AGEING EFFECTS ON STIMULUS-INDUCED MOTOR PREPARATION PROCESSES – AN EVENT-RELATED POTENTIAL STUDY

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Ageing Effects On Stimulus-induced Motor Preparation Processes – An Event-related Potential Study

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CERTIFICATE OF ORIGINALITY

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_____ (Signature)

Xin WANG (Name of Student)

October 2015

DEDICATION

I dedicate this work to my beloved parents who fully supported me throughout the special period during my MPhil study.

ABSTRACT

Sensorimotor processing begins from stimulus onset to movement onset and contains separate but partially overlapping stages, including stimulus perception, response selection, and motor response generation. Different factors may modulate different stages of sensorimotor processing. The current study aimed to explore the changes in stimulus-induced motor preparation and execution associated with aging and how different factors, such as laterality and complexity of sequence finger movements, modulate these age-related changes on movement preparation. We hypothesized that aging would affect performance on finger-tapping tasks in the late response selection stage and that the motor response generation stage and factors, such as sequence length and complexity, would affect motor preparation processing.

We studied a total of 41 right-handed volunteers [20 younger subjects aged (mean ± SD) 24.1 ± 3.6 years and 21 older subjects aged 63.4 ± 3.1 years]. Both block-based choice-reaction and simple-reaction tasks were used in this study. Reaction time (RT), accuracy rate (ACC), and electroencephalography (EEG) were recorded during task performance.

The behavioral results of the CRT tasks showed an overall slowness in RT in the older groups compared with the younger groups ($p<0.001$), and the accuracy rate was higher in the younger than the older groups ($p<0.001$). The ACC for older group decreased with increasing task complexity, and RT was prolonged with increased sequence complexity.

The prolongation of N1 latency in the older group may suggest a delay in

visual stimulus processing stage (p=0.004). The amplitude of the P3 component was more positive in the younger group and the P3 peak amplitude differed due to different cueing types (p<0.001). In younger group, the P3 amplitude for left-hand-initiated sequence presented a more negative waveform than that of the right-hand-initiated sequence (p=0.036). The amplitude of s-LRP was influenced by sequence complexity (p=0.005) and response by hand (p=0.001). The peak amplitude was higher in the older group in the right-hand-initiated sequences and the r-LRP latency was longer for the older group.

The larger P3 amplitude for older group indicated that more attention resources need increased with aging. The P3 component is related to attention and memory-related operations; thus, the delayed P3 latency in the older group may not contribute to behavioral slowness in RT because no age-related delay in onset latency of s-LRP was found (p>0.050). The s-LRP results suggested that would influence less on the association of the shape-and-arrow configurations with the specific finger tapping sequence, as well as the response selection processes.

The age-related difference in the onset latency of r-LRP suggests that aging may have had an effect on the motor response generation stage. For the right-hand-initiated tapping sequence, extra-neural activity from the contralateral motor cortex was required for movement execution in older subjects. The prolonged onset latency of r-LRP on the left-hand-initiated tapping sequence of older group demonstrated that the contralateral brain cortex was recruited more for non-dominant hand side movement in the older group when movement planning and execution processes were needed for a given task. The longer r-LRP raising time for right-hand-initiated movements represented a stronger facilitation for left hand

movement that originated from the right hemisphere. The delayed latency and reduced amplitude of r-LRP with aging may indicate a top-down regulation and functional facilitation. The results of the r-LRP also suggested decreased inter-hemispheric differences due to increased inhibitory control from the contralateral hemisphere.

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Table of Contents

LIST OF FIGURES

CHAPTER I

INTRODUCTION

This chapter provides an outline of the study on the cognitive effects of aging on motor preparation and execution as measured by EEG. The chapter begins with the aim of the study and the questions addressed by study, followed by background information and justification for the study. This chapter ends with an outline of the entire thesis.

Study Briefing and Purpose

This study was designed to investigate the mechanism underlying motor preparation and execution in younger and older subjects. The experimental task was the finger-tapping paradigm during which ERPs and LRPs were captured. The entire study was conducted in the Applied Cognitive Neuroscience Laboratory of The Hong Kong Polytechnic University. Visual cues were presented to the subjects to signal initiation of finger-tapping movements. Subjects received training to become familiarized with the visual cues used to signal performance of different tapping sequences. ERP signals were analyzed and two different LRPs were computed: stimulus-locked LRP (s-LRP) and response-locked LRP (r-LRP); they were used to quantify movement preparation and execution processes. The LRPs were compared between the younger and older age groups.

