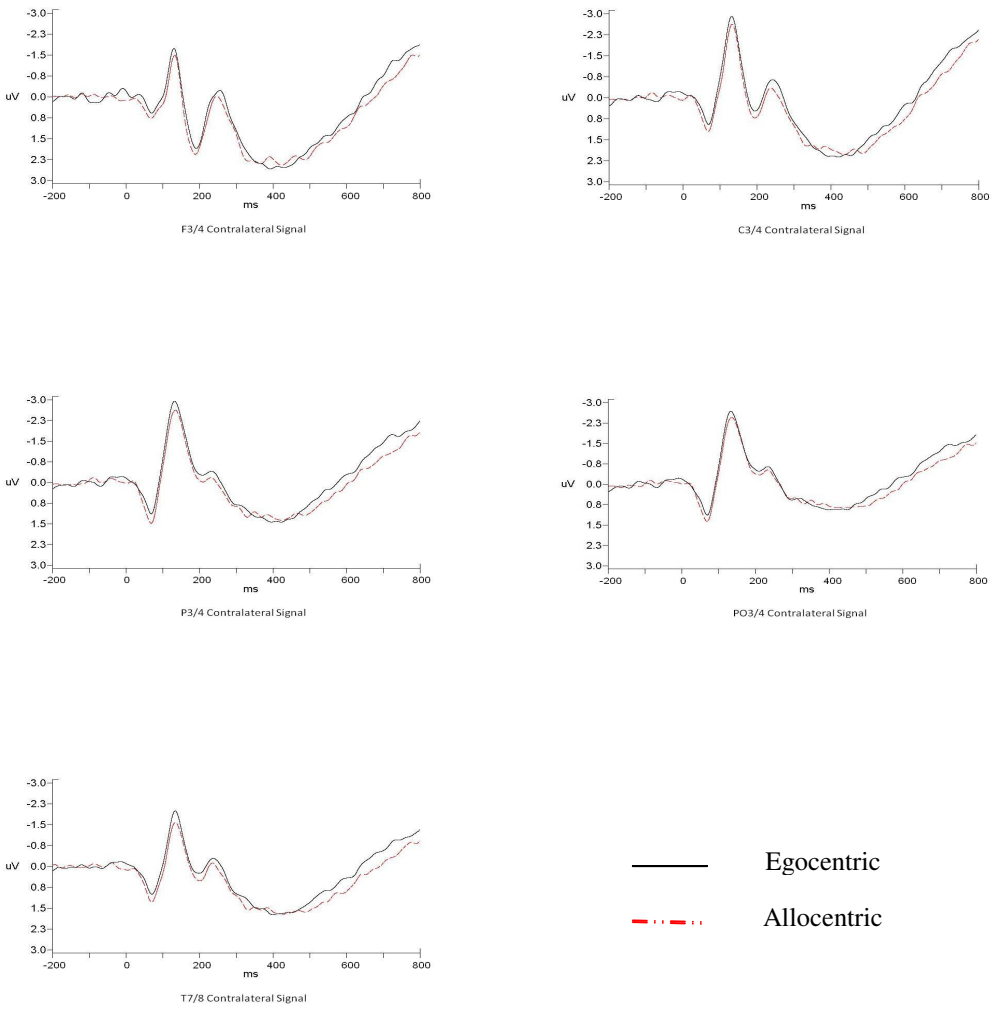


Figure 4.13
The grand average of contralateral signal to visual stimuli recorded from five paired electrodes in egocentric and allocentric conditions in the older adults

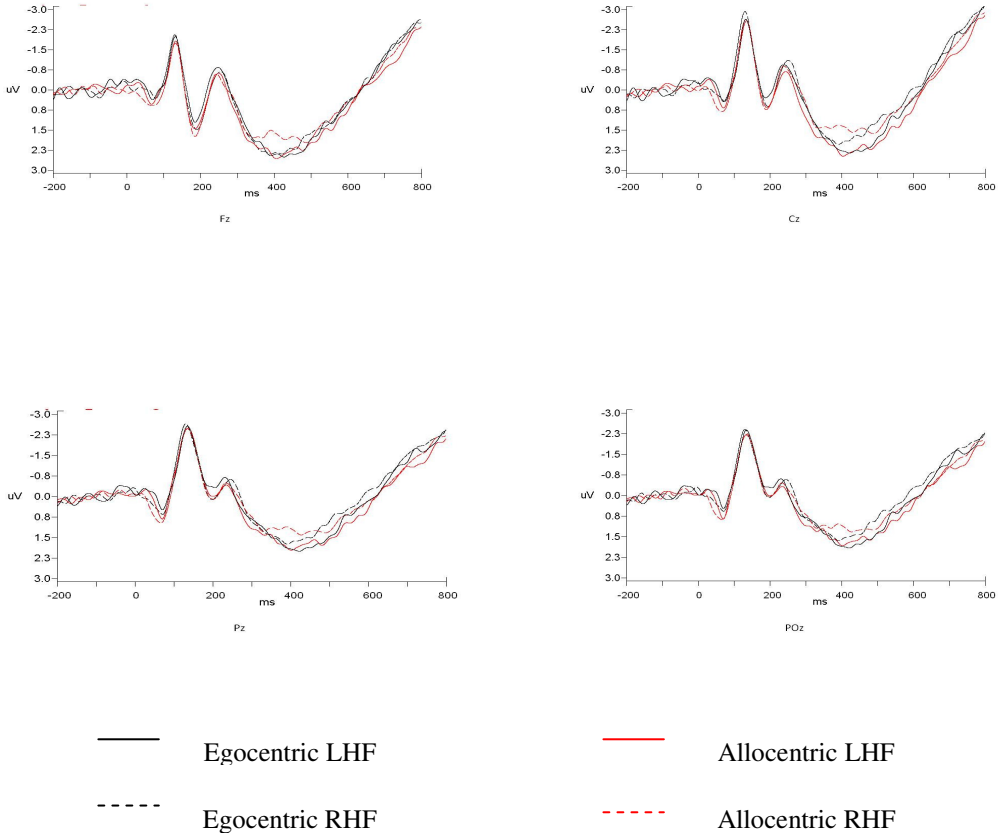


Figure 4.14
The grand average of ERP signals to visual stimuli recorded from four midline electrodes in egocentric and allocentric conditions in the older adults
(LHF: visual stimuli presented at left hemi-field,
RHF: visual stimuli presented at right hemi-field)

Comparisons between young and older groups

The results of behavioral and ERP analyses in previous sections showed that there were differences in some behavioral observations and ERP components between the young and older groups. Such differences were described as follows:

Reaction time (RT)

The young group responded faster when the stimuli were presented to their right (651.75±25.86 ms) compared to their left (689.24±27.12 ms) visual hemi-fields, $F(1, 16)=18.39$, $p=0.001$. However, no such difference was found in the older group, $F(1, 15)=0.11$, $p=0.750$.

Accuracy rate (AC)

Condition effect was found in the older group, $F(1, 15)=17.47$, $p=0.001$ but not in young group, $F(1, 16)=0.97$, $p=0.340$.

P1 Component

Mean amplitude

The effect of Laterality was found in both hemispheres in the older group, $F(1.00, 15.00)=11.90$, $p=0.004$ but it was only found in the left hemisphere in the young group, $F(1.00, 16.00)=46.46$, $p<0.001$.

Peak latency

Main effect of Laterality was found in the young group, $F(1.00, 16.00)=6.35$, $p=0.023$ but the effect of Laterality was found only at F3/4 in the

older group, F(1.00, 15.00)=9.09, p=0.009 by the post-hoc analysis for the interaction effect between Condition, Laterality and Site. In the midline site model, Site effect was not found in the older group, F(1.50, 22.43)= 3.34, p=0.066 but in the egocentric condition in the young group, .F(2.35, 37.66)=18.46, p<0.001.

N1 Component

Mean Amplitude

Main effect of Hemisphere was found in the young, F(1.00, 16.00)=12.21, p=0.003 but not the older group, F(1.00, 15.00)=0.15, p=0.706. The mean amplitude was found greater in the left (-1.80±0.27μV) than right hemisphere (0.95±0.24μV) in the young group only. Site effect was only found in the older group in the allocentric condition, F(1.48, 22.24)=4.66, p=0.029 but not found in any condition in the young group, F(1.41, 22.47)=1.76, p=0.199.

Peak latency

Hemisphere effect was only found in the young group with shorter latency in the left hemisphere (116.79±1.90 ms) than right hemisphere (119.76±1.72 ms), F(1.00, 16.00)=7.83, p=0.013. However, it was not found in the older group, F(1.00, 15.00)=2.80, p=0.170. Site effect was found in the young group, F(1.06, 17.02)=18.49, p<0.001 but not in the older group, F(1.50, 22.43)= 3.34, p=0.066 by the analyses with the midline site model.

N2 Component

Mean Amplitude

Main effect of Laterality was only found in the older group, F(1.00, 15.00)=22.13 p<0.001 but not in the young group, F(1.00, 16.00)=0.50, p=0.491. The Cz showed marginal effect of Condition in the older group, F(1.00, 15.00)=4.34, p=0.055 which was not found in the young group. Mean amplitude of egocentric (0.14±0.66μV) was less positive than allocentric condition (0.45±0.71μV) at Cz.

Peak latency

For the young group, main effect of Condition was found in the midline model, F(1.00, 16.00)=8.56, p=0.010. Peak latency of the N2 was shorter in egocentric (286.08±7.10 ms) than allocentric condition (298.75±8.68 ms) in the young but not in the older group in the midline site model, F(1.00, 15.00)= 0.21, p=0.653.

P3 Component

Mean Amplitude

Pairwise comparisons showed that the mean amplitude was larger at F3/4 (2.57±0.39μV) and C3/4 (2.16±0.43μV) than at P3/4 (1.48±0.45μV), PO3/4 (1.08±0.39μV) and T7/8 (1.82±0.32μV) in the older group (p<0.05). In contrast, F3/4 (0.29±0.36μV) had the smallest mean amplitudes among the electrode sites

by pairwise comparisons in the young group ($p<0.05$). Effect of Laterality was found in the left hemisphere in both egocentric condition, $F(1.00, 15.00)=17.26$, $p=0.001$ and allocentric condition, $F(1.00, 15.00)=20.81$, $p<0.001$ in the older group. However, there was no any effect of Laterality in the left hemisphere in the young group, $F(1.00, 16.00)=0.19$, $p=0.672$.

In the older group, the midline site model showed main effect of Hemi-field, $F(1.00, 15.00)=6.45$, $p=0.023$. Mean amplitude of the P3 was larger for the visual stimuli presented on the left hemi-field ($3.25\pm0.52\mu V$) than right hemi-field ($2.90\pm0.49\mu V$). Contrarily, the mean amplitude was marginally larger for the visual stimuli presented at right hemi-field ($1.22\pm0.48\mu V$) than left hemi-field ($0.86\pm0.55\mu V$) in the young group, $F(1.00, 16.00)=4.17$, $p=0.058$.

Pairwise comparisons showed that the mean amplitude of Fz ($3.59\pm0.45\mu V$) was significantly larger than Pz ($2.82\pm0.56\mu V$) and Pz ($2.63\pm0.50\mu V$) in the older group ($p<0.05$). In the young group, however, the mean amplitude of Fz was significantly smaller than the other midline sites ($p<0.05$).

Peak Latency

Main effect of Hemisphere at F3/4 by post-hoc analysis was found, $F(1.00, 16.00)=4.59$, $p=0.05$ only in the young group. That means shorter peak latency in the left hemisphere (367.22 ± 13.11 ms) than the right hemisphere (378.25 ± 12.22 ms) was found at F3/4 in the young group.

CDA

Main effect of Condition was only found in the older group, F(1.00, 15.00)=5.43, p=0.034 (Table 4.21). Mean amplitude of the CDA was found larger in egocentric (-0.64±0.09μV) than allocentric condition (-0.47±0.07μV).

Early CNV Component

Although both the young, F(15.63, 41.96)=5.96, p=0.18 and older group, F(1.41, 21.89)=4.49, p=0.035 had site effects, their greatest mean amplitudes of CNV were found at Fz (-0.80±0.47μV) and POz (0.60±0.46μV) respectively.

Based on the above observations, the older group seemed different from the young group in some aspects. To verify such differences, the data between young and older groups were compared and analyzed as follows:

Behavioral data

Reaction time and accuracy rate were separately analyzed in a Condition (Egocentric vs. Allocentric) x Hemi-field (Left vs. Right) x Cue-validity (Valid vs. Invalid) repeated measures ANOVA with Group (Young vs. Older adults) as a between-subject factor.

ERP data

P1, N1, N2 & P3

For the lateral site model, the data was analyzed in a Condition (Egocentric vs. Allocentric) x Hemisphere (Left vs. Right) x Laterality (Contralateral vs. ipsilateral signal relative to visual stimuli) x Lateral Sites (F3, F4, C3, C4, P3, P4, PO3, PO4, T7, T8) repeated measures ANOVA with Group (Young vs. Older adults) as a between-subject factor. The sites for the left hemisphere were: F3, C3, P3, PO3 and T7; those on the right hemisphere were F4, C4, P4, PO4 and T8.

For the midline site model, the data was analyzed in a Condition (Egocentric vs. Allocentric) x Hemi-field (Left vs. Right) x Midline Sites (Fz, Cz, Pz, POz) repeated measures ANOVA with Group (Young vs. Older adults) as a between-subject factor.

CDA

The CDA component was analyzed by a three-way repeated measures ANOVA with Condition (Egocentric vs. Allocentric) x Homologous paired site (F3/4, C3/4, P3/4, PO3/4) x Group (Young vs. Old).

Early CNV

The CNV component was analyzed by a two-way repeated measures ANOVA with Condition (Egocentric vs. Allocentric) x Midline site with averaged signal from left & right hemi-fields (Fz, Cz, Pz, POz) x Group (Young vs. Old).

RESULTS IN YOUNG AND OLD GROUP COMPARISONS

Behavioral Results

Group effects were found on both reaction time (RT), $F(1,31)= 18.84$, $p<0.001$ and accuracy rate (AC), $F(1,31)=17.69$, $p<0.001$. The older group responded slower (828.43$\pm$26.12 ms) and less accurate (83.87$\pm$1.54%) than young group (670.50$\pm$25.34 ms) (92.90$\pm$1.49%).

For RT, interaction effect between Group and Hemi-field was found, $F(1.00,31.00)=11.99$, $p=0.002$ (Appendix XVII (a)). As shown in the results in young group (Appendix XIII (a)), main effect of Hemi-field was found in this group. That means they responded faster when the visual stimuli were presented to their right (651.75$\pm$25.86 ms) compared to their left (689.24$\pm$27.12 ms) hemi-fields. However, no such phenomenon was found in the older group.

For AC, interactions were found between group and condition, $F(1.00,31.00)=8.92$, $p=0.005$ and between group and validity, $F(1.00,31.00)=15.55$, $p<0.001$ (Appendix XVII (b)). The results from the older and young groups showed that main effect of Condition was only found in the older group, $F(1, 15)=14.66$, $p=0.002$ but not the young group, $F(1,16)=0.97$, $p=0.340$. The older group responded more accurately in egocentric (85.64$\pm$1.31%) than allocentric (82.09$\pm$1.64%) but no such difference was found in the young group ($p>0.05$).

Both young and older group responded more accurately in valid (Young: 95.11±1.25%; Older: 91.22±0.87%) than invalid trial (Young: 90.67±2.02%; Older: 76.52±2.50%) ($p<0.001$).

ERP Measures

P1 Component

Mean Amplitude

Group effect was indicated in the lateral site model with greater mean amplitude was found in the older group (0.42±0.15μV) when compared to the young group (-0.10 ±0.14μV), $F(1, 31)=6.28$, $p=0.018$. Interaction effect between Group, Hemisphere and Laterality was found, $F(1.00, 31.00)=12.54$, $p=0.001$ (Appendix XVII (c)). Separate post-hoc tests by three-way repeated measures ANOVA with Condition (Egocentric vs. Allocentric) x Laterality (Contralateral vs. Ipsilateral signal relative to visual stimuli) x Lateral site (F3, F4, C3, C4, P3, P4, PO3, PO4, T7, T8) in each hemisphere in each group found main effect of Laterality in the left hemisphere $F(1.00, 16.00)=46.46$, $p<0.001$ but not right hemisphere in the young group, $F(1.00, 16.00)=2.60$, $p=0.126$. The mean amplitude was greater in contralateral (0.39±0.16μV) than ipsilateral signal (-0.26±0.19μV) in the left hemisphere in this group. However, no such effect was found in the older group, $F(1.00, 15.00)=3.52$, $p=0.080$.

The midline site model showed marginal group effect, F(1, 31)=4.11, p=0.051 by a four-way repeated measured ANOVA in which the within-subject factors were Condition (Egocentric vs. Allocentric) x Hemi-field (Left vs. Right) x Midline site (Fz, Cz, Pz, POz) and Group (Young vs. Older) as a between factor. The mean amplitude of the P1 was marginally greater in the older (0.23±0.21μV) than young group (-0.37±0.21μV). Interaction effect between Group and Hemi-field was found, F(1.00, 31.00)=13.04, p=0.001 (Appendix XVII (d)). Separate post-hoc tests in each group by three-way repeated measures ANOVA with Condition (Egocentric vs. Allocentric) x Hemi-field (Left vs. Right) x Lateral site (F3, F4, C3, C4, P3, P4, PO3, PO4, T7, T8) found main effect of Hemi-field only in the young group. Mean amplitude of the P1 was larger for the visual stimuli presented at right hemi-field (0.07±0.20μV) than left hemi-field (-0.81±0.24μV). No such effect was found in the older group.

Peak Latency

Similar as mean amplitude, the lateral site model found group effect, F(1, 31)=8.79, p=0.006 with longer latency in the older group (69.79±2.3 ms) when compared with the young group (60.25±2.24 ms). Interaction effects were found between Group and Site, F(2.43, 75.22)=2.78, p<0.001 and between Group, Laterality and Site, F(3.26, 100.96)=3.74, p=0.011 (Appendix XVII (e)). Separate post-hoc tests by four-way repeated measures ANOVA with Condition (Egocentric vs. Allocentric) x Hemisphere (Left vs. Right) x Laterality (Contralateral vs. Ipsilateral signal relative to visual stimuli) x Lateral site (F3, F4, C3, C4, P3, P4, PO3, PO4, T7, T8) in each group found main effect of lateral site only in the young

group, F(2.35, 37.66)=18.46, p<0.001 but not in the older group, F(2.17, 32.62)=1.19, p=0.320. Peak latency of PO3/4 (69.62±2.51 ms) was the longest in the young group when compared to those of F3/4 (50.96±2.20 ms), C3/4 (58.06±2.37 ms), P3/4 (63.82±2.35 ms) and T7/8 (58.79±2.64 ms) in pairwise comparisons (p<0.05). Interaction effect between Laterality and Site was also only found in the young group, F(4, 64)=3.60, p=0.010. Separate post-hoc test by three-way repeated measures ANOVA with Condition (Egocentric vs. Allocentric) x Hemisphere (Left vs. Right) x Laterality (Contralateral vs. Ipsilateral signal relative to visual stimuli) in each paired lateral site in this group found main effect of Laterality at P3/4, F(1.00, 16.00)=6.38, p=0.022, PO3/4, F(1.00, 16.00)=8.51, p=0.010 and marginal at T7/8, F(1.00, 16.00)=4.41, p=0.052 but not at F3/4, F(1.00, 16.00)=0.01, p=0.906, C3/4, F(1.00, 16.00)=1.60, p=0.223. That means the peak latency of contralateral signals recorded at posterior sites (P3/4 and PO3/4) were significantly shorter than their ipsilateral signals.

Similar as the results from the lateral site model, the midline site model also showed group effect of Site, F(1, 31)=7.26, p=0.011 with longer latency in the older group (67.30±2.6 ms) when compared with the young group (57.67±2.49 ms). Interaction effects were found between Group and Site, F(1.42, 43.94)=13.12, p<0.001 (Appendix XVII (f)). Separate post-hoc tests by three-way repeated measured ANOVA with Condition (Egocentric vs. Allocentric) x Hemi-field (Left vs. Right) x Midline site (Fz, Cz, Pz, POz) in each group found main effect of midline site only in the young group, F(1.67, 26.72)=12.12, p<0.001 but not in the older group, F(1.19, 17.83)=3.21, p=0.085. Pairwise comparisons showed that

peak latencies of Pz (61.66±2.56 ms) and POz (63.60±2.54 ms) were significantly longer than Fz (50.52±2.29 ms) and Cz (54.91±2.63 ms) in the young group ($p<0.05$).

N1 Component

Mean Amplitude

No Group effect, $F(1, 31)=0.16$, $p=0.692$ or any interaction effect with group ($p>0.05$) was found in the lateral site model (Appendix XVII (g)).

Similar to the lateral site model, no any Group effect or interaction effect with group was found in the midline site model, $F(1, 31)=0.23$, $p=0.634$ (Appendix XVII (h)).

Peak Latency

The lateral site model found group effect, $F(1, 31)=29.43$, $p<0.001$ with longer latency in the older group (133.37±2.00 ms) when compared with the young group (118.27±1.94 ms). Interaction effects were found between Group and Condition, $F(1.00, 31.00)=4.99$, $p=0.033$ and between Group and Site, $F(1.75, 54.37)=8.25$, $p=0.001$ (Appendix XVII (i)). Separate post-hoc tests by four-way repeated measures ANOVA with Condition (Egocentric vs. Allocentric) x Hemisphere (Left vs. Right) x Laterality (Contralateral vs. Ipsilateral signal relative to visual stimuli) x Lateral site (F3, F4, C3, C4, P3, P4, PO3, PO4, T7, T8) in each group did not find main effect of Condition in the young group, $F(1.00, 16.00)=3.38$, $p=0.084$ or the older group, $F(1.00, 15.00)= 2.76$, $p=0.117$.

Subsequent post-hoc tests with four-way repeated measures ANOVA in each condition with Hemisphere (Left vs. Right) x Laterality (Contralateral vs. Ipsilateral signal relative to visual stimuli) x Lateral site (F3, F4, C3, C4, P3, P4, PO3, PO4, T7, T8) with 2 groups as a between-subject factor found group effect in both egocentric, $F(1, 31)=19.90$, $p<0.001$ and allocentric condition, $F(1, 31)=29.73$, $p<0.001$. Peak latency of the N1 was longer in the older group (Egocentric:132.72$\pm$2.00 ms , Allocentric: 134.03$\pm$2.34 ms) than the young group (Egocentric: 120.31$\pm$1.94 ms , Allocentric: 116.21$\pm$2.27 ms). Separate post-hoc tests by four-way repeated measures ANOVA with Condition (Egocentric vs. Allocentric) x Hemisphere (Left vs. Right) x Laterality (Contralateral vs. Ipsilateral signal relative to visual stimuli) x Lateral site (F3, F4, C3, C4, P3, P4, PO3, PO4, T7, T8) in each group found main effect of Site only in the young group, $F(1.87, 29.84)=36.33$, $p<0.001$ but not the older group, $F(2.17, 32.62)= 1.19$, $p=0.320$. Pairwise comparisons showed that each pair of lateral site in the young group was significantly different from each other ($p<0.01$). The shortest peak latency was found at F3/4 (108.57$\pm$1.78 ms) while the longest was at PO3/4 (126.91$\pm$2.27 ms).

Similar as the results from lateral site model, the midline site model also showed between-group effect, $F(1, 31)=24.06$, $p<0.001$ with longer latency in the older group (130.19$\pm$2.35 ms) when compared with the young group (114.14$\pm$2.28 ms). Interaction effects were found between Group and Condition, $F(1.00, 31.00)=5.76$, $p=0.023$ and between Group and Site, $F(1.18, 36.51)=7.44$, $p=0.007$

(Appendix XVII (j)). Separate post-hoc tests by three-way repeated measured ANOVA with Condition (Egocentric vs. Allocentric) x Hemi-field (Left vs. Right) x Midline site (Fz, Cz, Pz, POz) in each group did not find main effect of Condition in the young group, $F(1.00, 16.00)=2.92$, $p=0.107$ and the older group, $F(1.00, 15.00)= 4.04$, $p=0.063$. Another post-hoc tests with three-way repeated measures ANOVA in each condition with Hemi-field (Left vs. Right) x Midline sites (Fz, Cz, Pz, POz) with 2 groups as a between-subject factor found Group effect in both egocentric, $F(1, 31)=12.36$, $p=0.001$ and allocentric conditions, $F(1, 31)=29.38$, $p<0.001$. Peak latency of the N1 was longer in the older group (Egocentric:128.84$\pm$2.56 ms , Allocentric: 131.53$\pm$2.59 ms) than the young group (Egocentric: 116.32$\pm$2.48 ms , Allocentric: 111.96$\pm$2.52 ms).

N2 Component

Mean Amplitude

No between group effect was found in the lateral site model, $F(1, 31)=0.40$, $p=0.533$. Interaction effects were found between Group and Laterality, $F(1.00, 31.00)=5.25$, $p=0.029$ and between Group and Site, $F(1.63, 50.57)=6.37$, $p=0.006$ (Appendix XVII (k)). Separate post-hoc tests by four-way repeated measures ANOVA with Condition (Egocentric vs. Allocentric) x Hemisphere (Left vs. Right) x Laterality (Contralateral vs. Ipsilateral signal relative to visual stimuli) x Lateral site (F3, F4, C3, C4, P3, P4, PO3, PO4, T7, T8) in each group found main effect of Laterality only in the older group, $F(1.00, 15.00)=22.13$, $p<0.001$ but not the young group, $F(1.00, 16.00)= 0.50$, $p=0.491$. Mean amplitude of the N2 in the

older group was less positive in contralateral (0.59±0.46μV) than ipsilateral signal (1.00±0.42μV) in the lateral site model. Main effect of Site was also found, F(2.43, 33.46)=3.35, p=0.038. Pairwise comparisons showed that the mean amplitude of PO3/4 (0.35±0.40μV) was significantly less than F3/4 (1.27±0.45μV) and T7/8 (0.90±0.37μV) ($p<0.05$).

No any between-subject effect of Group, F(1, 31)=0.38, p=0.542 or any interaction effect with group was found in the midline site model (Appendix XVII (l)).

Peak Latency

The lateral site model found group effect, F(1, 31)=19.23, $p<0.001$ with longer latency in the young group (293.39±6.75 ms) when compared with the older group (250.88±6.96 ms). However, there was no any interaction effect with group was found (Appendix XVII (m)).

Similar as the results of lateral site model, the midline site model also showed between-group effect, F(1, 31)=12.07, p=0.002 with longer latency in the young group (292.42±7.65 ms) when compared with the older group (254.23±7.89 ms). Interaction effects were found between Group and Condition, F(1.00, 31.00)=5.59, p=0.025 (Appendix XVII (n)). Separate post-hoc tests by three-way repeated measured ANOVA with Condition (Egocentric vs. Allocentric) x Hemi-field (Left vs. Right) x Midline site (Fz, Cz, Pz, POz) in each group found main effect of Condition only in the young group, F(1.00, 16.00)=8.56, p=0.0.10 with shorter latency in egocentric (286.08±7.10 ms) than allocentric conditions

(298.75±8.68 ms). However, no such difference was found in the older group, F(1.00, 15.00)= 0.06, p=0.814.

P3 Component

Mean Amplitude

No between-subject effect of Group was found in the lateral site model, F(1, 31)=2.00, p=0.167. Interaction effects were found between Group and Laterality, F(1.00, 31.00)=6.34, p=0.017, between Group and Site, F(1.60, 49.63)=14.53, p<0.001 and between Group, Hemisphere and Laterality, F(1.00, 31.00)=17.54, p<0.001 (Appendix XVII (0)). To investigate the interaction effect between Group, Hemisphere and Laterality, separate post-hoc tests by three-way repeated measures ANOVA with Condition (Egocentric vs. Allocentric) x Laterality (Contralateral vs. Ipsilateral signal relative to visual stimuli) x Lateral site (F3, F4, C3, C4, P3, P4, PO3, PO4, T7, T8) in each hemisphere in each group were used. For the young group, main effect of Laterality was found only in the right hemisphere, F(1.00, 16.00)=10.78, p=0.005 but not left hemisphere, F(1.00, 16.00)=0.19, p=0.672. In contrast to the young group, effect of Laterality was only found in the left hemisphere in the older group, F(1.00, 15.00)= 23.95, p<0.001 but not in the right hemisphere, F(1.00, 15.00)=3.89, p=0.067. Effect of Laterality in the P3 component found that the mean amplitude of ipsilateral signal was larger than the contralateral signal (p<0.05). To study the interaction effect between Group and Site, separate post-hoc tests by four-way repeated measures ANOVA in each group with Condition (Egocentric vs. Allocentric) x Hemisphere (Left vs. Right) x

Laterality (Contralateral vs. Ipsilateral signal relative to visual stimuli) x Lateral site (F3, F4, C3, C4, P3, P4, PO3, PO4, T7, T8) were conducted. Effect of Site was found in both young, $F(1.36, 21.72)=5.10$, $p=0.025$ and older group, $F(2.23, 33.46)=16.23$, $p<0.001$. Pairwise comparisons indicated that the mean amplitude of F3/4 ($0.29\pm0.36\mu V$) was the smallest among the recording lateral electrode sites in the young group. However, the mean amplitude was found larger at F3/4 ($2.57\pm0.39\mu V$) and C3/4 ($2.16\pm0.43\mu V$) than P3/4 ($1.48\pm0.45\mu V$), PO3/4 ($1.08\pm0.39\mu V$) and T7/8 ($1.82\pm0.32\mu V$) in the older group. Further analyses for the interaction effect between Group and Site, separate post-hoc tests by four-way repeated measures ANOVA with Condition (Egocentric vs. Allocentric) x Hemisphere (Left vs. Right) x Laterality (Contralateral vs. Ipsilateral signal relative to visual stimuli) x Group (Young and Older) in each paired lateral site were conducted. Main effect of Group was only found at, F3/4, $F(1, 31)=18.68$, $p<0.001$ which showed that the mean amplitude of F3/4 was larger in the older group ($2.57\pm0.38\mu V$) than the young group ($0.29\pm0.37\mu V$).

Between-subject effect of Group, $F(1, 31)=8.15$, $p=0.008$ and interaction effect between Group and Hemi-field, $F(1.00, 31.00)=9.91$, $p=0.004$ and between Group and Site, $F(1.27, 39.38)=11.38$, $p=0.001$was found in the midline site model (Appendix XVII (p)). To study the interaction effect between Group and Hemi-field, separate post-hoc tests by three-way repeated measures ANOVA in each group with Condition (Egocentric vs. Allocentric) x Hemi-field (Left vs. Right) x Midline site (Fz, Cz, Pz, POz) were conducted. Effect of Hemi-field was found in the older group, $F(1.00, 15.00)=6.45$, $p=0.023$ but marginal in the young group,

F(1.00, 16.00)=4.17, p=0.058. Larger P3 was found when stimuli appeared at RHF (1.22±0.48μV) than LHF (0.86±0.55μV) in the young group. However, it is the other way round for the older adults. Their P3 was larger for the stimuli presented at the LHF (3.25±0.52μV) than the RHF (2.90±0.49μV). To investigate the interaction effect between Group and Site, separate post-hoc tests by three-way repeated measures ANOVA in each group with Condition (Egocentric vs. Allocentric) x Hemi-field (Left vs. Right) x Midline sites (Fz, Cz, Pz, POz) were conducted. Effect of Site was found in both young group, F(1.21, 19.38)=6.24, p=0.017 and older group, F(1.46, 21.84)=7.15, p=0.008. Pairwise comparisons in each group showed that the mean amplitude of Fz (0.04±0.47μV) was found significantly smaller than the other midline sites (Cz(0.95±0.51μV), Pz (1.66±0.65μV), POz (1.52±0.63μV)) in the young group ($p<0.05$). However, Fz (3.59±0.45μV) was significantly larger than Pz (2.82±0.56μV) and POz (2.63±0.50μV) ($p<0.05$) in the older group (Figure 4.15).

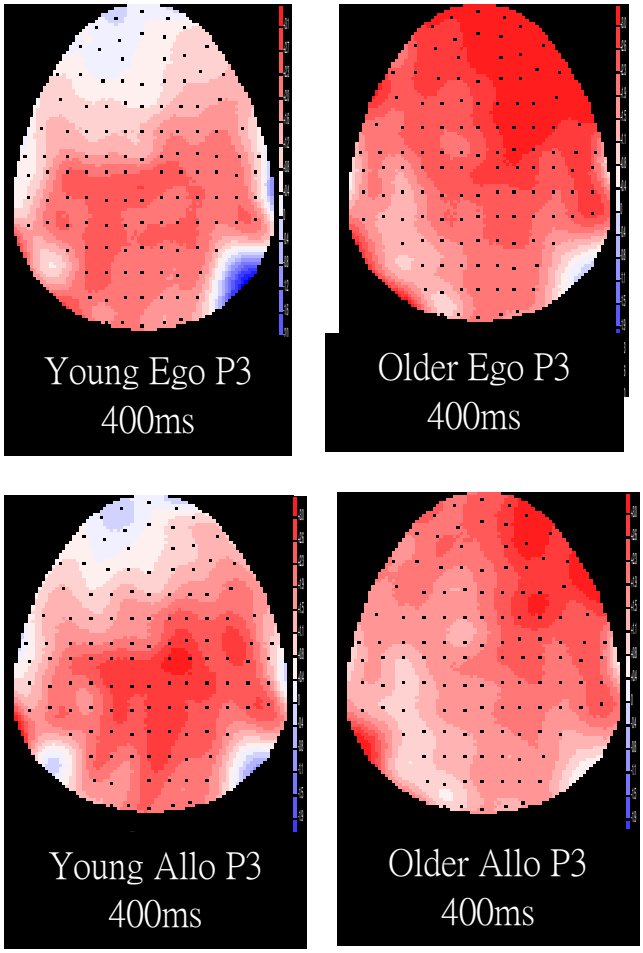


Figure 4.15
Topographical distribution of the P3 components between groups in egocentric and allocentric conditions

Peak Latency

The lateral site model found between-subject effect of Group, F(1, 31)=8.34, p=0.007 with longer latency in the older group (415.91±10.25 ms) when compared with the young group (374.68±9.94 ms). Interaction effects were found between Group and Condition, F(1.00, 31.00)=4.33, p=0.046 and between Group, Condition, Hemisphere and Site, F(2.76, 85.42)=2.96, p=0.041 (Appendix XVII (q)). To study the interaction effect between Group and Condition, separate post-hoc tests by four-way repeated measures ANOVA in each group with Condition (Egocentric vs. Allocentric) x Hemisphere (Left vs. Right) x Laterality (Contralateral vs. Ipsilateral signal relative to visual stimuli) x Lateral site (F3, F4, C3, C4, P3, P4, PO3, PO4, T7, T8) were conducted. No effect of Condition was found in either young, F(1.00, 16.00)=2.74, p=0.117 or older group, F(1.00, 15.00)=1.77, p=0.204. To further analyze the interaction effect, separate post-hoc tests by four-way repeated measures ANOVA in each condition with Hemisphere (Left vs. Right) x Laterality (Contralateral vs. Ipsilateral signal relative to visual stimuli) x Lateral site (F3, F4, C3, C4, P3, P4, PO3, PO4, T7, T8) x Group (Young and Older) were conducted. The peak latency of P3 at lateral sites were shorter in young group (371.31±9.61 ms) than the older group (419.38±9.91 ms) in egocentric condition, F(1, 31)=12.12, p=0.002. Similarly, peak latency was also shorter in young group (378.44+10.77 ms) than the older group (412.44+11.09 ms) in allocentric condition, F(1, 31)=4.95, p=0.033. To test for the interaction effect between Group, Condition, Hemisphere and Site, separate post-hoc tests by three-way repeated measures ANOVA in each group with Condition (Egocentric vs.

Allocentric) x Hemisphere (Left vs. Right) x Laterality (Contralateral vs. Ipsilateral signal relative to visual stimuli) for each paired lateral site was conducted. Main effects of Condition, F(1.00, 16.00)=4.76, p=0.044 and Hemisphere, F(1.00, 16.00)=4.59, p=0.048 were only found at F3/4 in the young group. The latency of P3 at F3/4 was shorter in egocentric condition (366.62±12.63 ms) than allocentric condition (378.85±12.81 ms) and left hemisphere (367.22±13.11 ms) than right hemisphere (378.25±12.22 ms) in the young group.

Between-subject effect of Group was marginal in the midline site model, F(1, 31)=3.86, p=0.059 with longer latency in the older group (412.32±12.08 ms) when compared with the young group (379.27±11.72 ms). No any interaction effects with group was found (p>0.05) (Appendix XVII (r)).

CDA

No between-subject effect of Group was found by three-way repeated measures ANOVA with Condition (Egocentric vs. Allocentric) x Homologous paired site (F3/4, C3/4, P3/4, PO3/4) x Group (Young vs. Old), F(1, 31)=0.05, p=0.821. However, interaction effects were found between Group and Condition, F(1.00, 31.00)=5.74, p=0.023 and between Group and Site, F(2.70, 95.20)=3.04, p=0.038. Post-hoc tests by two-way repeated measures ANOVA with Condition (Egocentric vs. Allocentric) x Homologous paired site (F3/4, C3/4, P3/4, PO3/4) in each group showed that only the older group had condition effect, F(1.00, 15.00)=5.43, p=0.034. Mean amplitude of the CDA was found larger in egocentric

(-0.64±0.09μV) than allocentric condition (-0.47 ±0.07μV). No condition effect was found in the young group, F(1.00, 16.00)=0.64, p=0.435. On the other hand, effect of Site was only found in the young group, F(2.11, 33.72)=5.59, p=0.007. The mean amplitude of F3/4 (-0.28±0.042μV) in the young group was the least among the homologous paired sites by pairwise comparisons ($p<0.01$).

Early CNV Component

Main effects of Condition, F(1.00, 31.00)=11.59, p=0.002 and Site, F(1.30, 40.28)=1.56, p=0.048 were found by a two-way repeated measures ANOVA with Condition (Egocentric vs. Allocentric) x Midline site with averaged signal from left and right hemi-fields (Fz, Cz, Pz, POz) x Group (Young vs. Old). The amplitudes of CNV for the egocentric (0.35±0.32μV) was more negative-going than those for the allocentric condition (0.75±0.35μV). Interaction effects between Site and Group was also found, F(1.30, 40.30)=9.66, p=0.002. Post hoc tests showed that Fz (-0.57+0.49μV) and POz (0.60+0.49μV) were sites with the most negative-going waveforms in the young and older group respectively.

CHAPTER FIVE

DISCUSSION

In this chapter, the findings of visual attention modulated by egocentric and allocentric frames of reference in the young adult group will be discussed. This will be followed by a discussion of the findings obtained from the older group.

MODULATION OF VISUAL ATTENTION BY EGOCENTRIC AND ALLOCENTRIC FRAMES OF REFERENCE IN YOUNG ADULTS

The aim of the study on young adult subjects was to examine the effects of egocentric and allocentric frames of reference in the modulation of visual attention. It was hypothesized that visual attention would be modulated by using different frames of reference and most important, the cognitive processes associated with these frames of reference would be obtained with electrophysiological measures which would be used to compare the results found in the second part of the main study which targeted at the older group.

Behavioral Performance

The results showed that the young subjects responded faster in the valid than the invalid condition which are consistent with previous studies that facilitative effects in reaction time was observed in valid trials (Posner, 1988; Posner & Petersen, 1990). This facilitative effect is regarded as the mobilization of automatic visuospatial attention, which facilitates sensory processing at the

attended location (Posner & Cohen, 1984). They explained that attention will be shifted to the cued location. Therefore, it is more ready in responding to the target which appears at that already attended location and results in the shortening of target detection time. On the invalid-cue trials, however, additional time is required to initiate and shift the attention from the already attended location to another location where the target unexpectedly appears.

The RT in egocentric was shorter than allocentric condition. This finding is consistent with previous study (Barrett et al., 2001). It is also supported by Farah and colleagues (1990) that as visual stimuli are relatively automatically encoded in retinotopic coordinates egocentrically, it requires little computation to derive their locations. In other words, egocentric frame of reference is more natural and efficient in allocating attention for detecting target. On the other hand, the accuracy rate did not have any difference between egocentric and allocentric conditions. As reflected by high accuracies in valid trial in both egocentric: LHF: 95.14$\pm$5.30%, RHF: 96.48$\pm$3.84%; and Allocentric: LHF: 94.22$\pm$5.75%, RHF: 94.59$\pm$6.48) (Table 4.2), it indicates that the young subjects could effectively make use of information provided by the cues in either conditions to anticipate the target locations. Such high accuracy rate, however, can also be possibly due to a ceiling effect of the task has been reached.

Interestingly, the findings show that young adults responded faster when the visual stimuli appeared on the right hemi-field which contradict to the hypothesis of leftward biased of visual attention in healthy young adults when participated in tasks with bisection in nature (McCourt & Jewell, 1999). This

leftward biased phenomenon of visual attention was observed when subjects were required to divide a line into two equal segments. They tended to systematically misbisect horizontal lines to the left of the actual centre, a phenomenon known as pseudoneglect (Bowers & Heilman, 1980). As similar neglect symptom with rightward biased is commonly found in patients with right brain damage, different models were proposed to explain these phenomena (Heilma, Watson, & Valenstein, 2002; Kinsbourne, 1970; Mesulam, 1981). They generally agreed that right hemisphere spatially represented both sides of space, whereas the left hemisphere only directs attention predominately to the right (contralateral) side (Corbetta & Shulman, 2002; Heilma, Watson, & Valenstein, 2002; Mesulam, 1981). It was postulated that due to the predominant role of right hemisphere in visual attention, slight bias in attention towards the left in normal participants would be resulted, which gave rise to the overestimation of the length of the left half of the line (Milner, Brechmann, & Pagliarini, 1992). This hypothesis, however, is contradicted with the findings of recent studies that rightward bias of automatic visual attention should be more dominant than that of leftward bias (Castro-Barros et al., 2008; Righi & Ribeiro-do-Valle, 2011). These studies used the peripheral cues which presented in either hemi-field or bilateral hemi-fields in order to test the differences of facilitative effects between left and right hemi-fields (Castro-Barros et al., 2011). One of the factors to be modulated was (Cue-target onset asynchrony) CTOA and they found that only longer CTOA (about 100ms) could favor the automatic visual attention to the right hemi-field in terms of shorter RT. It was explained that sufficient time was required for the inter-hemispheric signal transmission to allow the right hemisphere to control attention to the right side

(ipsilateral) of the space. The methods used in these studies were similar to those used in the present study in terms of presentation of peripheral cues and long CTOA. It may explain the reason why the subjects in the present study responded faster in the right hemi-field with the rightward bias of automatic visual attention.

Gender difference in visual attention to hemi-fields was found in a previous study in which the male subject responded faster to the right hemi-field (Davidson, Cave, & Snellner, 2000). This possible gender factor did not exist in the present study as supported by the results obtained by comparing the data against gender. The possible reason for such discrepancy is due to the difference in study designs. The paradigm designed by Davidson and his colleagues included two tasks: one of them was the Letter Task which required the subjects to memorize the letter presented at a fixation before the target appeared and pressing a button when this target was detected. Another task was the Dots Task which was similar to the Letter Task but the subject had to memorize the location of two dots instead of the lexical information. In fact, the gender difference in their study was only found in the Letters Task which required memorizing the lexical information but not the Dots Task which involved in memorizing the spatial location. The present study involved mainly the spatial visual attention without any lexical memory which is similar to the Dot Tasks of Davidson's study and therefore no gender effect was expected.

ERP Results

The differences in behavioral data found between the two coding frames of reference may be explained by their differences in the cognitive processes involved which were reflected by the ERP components.

No obvious C1 was found from the grand average waveforms. A number of reasons may explain such phenomenon. Small C1 amplitude was previously reported to be elicited from the unilateral visual stimulus (Fu et al., 2010). As the visual stimuli in this experiment were presented unilaterally and no clear C1 would be expected. Besides, the C1 component has been shown to be sensitive to retinal location of the stimulus and its polarity reverses in upper and lower visual field C1 polarity, upper field presentations would produce a C1 that manifests as scalp negativity and lower field presentations producing a scalp positivity (Clark et al., 1995; Kelly et al., 2008; Stolarova et al., 2006). Same number of visual stimuli was presented between upper and lower visual fields in this study, i.e. both visual fields shared same number of visual stimuli. The C1 component elicited from these visual fields would have been cancelled out each other (Foxe et al., 2013). A number of studies have demonstrated that C1 would overlap with P1, and as a result a distinct C1 component may not be easily found in most of the experiments. In order to avoid from the merging effect of the positive-going P1 and the same polarity of C1 induced from the visual stimuli at lower visual field, the stimuli are suggested to present on the upper field only (Luck & Kappenman, 2012; Stolarova et al., 2006). Furthermore, for experiments with visual stimuli presented on all four quadrants and able to obtain an observable C1, more than a hundred of trials in

each quadrant would be required (Clark et al., 1995; Stolarova et al., 2006). However, the present study did not have sufficient number of successful trials to meet the suggested requirement for producing discernible C1: Egocentric left upper or lower quadrant: 78.8±13.5 trials, egocentric right upper or lower quadrant: 85.4±17.5 trials, allocentric left upper or lower quadrant: 75.8±18.4 trials, allocentric right upper or lower quadrant: 88.3±19.2 trials.

The P1 is related to the perceptual processing of the attended stimuli (Doallo et al., 2004) while the N1 is found to be modulated by the stimulus characteristics and spatial attention (Mangun, 1995). It means that both P1 and N1 are mainly for the early sensory processing of the visual stimuli (Heinze et al., 1994). Since both egocentric and allocentric conditions use the same set of cue stimuli, they share the same physical properties and locations of the three-circle-triad. Therefore, no condition effect was expected to be found in the early sensory components during the cue-target interval.

The latencies of P1 and N1 in this study were shorter than those revealed in other studies on visual attention. The design of the experimental paradigm used in this study may offer plausible reason for explaining this observation. The cue stimuli of the present study were flash-like in nature, which would induce the flash visual evoked potentials (FVEP). These are similar to the latency of FVEP in previous study (Diaz & Amenedo, 1998; Foxe, & Simpson, 2005).

The behavioral data shows that the reaction time of egocentric was faster than the allocentric condition. It is because the allocentric frame of reference is

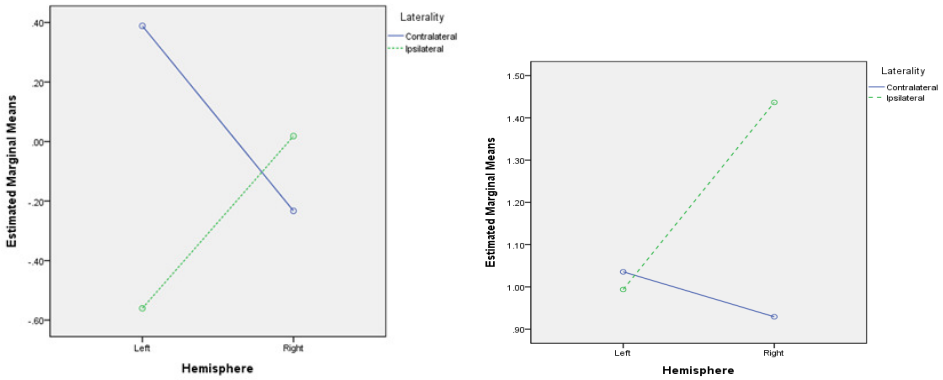
regarded as less automatic in coding of visual stimulus, it was expected that the subjects should allocated more attentional resources or spent longer time for encoding and interpreting the cues in this condition. This assumption is supported by the main effect of condition found in the latencies of posterior and anterior N2 components in the midline sites which indicates that their latencies are shorter in egocentric than allocentric condition. The posterior N2 is interpreted as reflecting selective processing and its latency increases with the difficulty in discrimination of stimuli (Tachibana, Aragane, & Sugita, 1996). The anterior N2, with later onset than the posterior N2, is proposed to relate in post-selection process of further task-directed processing of the relevant stimuli such as strategic process (Kenemans, Smulders, & Kok, 1995; Luck & Hillyard, 1994; Smid, Jakob, & Heinze, 2003). Although the physical appearance of the egocentric and allocentric cues were the same, they were interpreted differently. The cognitive processes involved in these two cued conditions may be interpreted by the roles of posterior and anterior N2. For the egocentric cued condition, the location of an illuminated circle was identified by discriminating from the other two non-illuminated circles (posterior N2). The spatial location of this illuminated circle would then be encoded and attended for the subsequent presence of a target (anterior N2). In allocentric condition, however, not only an illuminated but also two non-illuminated circles were needed to be discriminated from each other (posterior N2) which provided essential information for the additional post-selection processing in determining the relative position of the illuminated circle to the other two non-illuminated circles before it was being attended (anterior N2). These additional processes were reflected by longer latencies of the anterior and posterior N2 in the allocentric

condition. Additional resources allocated for the proposed post-selection processing by the anterior brain region in the allocentric condition are also supported by greater amplitude of the N2 at F3/4 which was only found in this condition.

The two frames of reference induced similar profiles of distribution of mean amplitudes across the scalp as measured by the electrode sites, i.e. most of the components (P1, N1, P3 and CDA) showed highest magnitudes in the posterior region (i.e. P3/4 and/ or PO3/4) but lowest in the frontal region (i.e. F3/4). This indicates that more resources were recruited in the occipitoparietal and parietal regions for processing the visual stimuli produced by cues. These regions have been considered primarily responsible for the automatic detection and coding of salient stimuli (Constantinidis & Steinmetz, 2005). On the other hand, the frontal regions did not activate much as compared to the posterior sites. As the activity in the frontal region is mainly for the top-down attentional control (Corbetta & Shulman, 2002; Li et al., 2010), this finding indicates that this group of subjects did not use much resources in the top-down process for coding and interpreting the cues in either condition.

An interesting phenomenon from the behavioral data shown that RT to the visual stimuli presented at the RHF was faster than at the LHF. It can be explained by greater mean amplitudes of the P1 and P3 components for the visual stimuli presented at the RHF were found. However, the hemisphere involved in the laterality effect of these two components was different. Although the effect of laterality was found in the left and right hemisphere for the P1 and P3 component

respectively, such hemispheric difference supports the phenomenon of faster RT to RHF. It is because the P1 component showed that the contralateral signal to the visual stimuli was greater than the ipsilateral signal in the left hemisphere (Figure 5.1a). On the other hand, for the P3 component, the ipsilateral signal was greater than the contralateral signal in the right hemisphere (Fig.5.1b). In other words, greater mean amplitude would be resulted for the visual stimuli presented at the RHF by the greater contralateral signal of the P1 component in the left hemisphere and greater ipsilateral signal of the P3 component in the right hemisphere.



(a) (b)

Figure 5.1 Distribution of mean amplitudes of the P1 (a) and P3 (b) in the young adults: Hemisphere vs. Laterality

Another possible reason for having faster RT to the visual stimuli appeared at RHF is the facilitative effect of the N1 component. The mean amplitude of the N1 component in the left hemisphere was significantly more negative in the egocentric condition (Figure 5.2) and the N1 was greater in the contralateral signal relevant to the visual stimuli. Since N1 was related to spatial orienting towards a relevant stimulus (Luck, et al., 1990; Nobre, Sebestyen, & Miniussi, 2000), the enhanced

N1 amplitude found in the left hemisphere represents the visual stimuli appeared at RHF would be facilitated. It indicates that the young subjects were more spatially attended to the visual stimuli appeared at RHF in the egocentric condition. As mentioned before, the rightward biased phenomenon was found in the automatic visual attention (Castro-Barros et al., 2008; Righi & Ribeiro-do-Valle, 2011). Rightward bias in the egocentric condition should be expected as it is regarded as automatic in nature.

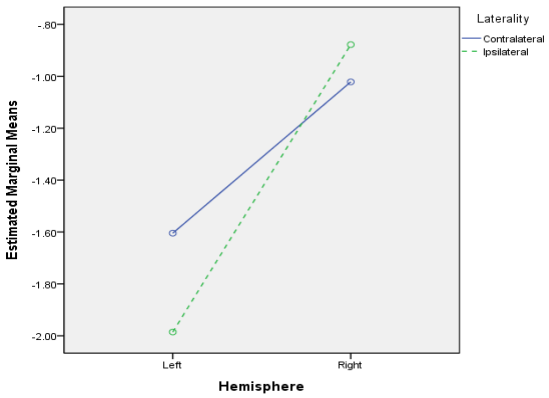


Figure 5.2 Distribution of mean amplitude of N1 in the egocentric condition in the young adults: Hemisphere vs. Laterality

MODULATION OF VISUAL ATTENTION BY EGOCENTRIC AND ALLOCENTRIC FRAMES OF REFERENCE IN OLDER ADULTS

We investigated how aging would affect different frames of reference in the allocation of visual attention. We expected that the older adults would show differences in both behavioral observation and ERP findings compared to those observed from the young adults.

Behavioral Performance

The RT was shorter and more accurate in egocentric than allocentric condition in the older adults. This is consistent with previous findings (Farah et al., 1990) and the results in Study One that egocentric frame of reference is regarded as more automatic. Facilitative effect was observed in valid trials in both reaction time and accuracy which also concurs with findings from previous studies (Posner, 1988; Posner & Petersen, 1990). This facilitative effect is regarded as the mobilization of automatic visuospatial attention, which facilitates sensory processing at the attended location (Posner & Cohen, 1984). They explained that attention will be shifted to the cued location. Therefore, it is more ready in responding to the target which appears at that already attended location and results in the shortening of target detection time. On the invalid-cue trials, however, additional time is required to initiate and shift the attention from the already attended location to another location where the target unexpectedly appears.

ERP Results

No obvious C1 component was found and the plausible reasons have been discussed in Study One.

The early components, i.e. P1, N1 and later component of N2 but not P3 showed lateralized effect. All these findings concur with the previous studies in visual attention (Kutas, Iragui, & Hillyard, 1994; O'Connell et al., 2011). Consistent with previous studies, the latencies of the P1, N1, N2 and P3 were longer in the older than the young adults (Curran et al., 2001; Czigler, Csibra, & Ambro, 1996; Kok, 2000).

Similar to the findings in Study One, no condition effect was expected in the early sensory components of P1 and N1 as the physical properties and locations of cues in egocentric and allocentric conditions were the same. Despite without any condition effect found in the P1, its mean amplitude was greater in the older than the young group. Some studies have also demonstrated the increase in P1 amplitude with age (Diaz & Amenedo, 1998; Talsma, Kok, & Ridderinkhof, 2006). On the other hand, other studies found that the amplitude of P1 remained equivalent (Curran et al., 2001; Nagamatsu et al., 2011) or even diminished in older adults (Ceponiene et al., 2008). However, such contradictory findings may due to the differences in paradigm design. To be more specific, all mentioned studies which did not find increased P1 amplitude with age adopted the central-cued paradigm while the present study and the studies which showed increased P1 did not use the central-cued paradigm. As facilitative effects by central and

peripheral cues were found different (Muller & Findlay, 1989), it may lead to such discrepancies in these findings. Another possible reason is that the tasks were more complex in the studies which did not show the increase in P1 with age (De Sanctis et al., 2008). The phenomenon of larger P1 in the older adults was accounted for by the inhibitory deficit hypothesis which proposed that an increased early sensory response should be demonstrated in the older adults as a result of the impaired frontocortical inhibition in suppressing the irrelevant stimuli (Knight et al., 1999; Kok, 1999; Zanto et al., 2010). An alternative for explaining the increase in P1 with age is that since P1 reflects allocation of more attentional resources at the early sensory processing for the demanding task (Fu et al., 2005; O'Connell et al., 2011), it implies that the older adults might tend to allocate more attentional resources at the early processing stage to compensate for their decline in the early sensory processing (De Sanctis et al., 2008).

The young adults showed longer latencies of anterior and posterior N2 in the allocentric than egocentric condition. However, such difference was not found in the older group. Posterior and anterior N2 are proposed to relate in stimulus discrimination and post-selection process of the relevant stimuli respectively. It implies that the older adults did not show difference in processing the cues between egocentric and allocentric conditions resulting from having difficulties in stimulus discrimination and post-selection process in both conditions.

Consistent with previous finding (Talsma, Kok, & Ridderinkhof, 2006), the frontal P3 was larger in the older than young adults in the present study. As the P3 component has been proposed to relate the resource allocation for a relevant

stimulus (Polich & Criado, 2006), it indicates that the older adults allocated more resources in the frontal region to process the visual information during the cue-target interval. Frontal P3 is related in the top-down control (Li et al., 2010; Li et al., 2013) which may be utilized for compensating the decline in early sensory processing.

The condition effect of contralateral delay activity (CDA) was only found in the older group in which the mean amplitude was greater in the egocentric than allocentric condition. CDA is a difference waveform with negative polarity which is obtained by subtracting the ipsilateral from the contralateral signals to the visual stimuli. It can be utilized as an index of working memory during the retention of cue-target interval (Vogel and Machizawa, 2004). It is mainly found in the posterior regions during the investigation of visual information retention (Gao, 2011; Vogel and Machizawa, 2004). However, some studies in visual working memory found additional CDA in the frontal region of older adults apart from the posterior regions (Li et al., 2010; Li et al., 2013). Although the functional significance of frontal CDA activity is still not clear, these activations may reflect the additional recruitment of resources for counteracting age-related cognitive decline and supporting the process of retention of visual image (Jost et al., 2011; Nagel et al., 2009). Visual working memory was found to significantly decline with age and associated with the decrement of CDA amplitudes (Jost et al., 2011; Wiegand et al., In press). However, lower amplitude was only found in the allocentric condition for the older group in the present study. Previous studies found that the elderly has difficulty in recalling the location of objects

(allocentrically coded) but relatively preserved in the exact location (egocentrically coded) from where the objects had been presented (Desrocher & Smith, 1998). The lower performance may relate to the lowered activations of the hippocampus and parahippocampal gyrus commonly found in older adults, and these neural substrates were suggested to mediate allocentric spatial memory (Antonova et al., 2009; Moffat, Elkins, & Resnick, 2006). The mean amplitudes of the CDA component in the frontal and parieto-occipital regions for the egocentric condition were significantly larger than those for the allocentric condition in the elderly. The amplitude of CDA found increased with the number of representations being held in visual working memory and up to a limit is reached which represents an individual's memory capacity (Vogel & Machizawa, 2004). In other words, its amplitude will not further enhance with increasing the number of representations being held in visual working memory if an individual's working memory capacity is reached to his/ her maximum. The present study shows that no condition effect was found in the young adults, implies that this group of subject could hold the template of cues in both conditions with similar degree of efficiency in visual working memory. However, it is not the case for the older adult. They encountered difficulties in holding the template of allocentric cues in visual working memory during the retention interval so that the amplitude of this cued condition reaches its maximum earlier than in the egocentric condition. It is in-line with lower accuracy in the allocentric than egocentric condition which was only found in the older adults. As the allocentric condition requires to keeping the position of an illuminated circle in relation to the other two non-illuminate circles in mind, it may be more demanding for the elderly to process this cued condition during the

retention interval. A previous study found that the activity in the frontal areas in the elderly became reduced with higher load in working memory (Mattay et al., 2006). They interpreted that this frontally mediated executive process may be flexible to allocate resources for supporting retention of visual information during the visual attention process albeit the resource is limited (Mattay et al., 2006). In other words, the frontal activity in the elderly will increase with load in working memory but it will reduce if the load is too much to handle. It may explain the reason for the reduced CDA amplitude in the frontal region in the allocentric condition in the older adults.

Although the condition effect on the early CNV existed in both groups (egocentric condition elicited more negative-going waveforms), there were differences revealed in the regions where the CNV was elicited - frontal region for the young and posterior region for the older group. Previous studies indicated that early CNV elicited at the frontal and posterior regions was related to anticipatory attention (Gomez et al., 2003, 2007; Gonzalez-Rosa et al., 2011) and maintenance rehearsal process respectively (Rohrbaugh et al., 1997). The frontally distributed topography for the young group suggested that participants could have processed the stimuli much earlier than those in older group, as reflected from the N2 activities in terms of discriminating the cue stimuli and then anticipated for the presence of target stimuli. However, the older group might not have been able to differentiate the cue stimuli well and early enough which facilitated subsequent stimulus interpretation. Participants in the older group henceforth would need to rely on rehearsing the spatial information of cueing stimulus before the target

appeared.

For most of the ERP components, older adults had greatest amplitude in the anterior regions while the young had it in the posterior regions. For example, the mean amplitude of N1 was highest at the C3/4 and P3/4 electrodes for the older and young adults respectively. It indicates that the older group tends to use relatively more resources in the anterior region for visual attentional processes. This phenomenon is also demonstrated by the distribution of P3 component across the scalp. It shows that the mean amplitudes of P3 were greatest in Fz in both conditions although no condition effect was found in this component. That means the older adults tended to use top-down control during the cue-target interval because the frontal P3 has been regarded as the allocation of attentional resources for top-down control (Li, et al., 2010; Li,et al., 2013). This may be a mechanism used by the older to compensate for the relative attenuated posterior P3 activity which has been posited to index the attention and sustained attention (Kok, 1997).

CHAPTER SIX

GENERAL DISCUSSION

Normal aging is associated with structural changes in cerebral white matter volumes (Gordon et al., 2008). Decrease in myelin density and alternations in myelin structure of white matter was found throughout the brain but the frontal, parietal and temporal regions are the most vulnerable to age-related degeneration (Davatzikos & Resnick, 2002; Salat et al., 2005) which affect the control of attention (Fabiani, 2012). The findings from these two studies indicate that aging would affect the cognitive processes involved for modulating visual attention in egocentric and allocentric frames of reference. The underlying reasons for such modulation of visual attention in egocentric and allocentric conditions are different between the young and old. For the young adults, the differences are found in the handling of cued stimuli between two frames of reference in the earlier and later visuospatial processes in the posterior and anterior brain regions respectively. However, it is the other way round for the older adults. The difference is mainly shown in their capacities of visual working memory for handling the cues with two frames of reference but not the earlier or later visuospatial processes.

The results show that rightward visual bias only observed in the young but not the older subjects. The laterality effects of the P3 between the young and the older adults were not the same. These effects were found in the right hemisphere for the young but in left hemisphere for the older subjects. Since the mean amplitude of the P3 was found greater in the ipsilateral than contralateral signal,

greater signals to the stimuli appeared at the RHF and LHF for the young and older adults were found respectively. Together with greater amplitude of P1 was found in the right hemisphere in the young adult, it can give the reason for the rightward visual bias observed in this group. The shift of the laterality effect from right to left hemisphere in aging is consistent with the proposed model of Hemispheric Asymmetry Reduction in Old Adults (HAROLD) which posits that the right hemisphere is subject to more rapid aging than the left hemisphere (Cabeza, 2002). The bi-hemispheric recruitment is thought to play a compensatory role for the aging brain to maintain optimal performance (Cabeza et al., 1997; Reuter-Lorenz et al., 2000). In fact, such activation of bilateral hemispheres, in contrast to unilateral hemispheric activation in young adults, is found to occur since middle age (Dixit et al., 2000).

Another finding by comparing the ERP components between these two groups is that the magnitudes of all measured sites in each component were generally greater in the elderly than the young for the same condition. Such age-related overactivation over the scalp was also found in some fMRI studies (Reuter-Lorenz & Cappell, 2008; Schneider-Garces et al., 2010). Previous studies speculated that older adults use more or new neural circuits to implement the same cognitive strategies as young adults in order to compensate for age-related neural decline in different brain systems (Reuter-Lorenz & Cappell, 2008).

Similar to the other fMRI studies (Ansado et al., 2012; Schneider-Garces et al., 2010), the overactivation phenomenon especially in the frontal region is found in the present study. This phenomenon is recently termed as Posterior-Anterior

Shift in Aging (PASA) (Davis et al., 2008) which is defined as the compensation for the declines in neural processing in the posterior regions by the anterior regions.

Clinical Implications

The effect of aging on visual attention is found in the present study and its underlying cognitive processes are revealed by the electrophysiological findings. The results show that healthy older adults have more difficulty in managing allocentrically than egocentrically coding visual stimuli in the working memory. In current clinical practice, allocentric frame of reference is rarely used when assessing whether the client has any problem in visual attention. To improve the sensitivity of current assessment and facilitate early detection of problems in visual attention, the assessment battery of visual attention should include items which require the client to code the visual stimuli with allocentric frame of reference.

Although both young and older adults have similar findings in responding faster in egocentric than allocentric condition under behavioral observation, the reasons for having this phenomenon are different in terms of the cognitive processes involved. Without using the ERP, the underlying processes for explaining the same behavioral observation cannot be revealed. Hence, this study gives a good example for the potential development of ERP in the clinical application.

CHAPTER SEVEN

CONCLUSIONS

The behavioral and ERP results in the two studies of this thesis were gathered from a visual attention paradigm in which frames of reference were manipulated. These studies show that the allocation of visual attention can be affected by the coding frames of reference. Both young and older subjects responded faster in the egocentric condition although differences in accuracy were only found in the older group, suggesting that they responded more accurate in the egocentric cued condition. Consistent with the results from behavioral measures, the ERP findings from the present studies suggest that the egocentrically coded information is more efficient in the anticipation of the target appearance in both age groups albeit the cognitive processes involved are different. There are age-related changes in the cognitive processes involved in the egocentric and allocentric frames of reference in visual attention. For the older subjects, the frontal regions were more activated in either egocentric or allocentric condition. Differences in the CDA component between the two conditions were only found in the older adults suggesting that it is more difficult for them to retain the visual information of the allocentric conditions in the visual working memory. However, differences in the N2 and P3 components between the two conditions were only found in the young subjects. In contrast to the older subjects, the young adults had relatively greater activities in the posterior than the anterior regions.

Limitation of the Present Study

There are a number of limitations in the present study. Firstly, the duration of the experiment was long. It lasted for more than five to seven hours (including training session and setup of cap). Some of the subjects might be tired at the end of the experiment which might affect their performances.

As education attainment would have affected cognitive reserve and compensatory strategies as examined by the ERP measures, interpretation should be made cautious as the educational attainments between participants in the young and older groups were different.

Apart from the expected larger heterogeneity in the elderly group, the sample size of this group was relatively small. This weakened the power of the statistical analyses in this group. The results therefore should be interpreted with caution. Even though priori assumption was adopted for each component, statistical analyses carried out individually for each ERP component may still increase the possibility of chance associations.

Suggestion for further study

To the best of our knowledge, it is the first study in discovering the cognitive processes involved for the age-related changes in the modulation of frames of reference in visual attention. To support the present age-related findings, further studies, which include other age groups such as middle age and or old old adults, are suggested in order to support the effect of working memory capacity on

different frames of reference.

A more comprehensive neuropsychological test can be introduced in order to get a more complete profile of cognitive functions of the subjects. On the other hand, some cognitive test e.g. Abbreviated Memory Inventory for the Chinese (AMIC) can be used for deliberately including or excluding the subjects with very mild dementia (VMD).

The original study was quite time consuming. To make it more feasible in clinical studies and application, it can be done in two ways. Firstly, the time spent for set up can be saved by using a cap with 32 or even 16 instead of 128 channels. Besides, data collection can be cut short by reducing the number of trial to half by presenting the visual stimuli only at upper visual fields. Such arrangement in stimuli presentation can enhance the C1 component as well.

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APPENDICES

Appendix I Informed written consent (English Version)

The Hong Kong Polytechnic University
Department of Rehabilitation Sciences

Research Project Informed Consent Form

Project title: Aging effect on egocentric and allocentric frames of reference in visual attention: An event-related potential study

Investigator(s): Prof. Chetwyn C. H. Chan, Mr. Brian Au

Purpose of the Study:

This study aims to investigate the neural processes underlying differences in allocentric and egocentric frames of references on visual attention between older and younger participants.

Project Information:

This project includes: (1) a 3-hour training on mastering using the two different reference frames to perform on a custom-designed experimental task on visual attention; and (2) 5-hour testing session which requires the participant to put on a cap for capturing electrical activities over the scalp when performing on different blocks of the experimental task.

You will need to wear an elastic cap with electrodes on your head. To improve conductivity, you need to scrub your face and back of ear with facial cleanser as well as wash your hair in the laboratory before the application of the cap. Fitting of the cap will involve injecting conductive gel into the electrodes. The whole set-up process will take about an hour to complete.

Findings of this project will enable better understanding on the neural processes underlying these two frames of reference how aging would modulate these

processes. The knowledge gained can serve as the basis for design of clinical assessment and interventions for the older population.

Potential Risk:

In the process of this study, there will be no danger on you. Although it is not expected to happen, you may feel tired or muscle tightness for performing the whole investigation. All information provided will be treated as strictly confidential. Participation is on voluntary basis and you are free to withdraw from the study at any time or any reason.

Consent:

I, _____, have been explained the details of this study. I voluntarily consent to participate in this study. I understand that I can withdraw from this study at any time without giving reasons, and my withdrawal will not lead to any punishment or prejudice against me. I am aware of any potential risk in joining this study. I also understand that my personal information will not be disclosed to people who are not related to this study and my name or photograph will not appear on any publications resulted from this study.

I can contact the investigator, Mr. Brian Au, at 6031XXXX, or the project supervisor, Prof. Chetwyn Chan at 2766 XXXX for any questions about this study. If I have complaints related to the investigator(s), I can contact Mrs. Leung Ka Yan, secretary of Departmental Research Committee, at 2766 XXXX. I know I will be given a signed copy of this consent form.

_____ _____

Signature (Subject) Date

_____ _____

Signature (Witness) Date

Appendix II Informed written consent (Chinese Version)

香港理工大學康復治療科學系科研同意書

科研題目：研究老年退化對隱藏視覺注意力的影響：使用“事件誘發電位 ”

科研人員：陳智軒教授，區啓明先生

科研目的：

此項研究的目的在於比較老年人及青年以自我為中心及物件為中心時對隱藏視覺注意力的相關神經過程。

科研資料

這科研包括(一) 3 小時訓練，藉此掌握為隱藏視覺注意力的實驗而特定設計的兩種不同參照方法。（二）5 小時的測試環節，參加者需要配帶腦電帽，目的是當進行不同的測試項目時獲取頭皮上的電流活動。

你需要配戴一頂具彈性並附有電極的腦電帽在頭上。為了改善導電情況，你必需在配戴腦電帽前，於本實驗室內用洗面膏洗涮面部及耳後與及清洗頭髮。配戴腦電帽時涉及注入導電膠在電極裡。整個過程約需要 1 小時完成。

這研究項目的結果將有助於瞭解這兩種參照的相關神經過程，並且可以瞭解老年退化如何調節這些過程。所獲取的知識可用作為老年人設計臨床評估及治療的基礎。

潛在危險性：

研究過程將不會對你構成任何危險。你有可能因進行整個研究而會覺得疲倦或肌肉緊張，但這並不預期會發生。所有提供的資料將視為絕對保密。參與者是自願參加，並可於任何時間及無需提供任何理由下而放棄參與此次研究。

同意書：

本人_____已瞭解此次研究的具體情況。本人願意參加此次研究及明白我可以在任何時候、無任何原因放棄參與此次研究，而此舉不會導致我受到任何懲罰或不公平對待。本人明白參加此研究課題的潛在危險性，而本人的資料將不會洩露給與此研究無關的人員，我的名字或相片亦不會出現在任何出版物上。 本人若對此次研究有任何問題可聯絡此次研究課題負責人區啓明先生(6031XXXX)及科研導師陳智軒教授(2766XXXX)。若本人對科研人員有任何投訴，亦可聯絡梁女士(部門科研委員會秘書)，電話：2766XXXX。本人亦明白我會收到此份同意書的簽署副本。

_____ _____

簽署（參加者） 日期

_____ _____

簽署（見證人） 日期

Appendix III

Letter of Ethics Approval of Department Committee, Department of Rehabilitation Sciences

THE HONG KONG POLYTECHNIC UNIVERSITY 香港理工大學

To	CHAN Che Hin (Department of Rehabilitation Sciences)		
From	TSANG Wing Hong Hector, Chair, Departmental Research Committee		
Email	rshtsang@	Date	05-Jul-2012

Application for Ethical Review for Teaching/Research Involving Human Subjects

I write to inform you that approval has been given to your application for human subjects ethics review of the following project for a period from 09-Jul-2012 to 29-Mar-2013:

Project Title:	Aging effect on covert visual attention: An event-related potential study
Department:	Department of Rehabilitation Sciences
Principal Investigator:	CHAN Che Hin

Please note that you will be held responsible for the ethical approval granted for the project and the ethical conduct of the personnel involved in the project. In the case of the Co-PI, if any, has also obtained ethical approval for the project, the Co-PI will also assume the responsibility in respect of the ethical approval (in relation to the areas of expertise of respective Co-PI in accordance with the stipulations given by the approving authority).

You are responsible for informing the Departmental Research Committee in advance of any changes in the proposal or procedures which may affect the validity of this ethical approval.

You will receive separate email notification should you be required to obtain fresh approval.

TSANG Wing Hong Hector

Chair

Departmental Research Committee

Appendix IV Information Sheet (English Version)

Information Sheet

Project title: Aging effect on visual attention: A event-related potential study

Project Information:

This study aims to investigate differences in allocentric and egocentric frames of references on visual attention between older and younger participants. Findings of this project will enable better understanding on the neural processes underlying these two frames of reference how aging would modulate these processes. The knowledge gained can serve as the basis for design of clinical assessment and interventions for the older population.

This project includes: (1) a 3-hour training on mastering using the two different reference frames to perform on a custom-designed experimental task on visual attention; and (2) 5-hour testing session which requires the participant to put on a cap for capturing electrical activities over the scalp when performing on different blocks of the experimental task.

Set up

You will need to wear an elastic cap with electrodes on your head. To improve conductivity, you need to scrub your face and back of ear with facial cleanser as well as wash your hair in the laboratory before the application of the cap. Fitting of the cap will involve injecting conductive gel into the electrodes. The whole set-up process will take about an hour to complete.

Experiment

There are 10 blocks in each of the allocentric and egocentric condition. You will be asked to use one frame of reference before the beginning of one block. Each block will take about 3 minutes to complete.

You can withdraw from this study at any time without giving reasons, and your withdrawal will not lead to any punishment or prejudice against you. Your personal information will not be disclosed to people who are not related to this study and your name or photograph will not appear on any publications resulted from this study.

Thank you very much for participating in this study.

Appendix V Information Sheet (Chinese Version)

香港理工大學康復治療科學系科研內容說明書

科研題目：研究老年退化對隱藏視覺注意力的影響：使用“事件誘發電位 ”

科研資料：

此項研究的目的在於比較青年及老年人以物件為中心及自我為中心時對隱藏視覺注意力的分別。這研究項目的結果將有助於瞭解這兩種參照的相關神經過程，並且可以瞭解老年退化如何調節這些過程。所獲取的知識可用作為老年人設計臨床評估及治療的基礎。

這科研包括(一) 3 小時訓練，藉此掌握為隱藏視覺注意力的實驗而特定設計的兩種不同參照方法。（二）5 小時的測試環節，參加者需要配帶腦電帽，目的是當進行不同的測試項目時獲取頭皮上的電流活動。

設置

你需要配戴一頂具彈性並附有電極的腦電帽在頭上。為了改善導電情況，你必需在配戴腦電帽前，於本實驗室內用洗面膏洗涮面部及耳後與及清洗頭髮。配戴腦電帽時涉及注入導電膠在電極裡。整個過程約需要 1 小時完成。

實驗

以自我為中心及物件為中心的測試項目各有 10 組。

在進行每組的測試項目之前，你將會先被通知採用一種參照來進行實驗，每組的測試項目需時約 3 分鐘。

您可以隨時在不需作出解釋之情況下退出此項研究，而將不會受到處罰或歧視。

您的個人資料將不會向本研究以外之人仕公開，並且您的姓名或照片將不會出現於任何研究之報告內。

謝謝您參與這項研究。

Appendix VI Annett Handness Questionnaire

Handedness 主要用手

Please indicate which hand you habitually use for each of the following sentence.

Which hand do you use in the following tasks?

你會用邊隻手做以下事情?

No.	Tasks	Left	Either	Right
1	To write a letter legibly?			
	你用邊隻手寫字?			
2	To throw a ball to hit a target?			
	你用邊隻手拎住個波，掟向一個目標？			
3	To hold a racket in tennis, squash or badminton?			
	你用邊隻手揸球拍打波?			
4	To hold a match whilst striking it?			
	你劃火柴既時候用邊隻手拎住支火柴?			
5	To cut with scissors?			
	你用邊隻手揸較剪？			
6	To guide a thread through the eye of a needle?			
	你穿針既時候用邊隻手揸住條線？			
7	At the top of a broom while sweeping?			
	揸掃把既時候，兩隻手你會用邊隻手揸柄的上端?			
8	At the top of a shovel when moving sand?			
	剷沙既時候, 兩隻手你會用邊隻手柄的上端?			
9	To deal playing cards?			
	派啤牌時, 你會用邊隻手派牌出去?			
10	To hammer a nail into wood?			
	踏釘時, 你用邊隻手揸鎚?			
11	To hold a toothbrush while cleaning your teeth?			
	刷牙既時候，你用邊隻手揸牙刷？			
12	To unscrew the lid of a jar?			
	開樽蓋嗰陣，你用邊隻手擰開個樽蓋?			

Scoring: Left: 3 Either: 2 Right: 1 Total Score_____

Annett M. (1970). British Journal of Psychology, 61, 303-321.

Appendix VII Block Arrangement with Latin Square Design

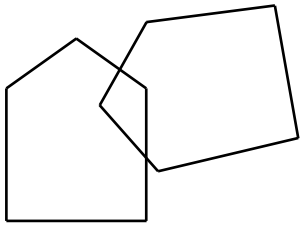
	Condition	Practice 1st	Allo 12		Adapt	Ego 12		Adapt	Allo 34		Adapt	Ego 34		Adapt	Allo 56		Adapt	Ego 56		Adapt	Allo 78		Adapt	Ego 78		Adapt	Allo 9 10		Adapt	Ego 9 10	
1	Block	Ego	A1	A2	Ego	E1	E2	Allo	A3	A4	Ego	E3	E4	Allo	A5	A6	Ego	E5	E6	Allo	A7	A8	Ego	E7	E8	Allo	A9	A10	Ego	E9	E10
	Condition		Ego 12			Allo 12			Ego 34			Allo 34			Ego 56			Allo 56			Ego 78			Allo 78			Ego 9 10			Allo 9 10	
2	Block	Allo	E1	E2	Allo	A1	A2	Ego	E3	E4	Allo	A3	A4	Ego	E5	E6	Allo	A5	A6	Ego	E7	E8	Allo	A7	A8	Ego	E9	E10	Allo	A9	A10
	Condition		Allo 34			Ego 34			Allo 56			Ego 56			Allo 78			Ego 78			Allo 9 10			Ego 9 10			Allo 12			Ego 12	
3	Block	Ego	A3	A4	Ego	E3	E4	Allo	A5	A6	Ego	E5	E6	Allo	A7	A8	Ego	E7	E8	Allo	A9	A10	Ego	E9	E10	Allo	A1	A2	Ego	E1	E2
	Condition		Ego 34			Allo 34			Ego 56			Allo 56			Ego 78			Allo 78			Ego 9 10			Allo 9 10			Ego 12			Allo 12	
4	Block	Allo	E3	E4	Allo	A3	A4	Ego	E5	E6	Allo	A5	A6	Ego	E7	E8	Allo	A7	A8	Ego	E9	E10	Allo	A9	A10	Ego	E1	E2	Allo	A1	A2
	Condition		Allo 56			Ego 56			Allo 78			Ego 78			Allo 9 10			Ego 9 10			Allo 12			Ego 12			Allo 34			Ego 34	
5	Block	Ego	A5	A6	Ego	E5	E6	Allo	A7	A8	Ego	E7	E8	Allo	A9	A10	Ego	E9	E10	Allo	A1	A2	Ego	E1	E2	Allo	A3	A4	Ego	E3	E4
	Condition		Ego 56			Allo 56			Ego 78			Allo 78			Ego 9 10			Allo 9 10			Ego 12			Allo 12			Ego 34			Allo 34	
6	Block	Allo	E5	E6	Allo	A5	A6	Ego	E7	E8	Allo	A7	A8	Ego	E9	E10	Allo	A9	A10	Ego	E1	E2	Allo	A1	A2	Ego	E3	E4	Allo	A3	A4
	Condition		Allo 78			Ego 78			Allo 9 10			Ego 9 10			Allo 12			Ego 12			Allo 34			Ego 34			Allo 56			Ego 56	
7	Block	Ego	A7	A8	Ego	E7	E8	Allo	A9	A10	Ego	E9	E10	Allo	A1	A2	Ego	E1	E2	Allo	A3	A4	Ego	E3	E4	Allo	A5	A6	Ego	E5	E6
	Condition		Ego 78			Allo 78			Ego 9 10			Allo 9 10			Ego 12			Allo 12			Ego 34			Allo 34			Ego 56			Allo 56	
8	Block	Allo	E7	E8	Allo	A7	A8	Ego	E9	E10	Allo	A9	A10	Ego	E1	E2	Allo	A1	A2	Ego	E3	E4	Allo	A3	A4	Ego	E5	E6	Allo	A5	A6
	Condition		Allo 9 10			Ego 9 10			Allo 12			Ego 12			Allo 34			Ego 34			Allo 56			Ego 56			Allo 78			Ego 78	
9	Block	Ego	A9	A10	Ego	E9	E10	Allo	A1	A2	Ego	E1	E2	Allo	A3	A4	Ego	E3	E4	Allo	A5	A6	Ego	E5	E6	Allo	A7	A8	Ego	E7	E8
	Condition		Ego 9 10			Allo 9 10			Ego 12			Allo 12			Ego 34			Allo 34			Ego 56			Allo 56			Ego 78			Allo 78	
10	Block	Allo	E9	E10	Allo	A9	A10	Ego	E1	E2	Allo	A1	A2	Ego	E3	E4	Allo	A3	A4	Ego	E5	E6	Allo	A5	A6	Ego	E7	E8	Allo	A7	A8

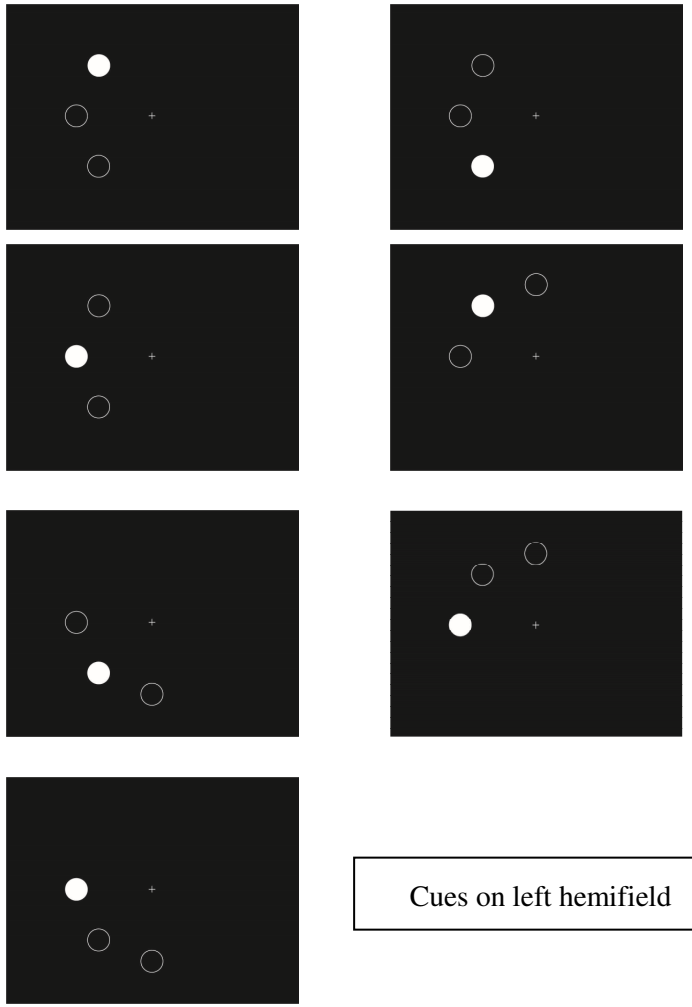
Appendix VIII Chinese Mini Mental Status Examination (C-MMSE)

Mini Mental State Examination

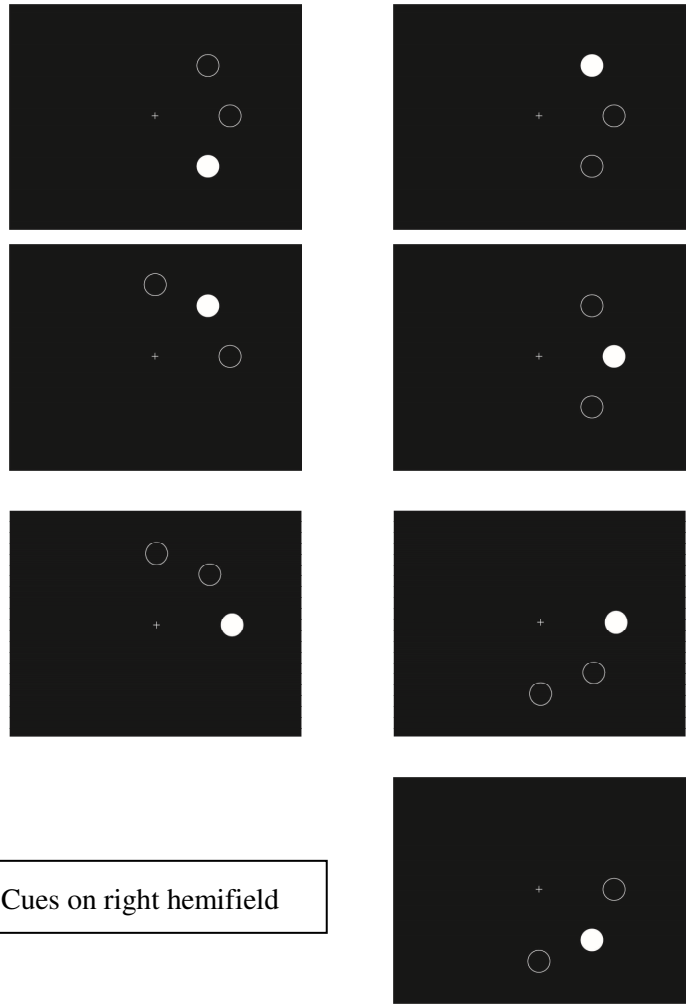
簡短智能測驗

代號_____姓名_____日期_____

最高分數		分數
5	依家係乜野日子(年份)(季節)(月份)(幾號)(星期幾)?	
5	我地依家係邊嘅? (九龍/新界/香港)(九龍/新界/香港既邊度)(醫院)(邊層樓)(病房) 或: (九龍/新界/香港)(九龍/新界/香港既邊度)(邊一科診所)(診所名字)(邊層樓) 或: (九龍/新界/香港)(九龍/新界/香港既邊度)(邊條街)(邊一座)(邊層樓) 或: (九龍/新界/香港)(九龍/新界/香港既邊度)(邊個屋村)(中心名字)(邊層樓)	
3	依家我會講三樣野既名， 講完之後， 請你重複一次。 請記住佢地， 因為幾分鐘後， 我會叫你講番俾我聽。 【蘋果】、【報紙】、【火車】。 依家請你講番哩三樣野俾我聽。 (以第一次講的計分， 一個一分， 然後重複物件， 直至全部三樣都記住。)	
5	☐ 請你用一百減七， 然後再減七， 一路減落去， 直至我叫你停為止。 (減五次後便停) ☐ 或: 依家我讀幾個數目俾你聽， 請你倒轉頭講番出黎。 【４２７３１】	
3	我頭先叫你記住既三樣野係乜野呀?	
9	哩樣係乜野? (鉛筆)(手錶)。(2) 請你跟我講句說話【姨丈買魚腸】(1) 依家檯上面有一張紙。 用你既右手拿起張紙， 用兩隻手一齊將紙摺成一半， 然後放番張紙係檯上面。(3) 請讀出哩張紙上面既字， 然後照住去做。(1) 請你講出任何一句完整既句子俾我聽。 例如:【我是一個人】、【今天天氣好好】。(1) 哩處有幅圖， 請你照住畫啦。(1)	
	拍手 	**總分**



Cues on left hemifield



Cues on right hemifield

Appendix IX

All possible combination of cues on left and right hemifields

Appendix X Demographic Data of Subjects

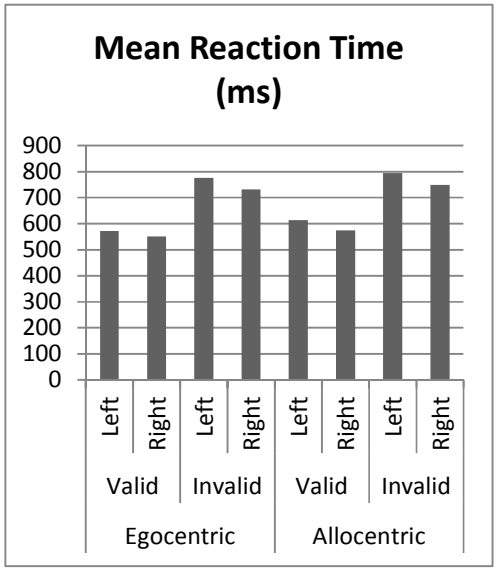
(a) Young Participants (n=17, 7 females)

	Mean	SD	Minimum	Maximum
Age	20.82	1.185	18	23
Year of education	14.41	0.795	13	15
Handedness score	12.89	0.936	12	14

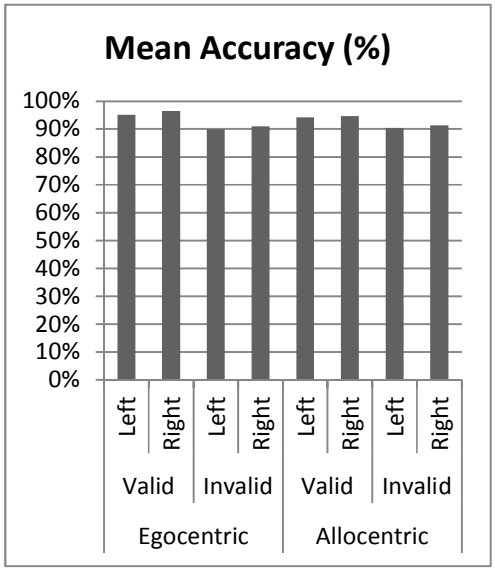
(b) Older Participants (n=16, 9 females)

	Mean	SD	Minimum	Maximum
Age (year)	62.75	1.571	60	66
Year of education	11.56	2.988	6	18
Handedness score	12.75	1.24	12	14

Appendix XI Reaction time and accuracy rate in egocentric and allocentric condition in young adults



(a) Reaction Time



(b) Accuracy

Appendix XII Mean reaction time (ms) in condition, validity and hemifield in young adults

Condition		Validity		Hemifield (HF)	
Egocentric	**Allocentric**	**Valid trial**	**Invalid trial**	**Stimuli on Left HF**	**Stimuli on Right HF**
658.210 ±24.388	682.786 ±28.900	577.879 ±20.322	763.116 ±36.593	689.241 ±27.122	651.754 ±25.856

Appendix XIII (a) Repeated measures ANOVA model for reaction time in main effects of Condition (Egocentric vs. Allocentric), Validity (Valid vs. Invalid trial) and Hemi-field (Left vs. Right) and the interactions between them in young adults

Within-Subjects Effect	df	F-value	p-value
Conditions	1, 16	4.72	0.045 *
Validity	1, 16	44.44	<0.001**
Hemi-field	1, 16	18.39	0.001 **
Condition x Validity	1, 16	1.21	0.287
Condition x Hemi-field	1, 16	2.02	0.174
Validity x Hemi-field	1, 16	2.56	0.129
Condition x Validity x Hemi-field	1, 16	0.73	0.407

**p<0.01, *p<0.05

Appendix XIII (b) Pair t-tests between left and right hemi-field in RT in young adults

Visual Stimuli Appeared on Left Hemi-field vs. Right Hemi-field		t	df	p-value after Bonferroni correction
Egocentric	Valid	2.80	16	0.052
	Invalid	3.11	16	0.028*
Allocentric	Valid	4.52	16	< 0.001**
	Invalid	3.42	16	0.020*

**p<0.01, *p<0.05

Appendix XIII (c) Results of repeated measures ANOVA to examine the effects of Condition, Validity and Hemi-field on accuracy rate in young adults

Within-Subjects Effect	Df	F-value	p-value
Conditions	1, 16	0.97	0.340
Validity	1, 16	19.80	<0.001**
Hemi-field	1, 16	1.92	0.185
Condition x Validity	1, 16	3.58	0.077
Condition x Hemi-field	1, 16	0.32	0.580
Validity x Hemi-field	1, 16	0.03	0.860
Condition x Validity x Hemi-field	1, 16	0.10	0.752

**p<0.01

Appendix XIII (d) The mean amplitudes (in µV) of the P1 N1, N2 and P3 components recorded contralateral and ipsilateral to visual stimuli at lateral sites in egocentric and allocentric trial in young adults

Component	Site	Egocentric		Allocentric	
		Contralateral	Ipsilateral	Contralateral	Ipsilateral
P1	F3	-0.08±0.91	-0.91±0.86	-0.02±0.90	-0.66±0.95
	F4	-0.93±0.94	-0.18±0.91	-0.66±1.24	-0.08±0.90
	C3	-0.14±0.92	-1.05±1.02	0.16±0.96	-0.84±1.17
	C4	-0.67±0.89	-0.28±0.81	-0.59±0.92	-0.04±0.62
	P3	0.54+1.07	-0.56±1.24	0.74+1.20	-0.58±1.23
	P4	-0.27±1.09	-0.08±0.76	-0.44±1.24	0.15±0.69
	PO3	0.67±0.93	-0.13±0.98	0.82±0.99	-0.21±1.03
	PO4	0.45±1.10	0.06±0.54	0.22±1.32	0.28±0.64
	T7	0.03±0.63	-0.76±0.86	0.210±0.65	-0.56±0.90
	T8	-0.23±0.67	-0.29±0.54	-0.23±0.74	0.00±0.43
N1	F3	-0.99±1.49	-1.02±1.10	-0.98±1.32	-0.78±0.95
	F4	-1.40±1.12	-1.01±1.34	-1.01±1.72	-0.95±1.33
	C3	-1.87±1.97	-1.34±1.46	-1.78±1.80	-1.23±1.37
	C4	-2.07±1.32	-1.11±1.34	-1.84±1.46	-1.08±1.16
	P3	-2.19±1.94	-1.29±1.85	-2.31±1.86	-1.17±1.61
	P4	-2.61±1.63	-0.88±1.50	-2.60±1.60	-1.17±1.29
	PO3	-1.38±1.30	-0.51±1.28	-1.53±1.29	-0.37±1.06
	PO4	-1.78±1.65	-0.38±0.98	-1.70±1.42	-0.56±1.05
	T7	-1.60±1.63	-0.96±1.23	-1.49±1.42	-0.93±1.18
	T8	-2.05±1.22	-1.00±1.10	-1.86±1.29	-0.99±0.97
N2	F3	0.26±1.04	0.28±1.89	0.23±1.59	0.44±1.50
	F4	0.25±1.74	0.62±1.12	0.51±1.56	0.58±1.65
	C3	0.69±1.20	0.86±2.00	0.79±1.58	1.04±2.01
	C4	0.95±1.89	1.22±1.56	1.20±1.86	1.38±1.80
	P3	1.76±2.58	1.34±2.71	1.81±2.66	1.80±2.83
	P4	1.53±2.54	1.83±2.00	1.63±2.72	1.91±2.01
	PO3	1.43±1.80	1.04±1.75	1.48±1.71	1.47±1.90
	PO4	1.57±2.39	1.46±1.94	1.71±2.45	1.60±2.02
	T7	0.70±1.03	0.84±1.69	0.80±1.29	1.14±1.50
	T8	1.28±1.62	1.33±1.33	1.52±1.63	1.50±1.48
P3	F3	0.00±1.39	-0.17±1.70	0.00±1.67	0.03±1.75
	F4	0.25±1.59	0.31±1.34	0.57±1.71	0.79±1.71
	C3	0.78±1.43	0.81±1.84	1.246±1.89	1.09±1.86
	C4	1.06±1.60	1.43±1.49	1.31±1.74	1.84±2.02
	P3	1.63±2.25	1.53±2.52	1.98±2.63	2.04±2.52
	P4	0.87±2.19	1.75±1.80	1.07±2.37	1.99±2.05
	PO3	1.28±1.66	1.18±1.74	1.42±1.91	1.62±1.78
	PO4	0.80±1.96	1.29±1.63	0.95±2.07	1.54±1.98
	T7	0.71±1.05	0.71±1.39	1.02±1.44	1.10±1.42
	T8	1.07±1.24	1.44±1.21	1.33±1.47	1.78±1.48

Appendix XIII (e) The mean amplitudes (in μV) of the P1 N1, N2 and P3 components recorded at midline sites in egocentric and allocentric trial in young adults

Component	Site	Egocentric		Allocentric	
		LHF	RHF	LHF	RHF
P1	Fz	-0.82±0.97	-0.12±0.95	-0.70±1.13	0.03±0.90
	Cz	-1.07±1.20	-0.26±1.10	-1.09±1.16	0.03±0.98
	Pz	-0.67±1.26	-0.07±1.08	-0.91±1.24	0.27±1.05
	POz	-0.47±1.24	0.19±0.88	-0.73±1.26	0.34±0.95
N1	Fz	-1.37±1.10	-1.13±1.52	-1.02±1.10	-1.11±1.39
	Cz	-1.76±1.19	-1.49±1.80	-1.55±1.42	-1.48±1.57
	Pz	-1.69±1.62	-1.51±1.78	-1.62±1.65	-1.74±1.51
	POz	-1.53±1.55	-1.22±1.60	-1.43±1.47	-1.48±1.40
N2	Fz	-0.04±2.11	0.22±1.43	0.09±2.00	0.13±1.99
	Cz	0.59±2.61	0.85±1.75	0.73±2.75	0.90±2.21
	Pz	1.27±2.84	1.60±2.52	1.49±3.06	1.61±2.60
	POz	1.15±2.86	1.42±2.48	1.39±2.98	1.44±2.53
P3	Fz	-0.20±2.00	0.04±1.63	-0.05±2.26	0.36±2.22
	Cz	0.64±2.34	0.97±1.69	0.82±2.48	1.38±2.42
	Pz	1.35±2.86	1.67±2.30	1.60±2.94	2.02±2.85
	POz	1.27±2.85	1.53±2.25	1.47±2.81	1.81±2.72

LHF: Visual stimuli appeared at left hemi-field
RHF: Visual stimuli appeared at right hemi-field

Appendix XIII (f) Repeated measures ANOVA model for main effects of Condition (Egocentric vs. Allocentric), Hemisphere (Left vs. Right), Laterality (Contralateral vs. Ipsilateral signals) and Lateral site (10 sites) and the interactions between them in mean amplitude of the P1 in young adults

Within-Subjects Effect	Df	F-value	p-value
Condition	1.00, 16.00	0.25	0.626
Hemisphere	1.00,16.00	0.04	0.837
Laterality	1.00,16.00	12.33	0.003**
Site	1.39, 22.25	5.41	0.020*
Condition x Hemisphere	1.00,16.00	0.51	0.487
Condition x Laterality	1.00, 16.00	0.58	0.458
Condition x Site	2.17, 34.68	2.82	0.070
Hemisphere x Laterality	1.00, 16.00	30.13	<0.001**
Hemisphere x Site	2.66, 42.59	1.10	0.353
Laterality x Site	1.63, 26.14	7.74	0.004**
Condition x Hemisphere x Laterality	1.00, 16.00	1.54	0.233
Condition x Laterality x Site	2.78, 44.44	1.24	0.072
Hemisphere x Laterality x Site	1.84, 18.22	2.73	0.086
Condition x Hemisphere x Laterality x Site	1.31, 21.02	1.72	0.207

**p<0.01, *p<0.05

(Appendix XIII (g) Repeated measures ANOVA model for main effects of Condition (Egocentric vs. Allocentric), Hemi-field (Left vs. Right), and Midline site (Fz, Cz, Pz, POz) and the interactions between them in the mean amplitude of the P1 in young adults

Within-Subjects Effect	Df	F-value	p-value
Condition	1.00, 16.00	0.16	0.695
Hemi-field	1.00,16.00	38.50	<0.001**
Site	1.31, 20.90	2.21	0.148
Condition x Hemi-field	1.00,16.00	2.25	0.153
Condition x Site	1.34, 21.45	2.71	0.106
Hemi-field x Site	1.25, 19.98	0.96	0.360
Condition x Hemi-field x Site	1.16, 18.47	1.87	0.189

**p<0.01

Appendix XIII (h) Repeated measures ANOVA model for main effects of Condition (Egocentric vs. Allocentric), Hemisphere (Left vs. Right), Laterality (Contralateral vs. Ipsilateral signals) and Lateral site (10 sites) and the interactions between them in peak latency of the P1 in young adults

Within-Subjects Effect	Df	F-value	p-value
Condition	1.00, 16.00	0.00	0.948
Hemisphere	1.00,16.00	0.08	0.788
Laterality	1.00,16.00	6.35	0.023*
Site	2.35, 37.66	18.46	<0.001**
Condition x Hemisphere	1.00,16.00	0.99	0.334
Condition x Laterality	1.00, 16.00	1.75	0.205
Condition x Site	4, 64	1.60	0.185
Hemisphere x Laterality	1.00, 16.00	0.34	0.569
Hemisphere x Site	4, 64	0.87	0.490
Laterality x Site	4, 64	3.60	0.010*
Condition x Hemisphere x Laterality	1.00, 16.00	0.45	0.514
Condition x Laterality x Site	4, 64	0.46	0.764
Hemisphere x Laterality x Site	1.91, 30.59	1.10	0.344
Condition x Hemisphere x Laterality x Site	1.96, 31.41	0.38	0.685

**p<0.01, *p<0.05

Appendix XIII (i) Repeated measures ANOVA model for main effects of Condition (Egocentric vs. Allocentric), Hemi-field (Left vs. Right), and Midline site (Fz, Cz, Pz, POz) and the interactions between them in peak latency of the P1 in young adults

Within-Subjects Effect	Df	F-value	p-value
Condition	1.00, 16.00	0.74	0.403
Hemi-field	1.00,16.00	2.84	0.111
Site	1.67, 26.72	12.12	<0.001**
Condition x Hemi-field	1.00,16.00	0.23	0.641
Condition x Site	1.77, 28.25	4.08	0.032*
Hemi-field x Site	1.89, 30.17	0.62	0.536
Condition x Hemi-field x Site	1.48, 23.61	0.31	0.670

**p<0.01, *p<0.05

Appendix XIII (j) Repeated measures ANOVA model for main effects of Condition (Egocentric vs. Allocentric), Hemisphere (Left vs. Right), Laterality (Contralateral vs. Ipsilateral signals) and Lateral site (10 sites) and the interactions between them in mean amplitude of the N1 in young adults

Within-Subjects Effect	Df	F-value	p-value
Condition	1.00, 16.00	0.27	0.608
Hemisphere	1.00,16.00	12.21	0.003**
Laterality	1.00,16.00	7.58	0.014*
Site	2.09, 33.49	4.50	0.017*
Condition x Hemisphere	1.00,16.00	10.92	0.004**
Condition x Laterality	1.00, 16.00	10.00	0.006**
Condition x Site	1.75, 27.95	2.53	0.104
Hemisphere x Laterality	1.00, 16.00	0.78	0.389
Hemisphere x Site	1.92, 30.66	4.50	0.021*
Laterality x Site	2.57, 41.05	7.20	0.001**
Condition x Hemisphere x Laterality	1.00, 16.00	1.65	0.217
Condition x Laterality x Site	1.78, 28.50	6.42	0.006**
Hemisphere x Laterality x Site	1.90, 30.45	0.27	0.753
Condition x Hemisphere x Laterality x Site	1.24, 19.85	0.35	0.606

**p<0.01, *p<0.05

Appendix XIII (k) Repeated measures ANOVA model for main effects of Condition (Egocentric vs. Allocentric), Hemi-field (Left vs. Right), and Midline site (Fz, Cz, Pz, POz) and the interactions between them in the mean amplitude of the N1 in young adults

Within-Subjects Effect	Df	F-value	p-value
Condition	1.00, 16.00	0.07	0.797
Hemi-field	1.00,16.00	0.18	0.681
Site	1.41, 22.47	1.76	0.199
Condition x Hemi-field	1.00,16.00	1.88	0.190
Condition x Site	1.26, 20.11	5.64	0.022*
Hemi-field x Site	1.44, 23.05	0.16	0.780
Condition x Hemi-field x Site	1.18, 18.83	0.14	0.754

*p<0.05

Appendix XIII (l) Repeated measures ANOVA model for main effects of Condition (Egocentric vs. Allocentric), Hemisphere (Left vs. Right), Laterality (Contralateral vs. Ipsilateral signals) and Lateral site (10 sites) and the interactions between them in the peak latency of the N1 in young adults

Within-Subjects Effect	Df	F-value	p-value
Condition	1.00, 16.00	3.38	0.084
Hemisphere	1.00,16.00	7.83	0.013*
Laterality	1.00,16.00	8.42	0.001**
Site	1.87, 29.84	36.33	<0.001**
Condition x Hemisphere	1.00,16.00	1.39	0.256
Condition x Laterality	1.00, 16.00	1.57	0.228
Condition x Site	2.28, 36.39	0.71	0.513
Hemisphere x Laterality	1.00, 16.00	5.82	0.028*
Hemisphere x Site	2.54, 40.57	2.12	0.112
Laterality x Site	2.21, 35.31	3.55	0.035*
Condition x Hemisphere x Laterality	1.00, 16.00	0.22	0.646
Condition x Laterality x Site	1.92, 30.71	1.36	0.270
Hemisphere x Laterality x Site	1.80, 28.86	0.21	0.794
Condition x Hemisphere x Laterality x Site	2.46, 39.38	2.49	0.085

**p<0.01, *p<0.05

Appendix XIII (m) The peak latency (in ms) of the N1 component recorded at lateral sites in young adults

F3/4	C3/4	P3/4	PO3/4	T7/8
108.57±1.78	114.74±1.93	123.50±2.14	126.91±2.27	117.65±2.04

Appendix XIII (n) Repeated measures ANOVA model for main effects of Condition (Egocentric vs. Allocentric), Hemi-field (Left vs. Right), and Midline site (Fz, Cz, Pz, POz) and the interactions between them in the peak latency of the N1 in young adults

Within-Subjects Effect	**Df**	**F-value**	**p-value**
Condition	1.00, 16.00	2.92	0.107
Hemi-field	1.00,16.00	2.47	0.136
Site	1.06, 17.02	18.49	<0.001**
Condition x Hemi-field	1.00,16.00	0.47	0.503
Condition x Site	1.31, 20.87	0.05	0.887
Hemi-field x Site	1.39, 22.31	0.06	0.890
Condition x Hemi-field x Site	1.52, 24.37	0.61	0.508

**p<0.01

Appendix XIII (o) Repeated measures ANOVA model for main effects of Condition (Egocentric vs. Allocentric), Hemisphere (Left vs. Right), Laterality (Contralateral vs. Ipsilateral signals) and Lateral site (10 sites) and the interactions between them in mean amplitude of N2 in young adults

Within-Subjects Effect	**Df**	**F-value**	**p-value**
Condition	1.00, 16.00	1.38	0.257
Hemisphere	1.00,16.00	1.57	0.191
Laterality	1.00,16.00	0.50	0.491
Site	1.27, 20.37	3.80	0.057
Condition x Hemisphere	1.00,16.00	0.15	0.705
Condition x Laterality	1.00, 16.00	1.31	0.269
Condition x Site	2.04, 32.63	0.47	0.634
Hemisphere x Laterality	1.00, 16.00	0.17	0.689
Hemisphere x Site	4, 64	0.75	0.564
Laterality x Site	2.51, 40.12	3.70	0.025*
Condition x Hemisphere x Laterality	1.00, 16.00	0.74	0.402
Condition x Laterality x Site	4, 64	3.16	0.020*
Hemisphere x Laterality x Site	2.08, 33.29	1.51	0.235
Condition x Hemisphere x Laterality x Site	1.56, 24.90	0.22	0.749

*$p<0.05$

Appendix XIII (p) Repeated measures ANOVA model for main effects of Condition (Egocentric vs. Allocentric), Hemi-field (Left vs. Right), and Midline site (Fz, Cz, Pz, POz) and the interactions between them in the mean amplitude of the N2 in young adults

Within-Subjects Effect	Df	F-value	p-value
Condition	1.00, 16.00	0.22	0.642
Hemi-field	1.00,16.00	0.94	0.347
Site	1.26, 20.17	3.85	0.056
Condition x Hemi-field	1.00,16.00	0.59	0.453
Condition x Site	1.93, 30.93	0.61	0.546
Hemi-field x Site	1.71, 27.42	0.08	0.896
Condition x Hemi-field x Site	1.24, 19.76	0.25	0.671

Appendix XIII (q) Repeated measures ANOVA model for main effects of Condition (Egocentric vs. Allocentric), Hemisphere (Left vs. Right), Laterality (Contralateral vs. Ipsilateral signals) and Lateral site (10 sites) and the interactions between them in the peak latency of the N2 in young adults

Within-Subjects Effect	Df	F-value	p-value
Condition	1.00, 16.00	0.89	0.359
Hemisphere	1.00,16.00	0.10	0.754
Laterality	1.00,16.00	0.19	0.672
Site	1.65, 26.33	0.62	0.514
Condition x Hemisphere	1.00,16.00	2.91	0.108
Condition x Laterality	1.00, 16.00	0.03	0.865
Condition x Site	4, 64	0.49	0.743
Hemisphere x Laterality	1.00, 16.00	0.40	0.534
Hemisphere x Site	4, 64	2.33	0.066
Laterality x Site	2.51, 40.14	1.30	0.286
Condition x Hemisphere x Laterality	1.00, 16.00	0.09	0.770
Condition x Laterality x Site	4, 64	0.97	0.429
Hemisphere x Laterality x Site	2.47, 39.48	0.99	0.395
Condition x Hemisphere x Laterality x Site	2.16, 34.63	0.80	0.467

Appendix XIII (r) Repeated measures ANOVA model for main effects of Condition (Egocentric vs. Allocentric), Hemi-field (Left vs. Right), and Midline site (Fz, Cz, Pz, POz) and the interactions between them in the peak latency of the N2 in young adults

Within-Subjects Effect	Df	F-value	p-value
Condition	1.00, 16.00	8.56	0.010*
Hemi-field	1.00,16.00	0.12	0.729
Site	1.18, 18.81	0.35	0.598
Condition x Hemi-field	1.00,16.00	0.21	0.651
Condition x Site	2.04, 32.63	0.11	0.896
Hemi-field x Site	3, 48	1.76	0.168
Condition x Hemi-field x Site	1.48, 23.62	1.42	0.258

*$p<0.05$

Appendix XIII (s) Repeated measures ANOVA model for main effects of Condition (Egocentric vs. Allocentric), Hemisphere (Left vs. Right), Laterality (Contralateral vs. Ipsilateral signals) and Lateral site (10 sites) and the interactions between them in mean amplitude of the P3 in young adults

Within-Subjects Effect	Df	F-value	p-value
Condition	1.00, 16.00	4.01	0.063
Hemisphere	1.00,16.00	1.10	0.309
Laterality	1.00,16.00	9.25	0.008**
Site	1.36, 21.72	5.10	0.025*
Condition x Hemisphere	1.00,16.00	0.50	0.491
Condition x Laterality	1.00, 16.00	1.09	0.312
Condition x Site	2.07, 33.12	0.27	0.775
Hemisphere x Laterality	1.00, 16.00	6.99	0.018*
Hemisphere x Site	4, 64	6.06	<0.001**
Laterality x Site	1.78, 28.54	3.97	0.034*
Condition x Hemisphere x Laterality	1.00, 16.00	0.00	0.981
Condition x Laterality x Site	4, 64	3.01	0.025*
Hemisphere x Laterality x Site	2.19, 35.03	1.25	0.302
Condition x Hemisphere x Laterality x Site	1.78, 28.49	0.65	0.514

**p<0.01, *p<0.05

Appendix XIII (t) Repeated measures ANOVA model for main effects of Condition (Egocentric vs. Allocentric), Hemi-field (Left vs. Right), and Midline site (Fz, Cz, Pz, POz) and the interactions between them in the mean amplitude of the P3 in young adults

Within-Subjects Effect	Df	F-value	p-value
Condition	1.00, 16.00	1.76	0.204
Hemi-field	1.00,16.00	4.17	0.058
Site	1.21, 19.38	6.24	0.017*
Condition x Hemi-field	1.00,16.00	0.28	0.604
Condition x Site	1.90, 30.34	0.15	0.848
Hemi-field x Site	1.65, 26.38	0.23	0.751
Condition x Hemi-field x Site	1.28, 20.50	0.23	0.698

*p<0.05

Appendix XIII (u) Mean amplitudes (in µV) of the P3 component recorded at midline sites in young adults

Fz	Cz	Pz	POz
0.04±0.47	0.95±0.51	1.66±0.65	1.52±0.63

Appendix XIII (v) Repeated measures ANOVA model for main effects of Condition (Egocentric vs. Allocentric), Hemisphere (Left vs. Right), Laterality (Contralateral vs. Ipsilateral signals) and Lateral site (10 sites) and the interactions between them in the peak latency of the P3 in young adults

Within-Subjects Effect	Df	F-value	p-value
Condition	1.00, 16.00	2.74	0.117
Hemisphere	1.00,16.00	0.00	0.963
Laterality	1.00,16.00	4.80	0.044*
Site	1.67, 26.74	0.97	0.377
Condition x Hemisphere	1.00,16.00	0.20	0.659
Condition x Laterality	1.00, 16.00	2.11	0.166
Condition x Site	4, 64	0.58	0.675
Hemisphere x Laterality	1.00, 16.00	1.47	0.243
Hemisphere x Site	4, 64	2.72	0.037*
Laterality x Site	4, 64	1.56	0.195
Condition x Hemisphere x Laterality	1.00, 16.00	0.21	0.655
Condition x Laterality x Site	2.12, 33.95	0.44	0.661
Hemisphere x Laterality x Site	2.13, 34.10	1.10	0.348
Condition x Hemisphere x Laterality x Site	4, 64	1.20	0.321

*$p<0.05$

Appendix XIII (w) Repeated measures ANOVA model for main effects of Condition (Egocentric vs. Allocentric), Hemi-field (Left vs. Right), and Midline site (Fz, Cz, Pz, POz) and the interactions between them in the peak latency of the P3 in young adults

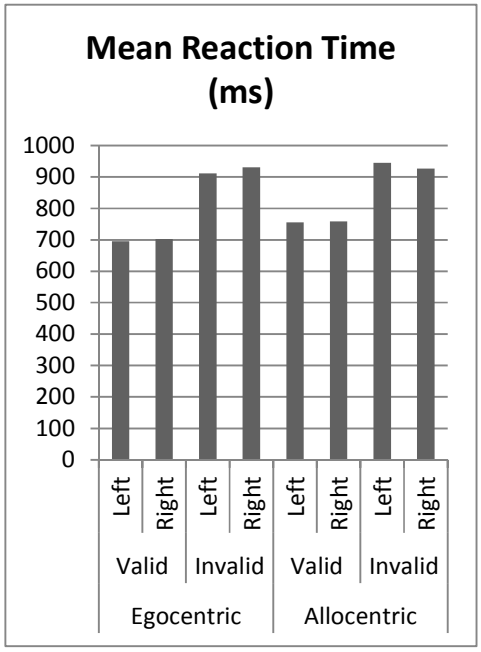
Within-Subjects Effect	Df	F-value	p-value
Condition	1.00, 16.00	1.42	0.251
Hemi-field	1.00,16.00	0.86	0.368
Site	1.28, 20.43	0.54	0.511
Condition x Hemi-field	1.00,16.00	0.01	0.922
Condition x Site	3, 48	0.64	0.591
Hemi-field x Site	3, 48	0.13	0.941
Condition x Hemi-field x Site	3, 48	1.23	0.310

Appendix XIII (x) Repeated measures ANOVA for main effects of Condition (Egocentric vs. Allocentric), Homologous pair (5 sites) and the interactions between them in mean amplitude of the CDA in young adults

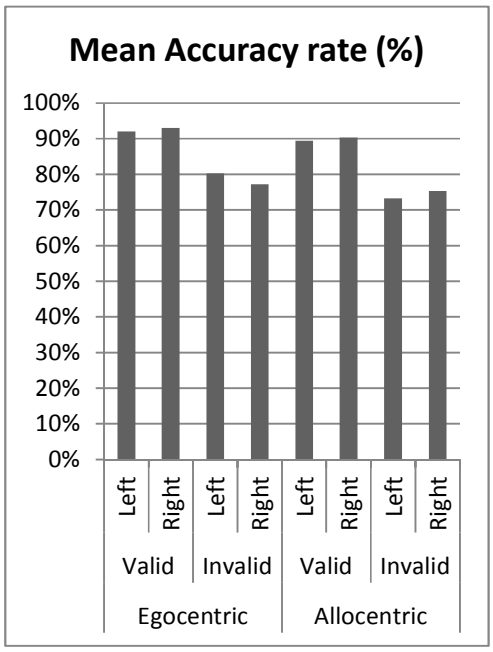
Within-Subjects Effect	df	F-value	p-value
Condition	1.00, 16.00	0.64	0.435
Site	2.14, 34.28	8.33	0.001**
Condition x Site	4, 64	1.81	0.139

**p<0.01

Appendix XIV Reaction time and accuracy rate in egocentric and allocentric condition in older adults



(a) Reaction Time



(b) Accuracy

Appendix XV Reaction time and accuracy rate in egocentric and allocentric condition in older adults

			Reaction Time (ms)		Accuracy Rate (%)	
Condition	**Validity**	**Hemi-field**	**Mean**	**SD**	**Mean**	**SD**
Egocentric	Valid	Left	696.08	109.38	92.07	4.42
		Right	703.07	99.40	92.99	4.50
	Invalid	Left	912.26	123.81	80.22	8.330
		Right	930.75	120.14	77.28	12.50
Allocentric	Valid	Left	755.37	120.32	89.42	3.76
		Right	758.10	109.77	90.38	4.20
	Invalid	Left	945.21	118.94	73.24	12.95
		Right	926.58	124.24	75.34	13.89

Appendix XVI (a) Repeated measures ANOVA examining the effects of Condition (Egocentric vs. Allocentric), Validity (Valid vs. Invalid trial) and Hemi-field (Left vs. Right) and the interactions between them on reaction time in older adults

Within-Subjects Effect	df	F-value	p-value
Conditions	1, 15	17.47	0.001 **
Validity	1, 15	89.50	<0.001**
Hemi-field	1, 15	0.11	0.750
Condition x Validity	1, 15	3.09	0.099
Condition x Hemi-field	1, 15	3.51	0.080
Validity x Hemi-field	1, 15	0.15	0.707
Condition x Validity x Hemi-field	1, 15	2.66	0.124

**p<0.01

Appendix XVI (b) Mean RTs (ms) of various condition, validity and hemi-field in the older adults

Condition		Validity		Hemi-field (HF)	
Egocentric	**Allocentric**	**Valid trial**	**Invalid trial**	**Stimuli on Left HF**	**Stimuli on Right HF**
810.54 ±24.99	846.31 ±26.15	728.15 ±26.24	928.70 ±28.42	827.23 ±25.77	829.62 ±25.20

Appendix XVI (c) Repeated measures ANOVA model for accuracy rate in main effects of Condition (Egocentric vs. Allocentric), Validity (Valid trial vs. Invalid trial) and Hemi-field (Left vs. Right) and the interactions between them in older adults

Within-Subjects Effect	df	F-value	p-value
Conditions	1, 15	14.66	0.002**
Validity	1, 15	35.32	<0.001**
Hemi-field	1, 15	0.05	0.829
Condition x Validity	1, 15	0.53	0.479
Condition x Hemi-field	1, 15	1.77	0.203
Validity x Hemi-field	1, 15	0.60	0.451
Condition x Validity x Hemi-field	1, 15	1.62	0.223

**p<0.01

Appendix XVI (d) The mean amplitudes (in μV) of the lateral electrodes for contralateral and ipsilateral signals from Egocentric and Allocentric trial for the P1, N1, N2 and P3 components in the older adults

Component	Site	Egocentric		Allocentric	
		Contralateral	Ipsilateral	Contralateral	Ipsilateral
P1	F3	0.21±0.90	0.10±0.6	0.57±1.03	0.24±1.02
	F4	0.35±0.75	0.27±0.79	0.47±1.00	0.50±1.05
	C3	0.39±0.89	-0.01±0.68	0.61±0.99	0.16±0.78
	C4	0.48±0.73	0.24±0.86	0.67±0.94	0.40±1.03
	P3	0.67±0.71	0.10±0.51	0.90±0.83	0.30±0.65
	P4	0.53±0.61	0.32±0.74	0.66±0.86	0.46±0.94
	PO3	0.69±0.83	0.02±0.49	0.86±0.92	0.18±0.65
	PO4	0.57±0.61	0.30±0.70	0.67±0.83	0.39±0.89
	T7	0.49±0.72	0.00±0.45	0.78±0.76	0.15±0.55
	T8	0.70±0.60	0.29±0.62	0.80±0.80	0.42±0.88
N1	F3	-0.99±1.49	-1.02±1.10	-0.98±1.32	-0.78±0.95
	F4	-1.40±1.12	-1.01±1.34	-1.01±1.72	-0.95±1.33
	C3	-1.87±1.97	-1.34±1.46	-1.78±1.80	-1.23±1.37
	C4	-2.07±1.32	-1.11±1.34	-1.84±1.46	-1.08±1.16
	P3	-2.19±1.94	-1.29±1.85	-2.31±1.86	-1.17±1.61
	P4	-2.61±1.63	-0.88±1.50	-2.60±1.60	-1.17±1.29
	PO3	-1.38±1.30	-0.51±1.28	-1.53±1.29	-0.37±1.06
	PO4	-1.78±1.65	-0.38±0.98	-1.70±1.42	-0.56±1.05
	T7	-1.60±1.63	-0.96±1.23	-1.49±1.42	-0.93±1.18
	T8	-2.05±1.22	-1.00±1.10	-1.86±1.29	-0.99±0.97
N2	F3	0.26±1.04	0.28±1.89	0.23±1.59	0.44±1.50
	F4	0.25±1.74	0.62±1.12	0.51±1.56	0.58±1.65
	C3	0.69±1.20	0.86±2.00	0.79±1.58	1.04±2.01
	C4	0.95±1.89	1.22±1.56	1.20±1.86	1.38±1.80
	P3	1.76±2.58	1.34±2.71	1.81±2.66	1.80±2.83
	P4	1.53±2.54	1.83±2.00	1.63±2.72	1.91±2.01
	PO3	1.43±1.80	1.04±1.75	1.48±1.71	1.47±1.90
	PO4	1.57±2.39	1.46±1.94	1.71±2.45	1.60±2.02
	T7	0.70±1.03	0.84±1.69	0.80±1.29	1.14±1.50
	T8	1.28±1.62	1.33±1.33	1.52±1.63	1.50±1.48
P3	F3	0.00±1.39	-0.17±1.70	0.00±1.67	0.03±1.75
	F4	0.25±1.59	0.3±1.34	0.57±1.71	0.79±1.71
	C3	0.78±1.43	0.81±1.84	1.25±1.89	1.09±1.86
	C4	1.06±1.60	1.43±1.49	1.31±1.74	1.84±2.02
	P3	1.63±2.25	1.53±2.52	1.98±2.63	2.04±2.52
	P4	0.87±2.19	1.75±1.80	1.07±2.37	1.99±2.05
	PO3	1.28±1.66	1.18±1.74	1.42±1.91	1.62±1.78
	PO4	0.80±1.96	1.29±1.63	0.95±2.07	1.54±1.98
	T7	0.71±1.05	0.71±1.39	1.02±1.44	1.10±1.42
	T8	1.07±1.24	1.44±1.21	1.33±1.47	1.78±1.48

Appendix XVI (e) The mean amplitudes (in μV) of the P1, N1, N2 and P3 components recorded at midline sites in egocentric and allocentric trial in the older adults

Component	Site	Egocentric		Allocentric	
		LHF	RHF	LHF	RHF
P1	Fz	0.07±0.79	0.09±1.02	0.24±1.12	0.42±1.11
	Cz	0.00±0.81	0.17±1.13	0.16±0.90	0.45±1.25
	Pz	0.05±0.71	0.34±0.89	0.20±0.89	0.52±1.08
	POz	0.06±0.68	0.30±0.91	0.24±0.87	0.49±1.03
N1	Fz	-1.28±1.74	-1.35±1.90	-0.98±1.78	-1.05±1.89
	Cz	-1.85±2.05	-2.20±2.27	-1.69±2.21	-1.96±2.27
	Pz	-1.90±2.00	-2.04±2.03	-1.82±2.18	-1.99±2.11
	POz	-1.75±1.65	-1.84±1.76	-1.65±1.75	-1.79±1.77
N2	Fz	0.31±1.99	0.46±2.12	0.74±2.12	0.62±2.50
	Cz	0.19±2.72	0.09±2.65	0.62±2.80	0.27±2.93
	Pz	0.46±2.55	0.38±2.48	0.70±2.71	0.46±2.65
	POz	0.48±2.06	0.35±2.17	0.67±2.35	0.44±2.24
P3	Fz	3.69±1.92	3.53±1.82	3.86±1.80	3.30±1.93
	Cz	3.39±2.32	3.05±2.08	3.66±2.21	2.97±2.33
	Pz	2.88±2.38	2.65±2.13	3.05±2.41	2.71±2.28
	POz	2.70±2.08	2.45±1.92	2.81±2.25	2.56±2.01

LHF: Visual stimuli appeared at left hemi-field
RHF: Visual stimuli appeared at right hemi-field

Appendix XVI (f) Repeated measures ANOVA model for main effects of Condition (Egocentric vs. Allocentric), Hemisphere (Left vs. Right), Laterality (Contralateral vs. Ipsilateral signals) and Lateral site (10 sites) and the interactions between them in the mean amplitude of P1 in older adults

Within-Subjects Effect	Df	F-value	p-value
Condition	1.00, 15.00	4.09	0.061
Hemisphere	1.00,15.00	3.78	0.071
Laterality	1.00,15.00	11.90	0.004**
Site	1.87, 28.00	1.18	0.318
Condition x Hemisphere	1.00,15.00	1.74	0.207
Condition x Laterality	1.00, 15.00	0.51	0.487
Condition x Site	1.77, 26.57	0.76	0.462
Hemisphere x Laterality	1.00, 15.00	3.52	0.080
Hemisphere x Site	4, 60	1.93	0.118
Laterality x Site	2.28, 34.13	8.62	0.001**
Condition x Hemisphere x Laterality	1.00, 15.00	0.11	0.742
Condition x Laterality x Site	4, 60	0.33	0.857
Hemisphere x Laterality x Site	1.56, 23.44	0.95	0.381
Condition x Hemisphere x Laterality x Site	1.52, 22.76	0.96	0.376

**p<0.01

Appendix XVI (g) Repeated measures ANOVA model for main effects of Condition (Egocentric vs. Allocentric), Hemi-field (Left vs. Right), and Midline site (Fz, Cz, Pz, POz) and the interactions between them in the mean amplitude of the P1 in older adults

Within-Subjects Effect	Df	F-value	p-value
Condition	1.00, 15.00	3.97	0.065
Hemi-field	1.00,15.00	4.74	0.046*
Site	1.34, 20.06	0.62	0.488
Condition x Hemi-field	1.00,15.00	0.10	0.761
Condition x Site	1.45, 21.78	1.67	0.214
Hemi-field x Site	1.37, 20.50	0.73	0.445
Condition x Hemi-field x Site	1.27, 19.11	0.51	0.528

*p<0.05

Appendix XVI (h) Repeated measures ANOVA model for main effects of Condition (Egocentric vs. Allocentric), Hemisphere (Left vs. Right), Laterality (Contralateral vs. Ipsilateral signals) and Lateral site (10 sites) and the interactions between them in the peak latency of the P1 in the older adults

Within-Subjects Effect	Df	F-value	p-value
Condition	1.00, 15.00	0.23	0.639
Hemisphere	1.00,15.00	1.72	0.209
Laterality	1.00,15.00	1.62	0.222
Site	2.17, 32.62	1.19	0.320
Condition x Hemisphere	1.00,15.00	1.53	0.235
Condition x Laterality	1.00, 15.00	0.02	0.885
Condition x Site	2.32, 34.82	0.43	0.685
Hemisphere x Laterality	1.00, 15.00	0.20	0.661
Hemisphere x Site	4, 60	0.96	0.438
Laterality x Site	4, 60	1.30	0.280
Condition x Hemisphere x Laterality	1, 15	2.66	0.124
Condition x Laterality x Site	4, 60	2.89	0.030*
Hemisphere x Laterality x Site	2.18, 32.73	0.22	0.826
Condition x Hemisphere x Laterality x Site	4, 60	0.87	0.489

*$p<0.05$

Appendix XVI (i) Repeated measures ANOVA model for main effects of Condition (Egocentric vs. Allocentric), Hemi-field (Left vs. Right), and Midline site (Fz, Cz, Pz, POz) and the interactions between them in the peak latency of the P1 in older adults

Within-Subjects Effect	Df	F-value	p-value
Condition	1.00, 15.00	0.88	0.364
Hemi-field	1.00,15.00	0.32	0.583
Site	1.19, 17.83	3.21	0.085
Condition x Hemi-field	1.00,15.00	3.66	0.075
Condition x Site	1.58, 23.72	1.52	0.238
Hemi-field x Site	1.89, 28.34	1.17	0.324
Condition x Hemi-field x Site	1.34, 20.11	1.24	0.294

Appendix XVI (j) Repeated measures ANOVA model for main effects of Condition (Egocentric vs. Allocentric), Hemisphere (Left vs. Right), Laterality (Contralateral vs. Ipsilateral signals) and Lateral site (10 sites) and the interactions between them in mean amplitude of the N1 in older adults

Within-Subjects Effect	Df	F-value	p-value
Condition	1.00, 15.00	1.99	0.179
Hemisphere	1.00,15.00	0.15	0.706
Laterality	1.00,15.00	23.79	<0.001**
Site	2.28, 34.12	7.23	0.002**
Condition x Hemisphere	1.00,15.00	4.70	0.047*
Condition x Laterality	1.00, 15.00	3.67	0.075
Condition x Site	1.55, 23.24	2.23	0.139
Hemisphere x Laterality	1.00, 15.00	0.62	0.445
Hemisphere x Site	1.68, 25.22	0.95	0.384
Laterality x Site	2.05, 30.67	9.05	0.001**
Condition x Hemisphere x Laterality	1.00, 15.00	0.01	0.923
Condition x Hemisphere x Site	4, 60	0.07	0.992
Condition x Laterality x Site	2.45, 36.78	0.19	0.866
Hemisphere x Laterality x Site	1.30, 19.53	0.87	0.391
Condition x Hemisphere x Laterality x Site	1.34, 20.10	0.36	0.620

**p<0.01, *p<0.05

Appendix XVI (k) Repeated measures ANOVA model for main effects of Condition (Egocentric vs. Allocentric), Hemi-field (Left vs. Right), and Midline site (Fz, Cz, Pz, POz) and the interactions between them in mean amplitude of the N1 in the older adults

Within-Subjects Effect	Df	F-value	p-value
Condition	1.00, 15.00	1.55	0.232
Hemi-field	1.00,15.00	0.76	0.398
Site	1.47, 22.01	3.92	0.046*
Condition x Hemi-field	1.00,15.00	<0.001	0.991
Condition x Site	1.21, 18.09	4.35	0.045*
Hemi-field x Site	1.39, 20.88	0.76	0.436
Condition x Hemi-field x Site	1.26, 18.83	0.17	0.744

*p<0.05

Appendix XVI (l) Repeated measures ANOVA model for main effects of Condition (Egocentric vs. Allocentric), Hemisphere (Left vs. Right), Laterality (Contralateral vs. Ipsilateral signals) and Lateral site (10 sites) and the interactions between them in the peak latency of N1 in older adults

Within-Subjects Effect	Df	F-value	p-value
Condition	1.00, 15.00	2.76	0.117
Hemisphere	1.00,15.00	2.08	0.170
Laterality	1.00,15.00	11.32	0.004**
Site	1.46, 21.90	7.96	0.005**
Condition x Hemisphere	1.00,15.00	1.44	0.249
Condition x Laterality	1.00, 15.00	2.12	0.166
Condition x Site	2.08, 31.27	0.61	0.554
Hemisphere x Laterality	1.00, 15.00	0.14	0.711
Hemisphere x Site	2.61, 39.12	1.38	0.263
Laterality x Site	1.77, 26.60	2.59	0.099
Condition x Hemisphere x Laterality	1.00, 15.00	0.01	0.906
Condition x Laterality x Site	2.47, 37.04	0.48	0.660
Hemisphere x Laterality x Site	4, 60	0.40	0.807
Condition x Hemisphere x Laterality x Site	1.75, 26.24	0.29	0.721

**p<0.01

Appendix XVI (m) Repeated measures ANOVA model for main effects of Condition (Egocentric vs. Allocentric), Hemi-field (Left vs. Right), and Midline site (Fz, Cz, Pz, POz) and the interactions between them in the peak latency of N1 in the older adults

Within-Subjects Effect	Df	F-value	p-value
Condition	1.00, 15.00	4.04	0.063
Hemi-field	1.00,15.00	0.54	0.475
Site	1.50, 22.43	3.34	0.066
Condition x Hemi-field	1.00,15.00	0.34	0.568
Condition x Site	2.13, 31.99	0.40	0.687
Hemi-field x Site	1.57, 23.51	0.46	0.593
Condition x Hemi-field x Site	1.83, 27.50	2.30	0.123

Appendix XVI (n) Repeated measures ANOVA model for main effects of Condition (Egocentric vs. Allocentric), Hemisphere (Left vs. Right), Laterality (Contralateral vs. Ipsilateral signals) and Lateral site (10 sites) and the interactions between them in the mean amplitude of the N2 in the older adults

Within-Subjects Effect	Df	F-value	p-value
Condition	1.00, 15.00	2.97	0.105
Hemisphere	1.00,15.00	0.45	0.834
Laterality	1.00,15.00	22.13	<0.001**
Site	2.43, 36.46	3.35	0.038*
Condition x Hemisphere	1.00,15.00	2.46	0.138
Condition x Laterality	1.00, 15.00	1.75	0.206
Condition x Site	2.34, 35.16	4.01	0.022
Hemisphere x Laterality	1.00, 15.00	2.13	0.165
Hemisphere x Site	2.33, 34.94	0.57	0.597
Laterality x Site	2.31, 34.59	1.60	0.214
Condition x Hemisphere x Laterality	1.00, 15.00	0.50	0.492
Condition x Laterality x Site	3.00, 45.01	4.81	0.005**
Hemisphere x Laterality x Site	1.33, 19.93	0.54	0.522
Condition x Hemisphere x Laterality x Site	1.30, 19.47	0.50	0.535

**p<0.01, *p<0.05

Appendix XVI (o) Repeated measures ANOVA model for main effects of Condition (Egocentric vs. Allocentric), Hemi-field (Left vs. Right), and Midline site (Fz, Cz, Pz, POz) and the interactions between them in mean amplitude of the N2 in the older adults

Within-Subjects Effect	Df	F-value	p-value
Condition	1.00, 15.00	3.14	0.097
Hemi-field	1.00,15.00	0.63	0.441
Site	1.85, 27.81	0.43	0.640
Condition x Hemi-field	1.00,15.00	0.54	0.475
Condition x Site	1.47, 22.03	5.14	0.022*
Hemi-field x Site	1.35, 20.21	0.90	0.384
Condition x Hemi-field x Site	1.41, 21.18	0.75	0.440

*p<0.05

Appendix XVI (p) Repeated measures ANOVA model for main effects of Condition (Egocentric vs. Allocentric), Hemisphere (Left vs. Right), Laterality (Contralateral vs. Ipsilateral signals) and Lateral site (10 sites) and the interactions between them in the peak latency of the N2 in the older adults

Within-Subjects Effect	Df	F-value	p-value
Condition	1.00, 15.00	0.21	0.653
Hemisphere	1.00,15.00	2.33	0.148
Laterality	1.00,15.00	0.88	0.364
Site	1.37, 20.53	0.79	0.423
Condition x Hemisphere	1.00,15.00	0.03	0.870
Condition x Laterality	1.00, 15.00	0.09	0.774
Condition x Site	1.61, 24.07	0.36	0.656
Hemisphere x Laterality	1.00, 15.00	0.59	0.455
Hemisphere x Site	1.74, 26.09	0.87	0.419
Laterality x Site	1.96, 29.38	1.66	0.099
Condition x Hemisphere x Laterality	1.00, 15.00	4.90	0.043*
Condition x Laterality x Site	2.11, 31.60	2.02	0.148
Hemisphere x Laterality x Site	2.33, 34.91	1.63	0.208
Condition x Hemisphere x Laterality x Site	2.03, 30.41	2.10	0.140

*$p<0.05$

Appendix XVI (q) Repeated measures ANOVA model for main effects of Condition (Egocentric vs. Allocentric), Hemi-field (Left vs. Right), and Midline site (Fz, Cz, Pz, POz) and the interactions between them in the peak latency of N2 in older adults

Within-Subjects Effect	Df	F-value	p-value
Condition	1.00, 15.00	0.06	0.814
Hemi-field	1.00,15.00	0.13	0.720
Site	1.70, 25.53	0.49	0.587
Condition x Hemi-field	1.00,15.00	0.06	0.813
Condition x Site	1.86, 27.83	1.65	0.211
Hemi-field x Site	1.25, 18.68	0.20	0.715
Condition x Hemi-field x Site	2.07, 31.11	1.02	0.374

Appendix XVI (r) Repeated measures ANOVA model for main effects of Condition (Egocentric vs. Allocentric), Hemisphere (Left vs. Right), Laterality (Contralateral vs. Ipsilateral signals) and Lateral site (10 sites) and the interactions between them in the mean amplitude of P3 in older adults

Within-Subjects Effect	Df	F-value	p-value
Condition	1.00, 15.00	2.97	0.105
Hemisphere	1.00,15.00	0.45	0.834
Laterality	1.00,15.00	22.13	<0.001**
Site	2.43, 36.46	3.35	0.038*
Condition x Hemisphere	1.00,15.00	2.46	0.138
Condition x Laterality	1.00, 15.00	1.75	0.206
Condition x Site	2.34, 35.16	4.01	0.022
Hemisphere x Laterality	1.00, 15.00	2.13	0.165
Hemisphere x Site	2.33, 34.94	0.57	0.597
Laterality x Site	2.31, 34.59	1.60	0.214
Condition x Hemisphere x Laterality	1.00, 15.00	0.50	0.492
Condition x Laterality x Site	3.00, 45.01	4.81	0.005**
Hemisphere x Laterality x Site	1.33, 19.93	0.54	0.522
Condition x Hemisphere x Laterality x Site	1.30, 19.47	0.50	0.535

**p<0.01, *p<0.05

Appendix XVI (s) The mean amplitudes (in μV) of the contralateral and ipsilateral signals of P3 component recorded in left and right hemispheres in older adults

Condition	Left Hemisphere		Right Hemisphere	
Egocentric	Contralateral	Ipsilateral	Contralateral	Ipsilateral
	1.25±0.40	2.07±0.52	1.85±0.37	2.16±0.34
Allocentric	1.17±0.37	2.14±0.45	1.94±0.37	1.99±0.35

Appendix XVI (t) Repeated measures ANOVA model for main effects of Condition (Egocentric vs. Allocentric), Hemi-field (Left vs. Right), and Midline site (Fz, Cz, Pz, POz) and the interactions between them in the mean amplitude of the P3 in the older adults

Within-Subjects Effect	**Df**	**F-value**	**p-value**
Condition	1.00, 15.00	0.31	0.583
Hemi-field	1.00,15.00	6.45	0.023*
Site	1.46, 21.84	7.15	0.008**
Condition x Hemi-field	1.00,15.00	1.14	0.304
Condition x Site	1.20, 17.93	0.60	0.477
Hemi-field x Site	1.34, 20.10	1.95	0.177
Condition x Hemi-field x Site	1.82, 27.31	4.65	0.021*

**p<0.01, *p<0.05

Appendix XVI (u) Repeated measures ANOVA model for main effects of Condition (Egocentric vs. Allocentric), Hemisphere (Left vs. Right), Laterality (Contralateral vs. Ipsilateral signals) and Lateral site (10 sites) and the interactions between them in the peak latency of the P3 in the older adults

Within-Subjects Effect	Df	F-value	p-value
Condition	1.00, 15.00	1.77	0.204
Hemisphere	1.00,15.00	1.63	0.221
Laterality	1.00,15.00	5.00	0.041*
Site	2.09, 31.39	1.64	0.209
Condition x Hemisphere	1.00,15.00	0.35	0.563
Condition x Laterality	1.00, 15.00	1.45	0.248
Condition x Site	1.56, 23.36	0.46	0.588
Hemisphere x Laterality	1.00, 15.00	0.68	0.424
Hemisphere x Site	2.53, 38.01	0.23	0.848
Laterality x Site	4, 60	0.60	0.661
Condition x Hemisphere x Laterality	1.00, 15.00	1.02	0.329
Condition x Laterality x Site	2.27, 34.11	0.94	0.410
Hemisphere x Laterality x Site	4, 60	1.51	0.212
Condition x Hemisphere x Laterality x Site	2.43, 36.37	1.77	0.178

*$p<0.05$

Appendix XVI (v) Repeated measures ANOVA model for main effects of Condition (Egocentric vs. Allocentric), Hemi-field (Left vs. Right), and Midline site (Fz, Cz, Pz, POz) and the interactions between them in the peak latency of the P3 in the older adults

Within-Subjects Effect	Df	F-value	p-value
Condition	1.00, 15.00	1.77	0.204
Hemi-field	1.00,15.00	0.49	0.494
Site	1.38, 20.67	0.37	0.618
Condition x Hemi-field	1.00,15.00	0.07	0.799
Condition x Site	1.93, 28.93	0.74	0.482
Hemi-field x Site	1.64, 24.66	0.92	0.394
Condition x Hemi-field x Site	2.06, 30.84	0.43	0.659

Appendix XVI (w) Repeated measures ANOVA model for main effects of Condition (Egocentric vs. Allocentric), Site (5 homologous sites) and the interactions between them in CDA in older adults

Within-Subjects Effect	df	F-value	p-value
Condition	1.00, 15.00	5.43	0.034*
Site	4, 60	1.83	0.134
Condition x Site	1.64, 24.60	4.19	0.034*

*p<0.05

Appendix XVII (a) Repeated measures ANOVA model for reaction time in main effects of Condition (Egocentric vs. Allocentric), Validity (Valid vs. Invalid trial) and Hemi-field (Left vs. Right) and the interactions between them in young and older adults

Effect	Df	F-value	p-value
Condition	1.00, 31.00	17.76	<0.001 **
Condition x Group	1.00, 31.00	0.61	0.440
Validity	1.00, 31.00	119.63	<0.001 **
Validity x Group	1.00 , 31.00	0.19	0.667
Hemi-field	1.00, 31.00	9.28	0.005 **
Hemi-field x Group	1.00, 31.00	11.99	0.002 **
Condition x Validity	1.00, 31.00	4.42	0.044 *
Condition x Validity x Group	1.00, 31.00	1.18	0.285
Condition x Hemi-field	1.00, 31.00	5.62	0.024 *
Condition x Hemi-field x Group	1.00, 31.00	0.81	0.374
Validity x Hemi-field	1.00, 31.00	1.57	0.219
Validity x Hemi-field x Group	1.00, 31.00	0.39	0.536
Condition x Validity x Hemi-field	1.00, 31.00	0.44	0.513
Condition x Validity x Hemi-field x Group	1.00	3.21	0.083

**p<0.01, *p<0.05

Appendix XVII (b) Repeated measures ANOVA model for accuracy rate in main effects of Condition (Egocentric vs. Allocentric), Validity (Valid vs. Invalid trial) and Hemi-field (Left vs. Right) and the interactions between them in young and older adults

Effect	Df	F-value	p-value
Condition	1.00, 31.00	15.33	<0.001 **
Condition x Group	1.00, 31.00	8.92	0.005**
Validity	1.00, 31.00	53.78	<0.001 **
Validity x Group	1.00 , 31.00	15.55	<0.001 **
Hemi-field	1.00, 31.00	0.81	0.376
Hemi-field x Group	1.00, 31.00	0.26	0.611
Condition x Validity	1.00, 31.00	0.00	0.987
Condition x Validity x Group	1.00, 31.00	1.95	0.172
Condition x Hemi-field	1.00, 31.00	0.84	0.366
Condition x Hemi-field x Group	1.00, 31.00	2.14	0.153
Validity x Hemi-field	1.00, 31.00	0.30	0.589
Validity x Hemi-field x Group	1.00, 31.00	0.56	0.459
Condition x Validity x Hemi-field	1.00, 31.00	1.62	0.213
Condition x Validity x Hemi-field x Group	1.00	0.87	0.358

**p<0.01

Appendix XVII (c) Repeated measures ANOVA model for main effects of Condition (Egocentric vs. Allocentric), Hemisphere (Left vs. Right), Laterality (Contralateral vs. Ipsilateral signals) and Lateral site (10 sites) and the interactions between them in mean amplitude of the P1 in young and older adults

Effect	Df	F-value	p-value
Condition	1.00, 31.00	2.76	0.107
Condition x Gp	1.00, 31.00	0.81	0.375
Hemisphere	1.00, 31.00	0.50	0.484
Hemisphere x Gp	1.00, 31.00	1.15	0.292
Laterality	1.00, 31.00	24.23	0.000**
Laterality x Gp	1.00, 31.00	0.01	0.928
Site	1.52, 47.20	5.90	0.009**
Site x Gp	1.52, 47.20	2.78	0.085
Condition x Hemisphere	1.00, 31.00	1.86	0.183
Condition x Hemisphere x Gp	1.00, 31.00	0.07	0.800
Condition x Laterality	1.00, 31.00	0.01	0.911
Condition x Laterality x Gp	1.00, 31.00	1.07	0.308
Hemisphere x Laterality	1.00, 31.00	30.81	0.000**
Hemisphere x Laterality x Gp	1.00, 31.00	12.54	0.001**
Condition x Hemisphere x Laterality	1.00, 31.00	1.21	0.280
Condition x Hemisphere x Laterality x Gp	1.00, 31.00	0.38	0.541
Condition x Site	2.12, 65.77	3.16	0.046*
Condition x Site x Gp	2.12, 65.77	1.13	0.331
Hemisphere x Site	2.82, 87.28	2.39	0.078
Hemisphere x Site x Gp	2.82, 87.28	0.11	0.949
Condition x Hemisphere x Site	3.14, 97.38	0.32	0.818
Condition x Hemisphere x Site x Gp	3.14, 97.38	0.54	0.667
Laterality x Site	1.94, 60.01	14.76	0.000**
Laterality x Site x Gp	1.94, 60.01	0.66	0.514
Condition x Laterality x Site	3.08, 95.45	1.06	0.370
Condition x Laterality x Site x Gp	3.08, 95.45	0.77	0.516
Hemisphere x Laterality x Site	1.85, 57.44	2.18	0.125
Hemisphere x Laterality x Site x Gp	1.85, 57.44	2.08	0.138
Condition x Hemisphere x Laterality x Site	1.37, 42.46	0.63	0.481
Condition x Hemisphere x Laterality x Site x Gp	1.37, 42.46	2.37	0.122

**p<0.01, *p<0.05

Appendix XVII (d) Repeated measures ANOVA model for main effects of Condition (Egocentric vs. Allocentric), Hemi-field (Left vs. Right), and Midline site (Fz, Cz, Pz, POz) and the interactions between them in the mean amplitude of the P1 in young and older adults

Effect	Df	F-value	p-value
Condition	1.00, 31.00	2.58	0.118
Condition x Group	1.00, 31.00	1.02	0.321
Hemi-field	1.00, 31.00	38.52	<0.001 **
Hemi-field x Group	1.00 , 31.00	13.04	0.001 **
Site	1.32, 40.75	2.54	0.110
Site x Group	1.32, 40.75	1.09	0.323
Condition x Hemi-field	1.00, 31.00	1.58	0.218
Condition x Hemi-field x Group	1.00, 31.00	0.66	0.425
Condition x Site	1.39, 43.16	3.59	0.042*
Condition x Site x Group	1.39, 43.16	0.80	0.414
Hemi-field x Site	1.30, 40.19	1.53	0.228
Hemi-field x Site x Group	1.30, 40.19	0.19	0.727
Condition x Hemi-field x Site	1.19, 36.92	1.00	0.337
Condition x Hemi-field x Site x Group	1.19, 36.92	1.98	0.166

**p<0.01, *p<0.05

Appendix XVII (e) Repeated measures ANOVA model for main effects of Condition (Egocentric vs. Allocentric), Hemisphere (Left vs. Right), Laterality (Contralateral vs. Ipsilateral signals) and Lateral site (10 sites) and the interactions between them in peak latency of the P1 in young and older adults

Effect	Df	F-value	p-value
Condition	1.00, 31.00	0.02	0.886
Condition x Gp	1.00, 31.00	0.07	0.796
Hemisphere	1.00, 31.00	1.14	0.293
Hemisphere x Gp	1.00, 31.00	0.44	0.513
Laterality	1.00, 31.00	5.65	0.024*
Laterality x Gp	1.00, 31.00	0.01	0.907
Site	2.43, 75.22	5.10	0.005**
Site x Gp	2.43, 75.22	2.78	<0.001**
Condition x Hemisphere	1.00, 31.00	2.51	0.123
Condition x Hemisphere x Gp	1.00, 31.00	0.05	0.833
Condition x Laterality	1.00, 31.00	0.69	0.412
Condition x Laterality x Gp	1.00, 31.00	1.08	0.307
Hemisphere x Laterality	1.00, 31.00	0.53	0.473
Hemisphere x Laterality x Gp	1.00, 31.00	0.01	0.932
Condition x Hemisphere x Laterality	1.00, 31.00	1.69	0.203
Condition x Hemisphere x Laterality x Gp	1.00, 31.00	0.02	0.898
Condition x Site	2.12, 65.77	0.56	0.629
Condition x Site x Gp	2.12, 65.77	1.83	0.152
Hemisphere x Site	4, 124	1.00	0.409
Hemisphere x Site x Gp	3.49, 108.16	0.84	0.490
Condition x Hemisphere x Site	3.09, 95.67	1.06	0.369
Condition x Hemisphere x Site x Gp	3.09, 95.67	0.60	0.621
Laterality x Site	4, 124	1.00	0.399
Laterality x Site x Gp	3.26, 100.96	3.74	0.011**
Condition x Laterality x Site	4, 124	0.536	0.709
Condition x Laterality x Site x Gp	3.33, 103.15	2.23	0.082
Hemisphere x Laterality x Site	2.07, 64.26	0.69	0.512
Hemisphere x Laterality x Site x Gp	2.07, 64.26	0.69	0.513
Condition x Hemisphere x Laterality x Site	2.35, 72.82	0.31	0.772
Condition x Hemisphere x Laterality x Site x Gp	2.35, 72.82	0.72	0.513

**p<0.01, *p<0.05

Appendix XVII (f) Repeated measures ANOVA model for main effects of Condition (Egocentric vs. Allocentric), Hemi-field (Left vs. Right), and Midline site (Fz, Cz, Pz, POz) and the interactions between them in the peak latency of the P1 in young and older adults

Effect	Df	F-value	p-value
Condition	1.00, 31.00	0.11	0.741
Condition x Group	1.00, 31.00	1.37	0.251
Hemi-field	1.00, 31.00	2.77	0.106
Hemi-field x Group	1.00 , 31.00	0.98	0.330
Site	1.42, 43.94	0.88	0.389
Site x Group	1.42, 43.94	13.12	<0.001**
Condition x Hemi-field	1.00, 31.00	1.82	0.187
Condition x Hemi-field x Group	1.00, 31.00	0.29	0.593
Condition x Site	1.92, 59.44	5.01	0.011*
Condition x Site x Group	1.92, 59.44	1.49	0.235
Hemi-field x Site	1.94, 60.08	0.27	0.758
Hemi-field x Site x Group	1.94, 60.08	1.42	0.250
Condition x Hemi-field x Site	1.47, 45.67	0.99	0.357
Condition x Hemi-field x Site x Group	1.47, 45.67	0.31	0.67

**p<0.01, *p<0.05

Table Appendix XVII (g) Repeated measures ANOVA model for main effects of Condition (Egocentric vs. Allocentric), Hemisphere (Left vs. Right), Laterality (Contralateral vs. Ipsilateral signals) and Lateral site (10 sites) and the interactions between them in mean amplitude of the N1 in young and older adults

Effect	Df	F-value	p-value
Condition	1.00, 31.00	1.91	0.177
Condition x Gp	1.00, 31.00	0.43	0.517
Hemisphere	1.00, 31.00	0.02	0.903
Hemisphere x Gp	1.00, 31.00	0.57	0.455
Laterality	1.00, 31.00	37.44	<0.001**
Laterality x Gp	1.00, 31.00	0.01	0.924
Site	2.76, 85.59	9.51	<0.001**
Site x Gp	2.76, 85.59	2.88	0.064
Condition x Hemisphere	1.00, 31.00	2.70	0.111
Condition x Hemisphere x Gp	1.00, 31.00	3.18	0.084
Condition x Laterality	1.00, 31.00	2.68	0.112
Condition x Laterality x Gp	1.00, 31.00	0.43	0.515
Hemisphere x Laterality	1.00, 31.00	0.06	0.804
Hemisphere x Laterality x Gp	1.00, 31.00	1.36	0.253
Condition x Hemisphere x Laterality	1.00, 31.00	0.72	0.402
Condition x Hemisphere x Laterality x Gp	1.00, 31.00	0.97	0.332
Condition x Site	1.73, 53.64	4.24	0.024*
Condition x Site x Gp	1.73, 53.64	0.51	0.580
Hemisphere x Site	1.88, 58.20	1.41	0.252
Hemisphere x Site x Gp	1.88, 58.20	0.23	0.778
Condition x Hemisphere x Site	2.96, 91.66	0.61	0.610
Condition x Hemisphere x Site x Gp	2.96, 91.66	1.16	0.328
Laterality x Site	2.02, 62.72	24.67	<0.001**
Laterality x Site x Gp	2.02, 62.72	2.08	0.133
Condition x Laterality x Site	2.61, 81.03	0.63	0.579
Condition x Laterality x Site x Gp	2.61, 81.03 103.15	0.22	0.859
Hemisphere x Laterality x Site	1.77, 55.00	0.62	0.521
Hemisphere x Laterality x Site x Gp	1.77, 55.00	0.32	0.703
Condition x Hemisphere x Laterality x Site	1.31, 40.44	0.45	0.558
Condition x Hemisphere x Laterality x Site x Gp	1.31, 40.44	0.24	0.694

**p<0.01, *p<0.05

Appendix XVII (h) Repeated measures ANOVA model for main effects of Condition (Egocentric vs. Allocentric), Hemi-field (Left vs. Right), and Midline site (Fz, Cz, Pz, POz) and the interactions between them in the mean amplitude of the N1 in young and older adults

Effect	Df	F-value	p-value
Condition	1.00, 31.00	1.15	0.292
Condition x Group	1.00, 31.00	0.50	0.484
Hemi-field	1.00, 31.00	0.04	0.841
Hemi-field x Group	1.00 , 31.00	0.73	0.398
Site	1.54, 47.75	5.55	0.002**
Site x Group	1.54, 47.75	0.46	0.584
Condition x Hemi-field	1.00, 31.00	1.01	0.332
Condition x Hemi-field x Group	1.00, 31.00	1.01	0.315
Condition x Site	1.24, 38.34	9.85	0.002**
Condition x Site x Group	1.24, 38.34	0.17	0.735
Hemi-field x Site	1.48, 45.73	0.18	0.768
Hemi-field x Site x Group	1.48, 45.73	0.60	0.506
Condition x Hemi-field x Site	1.21, 37.64	0.28	0.647
Condition x Hemi-field x Site x Group	1.21, 37.64	0.02	0.930

**p<0.01

Appendix XVII (i) Repeated measures ANOVA model for main effects of Condition (Egocentric vs. Allocentric), Hemisphere (Left vs. Right), Laterality (Contralateral vs. Ipsilateral signals) and Lateral site (10 sites) and the interactions between them in peak latency of N1 in young and older adults

Effect	Df	F-value	p-value
Condition	1.00, 31.00	1.32	0.260
Condition x Gp	1.00, 31.00	4.99	0.033*
Hemisphere	1.00, 31.00	8.44	0.007**
Hemisphere x Gp	1.00, 31.00	0.44	0.513
Laterality	1.00, 31.00	19.96	<0.001**
Laterality x Gp	1.00, 31.00	0.83	0.371
Site	1.75, 54.37	38.78	<0.001**
Site x Gp	1.75, 54.37	8.25	0.001**
Condition x Hemisphere	1.00, 31.00	2.66	0.113
Condition x Hemisphere x Gp	1.00, 31.00	0.08	0.780
Condition x Laterality	1.00, 31.00	0.07	0.789
Condition x Laterality x Gp	1.00, 31.00	3.72	0.063
Hemisphere x Laterality	1.00, 31.00	4.53	0.041*
Hemisphere x Laterality x Gp	1.00, 31.00	2.81	0.104
Condition x Hemisphere x Laterality	1.00, 31.00	0.22	0.643
Condition x Hemisphere x Laterality x Gp	1.00, 31.00	0.15	0.704
Condition x Site	2.27, 70.49	0.53	0.611
Condition x Site x Gp	2.27, 70.49	0.80	0.467
Hemisphere x Site	2.92, 90.51	1.00	0.409
Hemisphere x Site x Gp	2.92, 90.51	1.93	0.132
Condition x Hemisphere x Site	2.74, 84.92	1.12	0.342
Condition x Hemisphere x Site x Gp	2.74, 84.92	0.28	0.819
Laterality x Site	2.34, 72.61	6.01	0.002**
Laterality x Site x Gp	2.34, 72.61	0.23	0.829
Condition x Laterality x Site	2.41, 74.84	1.10	0.347
Condition x Laterality x Site x Gp	2.41, 74.84	0.99	0.388
Hemisphere x Laterality x Site	2.07, 64.09	0.32	0.736
Hemisphere x Laterality x Site x Gp	2.07, 64.09	0.17	0.848
Condition x Hemisphere x Laterality x Site	2.49, 77.31	1.75	0.173
Condition x Hemisphere x Laterality x Site x Gp	2.49, 77.31	1.44	0.241

**p<0.01, *p<0.05

Appendix XVII (j) Repeated measures ANOVA model for main effects of Condition (Egocentric vs. Allocentric), Hemi-field (Left vs. Right), and Midline site (Fz, Cz, Pz, POz) and the interactions between them in the peak latency of N1 in young and older adults

Effect	Df	F-value	p-value
Condition	1.00, 31.00	0.33	0.572
Condition x Group	1.00, 31.00	5.76	0.023*
Hemi-field	1.00, 31.00	2.66	0.113
Hemi-field x Group	1.00 , 31.00	0.37	0.549
Site	1.18, 36.51	19.47	<0.001**
Site x Group	1.18, 36.51	7.44	0.007**
Condition x Hemi-field	1.00, 31.00	0.74	0.397
Condition x Hemi-field x Group	1.00, 31.00	0.12	0.737
Condition x Site	1.57, 48.79	0.07	0.899
Condition x Site x Group	1.57, 48.79	0.24	0.733
Hemi-field x Site	1.48, 45.80	0.22	0.740
Hemi-field x Site x Group	1.48, 45.80	0.20	0.755
Condition x Hemi-field x Site	1.94, 60.16	1.93	0.155
Condition x Hemi-field x Site x Group	1.94, 60.16	0.21	0.808

**p<0.01, *p<0.05

Appendix XVII (k) Repeated measures ANOVA model for main effects of Condition (Egocentric vs. Allocentric), Hemisphere (Left vs. Right), Laterality (Contralateral vs. Ipsilateral signals) and Lateral site (10 sites) and the interactions between them in mean amplitude of the N2 in young and older adults

Effect	Df	F-value	p-value
Condition	1.00, 31.00	3.83	0.059
Condition x Gp	1.00, 31.00	0.10	0.922
Hemisphere	1.00, 31.00	0.88	0.356
Hemisphere x Gp	1.00, 31.00	1.44	0.240
Laterality	1.00, 31.00	11.54	0.002**
Laterality x Gp	1.00, 31.00	5.25	0.029*
Site	1.63, 50.57	0.77	0.444
Site x Gp	1.63, 50.57	6.37	0.006**
Condition x Hemisphere	1.00, 31.00	1.70	0.202
Condition x Hemisphere x Gp	1.00, 31.00	0.52	0.476
Condition x Laterality	1.00, 31.00	0.07	0.788
Condition x Laterality x Gp	1.00, 31.00	2.71	0.110
Hemisphere x Laterality	1.00, 31.00	0.70	0.408
Hemisphere x Laterality x Gp	1.00, 31.00	1.89	0.179
Condition x Hemisphere x Laterality	1.00, 31.00	1.22	0.278
Condition x Hemisphere x Laterality x Gp	1.00, 31.00	0.01	0.937
Condition x Site	2.84, 87.88	1.24	0.300
Condition x Site x Gp	2.42, 75.08	1.98	0.136
Hemisphere x Site	3.05, 94.46	1.16	0.328
Hemisphere x Site x Gp	3.05, 94.46	0.16	0.93
Condition x Hemisphere x Site	2.06, 63.70	0.03	0.610
Condition x Hemisphere x Site x Gp	2.96, 91.66	1.16	0.328
Laterality x Site	2.02, 62.72	24.67	<0.001**
Laterality x Site x Gp	2.02, 62.72	2.08	0.133
Condition x Laterality x Site	4.00, 105.26	7.11	<0.001**
Condition x Laterality x Site x Gp	4.00, 105.26	0.22	0.902
Hemisphere x Laterality x Site	1.78, 58.18	1.36	0.265
Hemisphere x Laterality x Site x Gp	1.78, 58.18	0.89	0.410
Condition x Hemisphere x Laterality x Site	1.57, 48.63	0.37	0.641
Condition x Hemisphere x Laterality x Site x Gp	1.57, 48.63	0.22	0.748

**p<0.01, *p<0.05

Appendix XVII (l) Repeated measures ANOVA model for main effects of Condition (Egocentric vs. Allocentric), Hemi-field (Left vs. Right), and Midline site (Fz, Cz, Pz, POz) and the interactions between them in the mean amplitude of the N2 in young and older adults

Effect	Df	F-value	p-value
Condition	1.00, 31.00	1.99	0.168
Condition x Group	1.00, 31.00	0.43	0.518
Hemi-field	1.00, 31.00	0.04	0.841
Hemi-field x Group	1.00 , 31.00	1.55	0.223
Site	1.38, 42.74	3.03	0.076
Site x Group	1.38, 42.74	3.04	0.076
Condition x Hemi-field	1.00, 31.00	1.13	0.297
Condition x Hemi-field x Group	1.00, 31.00	0.00	0.950
Condition x Site	1.84, 56.96	0.81	0.441
Condition x Site x Group	1.84, 56.96	2.93	0.066
Hemi-field x Site	1.63, 50.49	0.24	0.744
Hemi-field x Site x Group	1.63, 50.49	0.66	0.494
Condition x Hemi-field x Site	1.30, 40.40	0.31	0.638
Condition x Hemi-field x Site x Group	1.30, 40.40	0.52	0.523

Appendix XVII (m) Repeated measures ANOVA model for main effects of Condition (Egocentric vs. Allocentric), Hemisphere (Left vs. Right), Laterality (Contralateral vs. Ipsilateral signals) and Lateral site (10 sites) and the interactions between them in peak latency of the N2 in young and older adults

Effect	Df	F-value	p-value
Condition	1.00, 31.00	0.26	0.611
Condition x Gp	1.00, 31.00	1.05	0.313
Hemisphere	1.00, 31.00	0.72	0.402
Hemisphere x Gp	1.00, 31.00	1.69	0.203
Laterality	1.00, 31.00	0.36	0.551
Laterality x Gp	1.00, 31.00	1.08	0.306
Site	1.63, 50.66	0.52	0.563
Site x Gp	1.63, 50.66	0.76	0.448
Condition x Hemisphere	1.00, 31.00	1.66	0.207
Condition x Hemisphere x Gp	1.00, 31.00	2.18	0.150
Condition x Laterality	1.00, 31.00	0.10	0.750
Condition x Laterality x Gp	1.00, 31.00	0.00	0.950
Hemisphere x Laterality	1.00, 31.00	0.85	0.364
Hemisphere x Laterality x Gp	1.00, 31.00	0.02	0.877
Condition x Hemisphere x Laterality	1.00, 31.00	0.22	0.640
Condition x Hemisphere x Laterality x Gp	1.00, 31.00	1.04	0.316
Condition x Site	2.43, 75.26	0.12	0.917
Condition x Site x Gp	2.43, 75.26	0.74	0.506
Hemisphere x Site	2.52, 78.23	1.51	0.203
Hemisphere x Site x Gp	2.52, 78.23	2.05	0.124
Condition x Hemisphere x Site	3.02, 93.67	0.44	0.723
Condition x Hemisphere x Site x Gp	3.02, 93.67	1.23	0.305
Laterality x Site	2.96, 91.83	2.66	0.054
Laterality x Site x Gp	2.96, 91.83	0.14	0.936
Condition x Laterality x Site	3.15, 97.62	0.11	0.958
Condition x Laterality x Site x Gp	3.15, 97.62	2.55	0.057
Hemisphere x Laterality x Site	3.02, 93.67	1.44	0.237
Hemisphere x Laterality x Site x Gp	3.02, 93.67	1.00	0.399
Condition x Hemisphere x Laterality x Site	2.48, 76.74	0.62	0.573
Condition x Hemisphere x Laterality x Site x Gp	2.48, 76.74	2.32	0.093

Appendix XVII (n) Repeated measures ANOVA model for main effects of Condition (Egocentric vs. Allocentric), Hemi-field (Left vs. Right), and Midline site (Fz, Cz, Pz, POz) and the interactions between them in the peak latency of the N2 in young and older adults

Effect	Df	F-value	p-value
Condition	1.00, 31.00	6.77	0.014*
Condition x Group	1.00, 31.00	5.59	0.025*
Hemi-field	1.00, 31.00	0.26	0.616
Hemi-field x Group	1.00 , 31.00	0.00	0.998
Site	1.27, 39.42	0.26	0.667
Site x Group	1.27, 39.42	0.44	0.560
Condition x Hemi-field	1.00, 31.00	0.05	0.820
Condition x Hemi-field x Group	1.00, 31.00	0.26	0.614
Condition x Site	2.07, 64.10	0.96	0.391
Condition x Site x Group	2.07, 64.10	0.45	0.649
Hemi-field x Site	2.03, 63.01	1.21	0.306
Hemi-field x Site x Group	2.03, 63.01	1.10	0.340
Condition x Hemi-field x Site	1.58, 49.04	1.24	0.292
Condition x Hemi-field x Site x Group	1.58, 49.04	1.39	0.256

*p<0.05

Appendix XVII (o) Repeated measures ANOVA model for main effects of Condition (Egocentric vs. Allocentric), Hemisphere (Left vs. Right), Laterality (Contralateral vs. Ipsilateral signals) and Lateral site (10 sites) and the interactions between them in mean amplitude of the P3 in young and older adults

Effect	Df	F-value	p-value
Condition	1.00, 31.00	2.19	0.149
Condition x Gp	1.00, 31.00	2.94	0.096
Hemisphere	1.00, 31.00	4.31	0.046*
Hemisphere x Gp	1.00, 31.00	0.43	0.515
Laterality	1.00, 31.00	40.08	<0.001**
Laterality x Gp	1.00, 31.00	6.34	0.017*
Site	1.60, 49.63	2.02	0.151
Site x Gp	1.60, 49.63	14.53	<0.001**
Condition x Hemisphere	1.00, 31.00	0.63	0.432
Condition x Hemisphere x Gp	1.00, 31.00	0.06	0.809
Condition x Laterality	1.00, 31.00	0.01	0.927
Condition x Laterality x Gp	1.00, 31.00	2.30	0.140
Hemisphere x Laterality	1.00, 31.00	0.29	0.594
Hemisphere x Laterality x Gp	1.00, 31.00	17.54	<0.001**
Condition x Hemisphere x Laterality	1.00, 31.00	0.41	0.529
Condition x Hemisphere x Laterality x Gp	1.00, 31.00	0.46	0.504
Condition x Site	2.10, 65.12	0.51	0.612
Condition x Site x Gp	2.10, 65.12	0.13	0.890
Hemisphere x Site	4, 124	6.85	<0.001**
Hemisphere x Site x Gp	4, 124	1.47	0.224
Condition x Hemisphere x Site	2.85, 88.38	0.89	0.444
Condition x Hemisphere x Site x Gp	2.85, 88.38	0.99	0.399
Laterality x Site	2.00, 62.02	5.07	0.009**
Laterality x Site x Gp	2.00, 62.02	1.37	0.263
Condition x Laterality x Site	4, 124	5.00	0.001**
Condition x Laterality x Site x Gp	4, 124	1.01	0.405
Hemisphere x Laterality x Site	1.90, 58.87	0.90	0.408
Hemisphere x Laterality x Site x Gp	1.90, 58.87	0.88	0.417
Condition x Hemisphere x Laterality x Site	1.77, 54.97	0.73	0.470
Condition x Hemisphere x Laterality x Site x Gp	1.77, 54.97	1.45	0.243

**p<0.01, *p<0.05

Appendix XVII (p) Repeated measures ANOVA model for main effects of Condition (Egocentric vs. Allocentric), Hemi-field (Left vs. Right), and Midline site (Fz, Cz, Pz, POz) and the interactions between them in the mean amplitude of P3 in young and older adults

Effect	Df	F-value	p-value
Condition	1.00, 31.00	1.95	0.172
Condition x Group	1.00, 31.00	0.63	0.433
Hemi-field	1.00, 31.00	0.00	0.970
Hemi-field x Group	1.00 , 31.00	9.91	0.004**
Site	1.27, 39.38	1.08	0.322
Site x Group	1.27, 39.38	11.38	0.001**
Condition x Hemi-field	1.00, 31.00	0.05	0.832
Condition x Hemi-field x Group	1.00, 31.00	1.11	0.301
Condition x Site	1.54, 47.71	0.59	0.518
Condition x Site x Group	1.54, 47.71	0.21	0.750
Hemi-field x Site	1.61, 50.01	0.20	0.771
Hemi-field x Site x Group	1.61, 50.01	1.20	0.301
Condition x Hemi-field x Site	1.47, 45.48	0.70	0.460
Condition x Hemi-field x Site x Group	1.47, 45.48	2.19	0.136

**p<0.01

Appendix XVII (q) Repeated measures ANOVA model for main effects of Condition (Egocentric vs. Allocentric), Hemisphere (Left vs. Right), Laterality (Contralateral vs. Ipsilateral signals) and Lateral site (10 sites) and the interactions between them in peak latency of the P3 in young and older adults

Effect	Df	F-value	p-value
Condition	1.00, 31.00	0.00	0.977
Condition x Gp	1.00, 31.00	4.33	0.046*
Hemisphere	1.00, 31.00	0.88	0.356
Hemisphere x Gp	1.00, 31.00	0.76	0.391
Laterality	1.00, 31.00	9.83	0.004**
Laterality x Gp	1.00, 31.00	0.046	0.831
Site	1.94, 60.17	1.55	0.221
Site x Gp	1.94, 60.17	1.06	0.351
Condition x Hemisphere	1.00, 31.00	0.08	0.780
Condition x Hemisphere x Gp	1.00, 31.00	0.56	0.460
Condition x Laterality	1.00, 31.00	0.17	0.683
Condition x Laterality x Gp	1.00, 31.00	3.11	0.087
Hemisphere x Laterality	1.00, 31.00	0.00	0.969
Hemisphere x Laterality x Gp	1.00, 31.00	1.86	0.183
Condition x Hemisphere x Laterality	1.00, 31.00	0.36	0.553
Condition x Hemisphere x Laterality x Gp	1.00, 31.00	1.22	0.277
Condition x Site	2.64, 81.94	0.30	0.797
Condition x Site x Gp	2.64, 81.94	0.74	0.518
Hemisphere x Site	3.24, 100.41	1.66	0.178
Hemisphere x Site x Gp	3.24, 100.41	1.91	0.129
Condition x Hemisphere x Site	2.76, 85.42	1.42	0.245
Condition x Hemisphere x Site x Gp	2.76, 85.42	2.96	0.041*
Laterality x Site	3.15, 97.78	2.02	0.113
Laterality x Site x Gp	3.15, 97.78	0.39	0.770
Condition x Laterality x Site	2.81, 87.01	0.80	0.488
Condition x Laterality x Site x Gp	2.81, 87.01	0.59	0.612
Hemisphere x Laterality x Site	2.62, 81.17	0.60	0.593
Hemisphere x Laterality x Site x Gp	2.62, 81.17	1.77	0.166
Condition x Hemisphere x Laterality x Site	3.49, 108.11	0.89	0.459
Condition x Hemisphere x Laterality x Site x Gp	3.49, 108.11	2.07	0.099

*$p<0.05$

Appendix XVII (r) Repeated measures ANOVA model for main effects of Condition (Egocentric vs. Allocentric), Hemi-field (Left vs. Right), and Midline site (Fz, Cz, Pz, POz) and the interactions between them in the peak latency of P3 in young and older adults

Effect	Df	F-value	p-value
Condition	1.00, 31.00	0.88	0.355
Condition x Group	1.00, 31.00	0.50	0.486
Hemi-field	1.00, 31.00	1.24	0.274
Hemi-field x Group	1.00 , 31.00	0.00	0.951
Site	1.32, 40.98	0.48	0.544
Site x Group	1.32, 40.98	0.44	0.565
Condition x Hemi-field	1.00, 31.00	0.03	0.872
Condition x Hemi-field x Group	1.00, 31.00	0.08	0.785
Condition x Site	2.38, 73.74	0.30	0.777
Condition x Site x Group	2.38, 73.74	1.06	0.360
Hemi-field x Site	2.12, 65.72	0.35	0.721
Hemi-field x Site x Group	2.12, 65.72	0.69	0.511
Condition x Hemi-field x Site	2..34, 72.52	0.59	0.583
Condition x Hemi-field x Site x Group	2..34, 72.52	1.33	0.271