The two specific objectives set for the study were: 1) to investigate age-related effects on movement preparation and execution processes based on

simple finger-tapping movements; 2) to study how the laterality of upper limbs and the complexity of movement sequences could modulate age-related effects on movement preparation and execution processes.

Justifications of Study

Ageing affects motor and cognitive processes. Older age is associated with decreased performance on a wide range of tasks particularly related to a reduction in processing speed. Previous studies have indicated that tasks requiring lower cognitive process and functions, such as simple sensory and motor tasks, are less affected by age compared with those requiring higher cognitive process and functions, such as working memory, executive control, motor planning, and selective attention tasks (e.g. Craik & Byrd, 1982; Regan, 1989; Yordanova, Kolev, Hohnsbein, & Falkenstein, 2004). LRP has commonly been used by researchers as an indicator of motor programming and preparation (e.g. Leuthold & Schröter, 2011; Schröter & Leuthold, 2008, 2009), perception-to-response procedure (Leuthold, Sommer, & Ulrich, 2004), overlapping task processing (e.g. Keus, Munneke, Nijkrake, Kwakkel, & Bloem, 2009), and spatial stimulus response compatibility (Buhmann et al., 2003). The use of LRP in motor-related research is based on the notion that it can differentiate motor preparation processes from motor execution processes; nevertheless, the LRP cannot offer clear differentiation of the early processes associated with the onset of stimuli-eliciting motor responses.

Previous studies (e.g. Falkenstein, Yordanova, & Kolev, 2006; Kolev,

Falkenstein, & Yordanova, 2006; Yordanova et al., 2004) employed simple and choice-reaction tasks to investigate the aging effects on sensorimotor integration; these studies differentiate the sensorimotor information processing into three stages: stimulus processing, response selection, and motor response generation. These three stages were suggested to be associated with different ERP components, which include the P1, N1, P3, and LRP. Age-related slowness was shown to be attributable to the delayed latency of the frontal and parietal electrical activities over the scalp, which were associated with the processing and response selection of the incoming stimuli in stimulus-response tasks (Craik & Byrd, 1982; Kornhuber & Deecke, 1964; Shibasaki & Hallett, 2006; Wild-Wall, Falkenstein, & Hohnsbein, 2008). Among them, early components, such as P1 and N1, elicited from the central (sensory-motor) and occipital regions are associated the early processing of visual stimuli. The central-parietal distributed P3 was associated with the response selection processes.

Other studies have revealed that delayed response times appear to be related to the decline in functional regulation of the contralateral motor cortex during generation of the motor response in older subjects (Falkenstein et al., 2006; Kolev et al., 2006; Yordanova et al., 2004); such delays were aggravated by increasing task complexity as reflected by the LRP. The slowness aggravated by task complexity has been called “the complexity effect” (see Eimer, 1998 for a review). The lengths of the movement sequence also modulate the electrical activities. For example, different sequence lengths (oneversus three-finger taps) were found to modulate onset latency of the r-LRP but not of the s-LRP

(Smulders, Miller, Luck, & Kappenman, 2012); this phenomenon was called "the sequence length effect" (Schröter & Leuthold, 2008) which was replicated in a few recent studies (Leuthold & Schröter, 2011; Schröter & Leuthold, 2008, 2009). This study adopted s-LRP and r-LRP, as well as N1, P1, and P3, for investigating the age-effects on motor preparation and execution processes.

Research Questions and Hypotheses

This study aimed to investigate the effects of aging on the preparation and execution of motor-related activities during finger-tapping tasks. Motor preparation was further differentiated into stimulus processing, response selection, and motor response generation stages. The participants performed single or sequential finger-tapping movements signaled by visual stimuli.

There were three research questions: 1) Which stages of motor preparation were influenced by aging when fingers were tapped in different movement sequences? 2) How did the different finger-tapping sequences modulate the motor preparation and execution processes as measured by LRP? 3) How did left/right hand laterality (the first tapping hand) modulate motor preparation processes?

It was hypothesized that, compared with younger subjects, older subjects would demonstrate significant modulation of the motor preparation processes across different movement sequences. This modulation would intensify when the sequence of the movements became more complex, affecting the onset latency of r-LRP but not the s-LRP and differences in LRPs between those

elicited by the left- versus right-hand tapping sequence.

Organization of Chapters

This thesis consists of six chapters including the Introduction. Chapter II is a literature review on the current understanding of the mechanism of motor preparation and execution for finger-tapping movements, the cognitive processes involved in different stages of motor preparation, and the effect of aging on motor performance. Chapter III presents the design of the study, including inclusion and exclusion criteria of subjects, the experimental paradigm, and the methods used for data recording and analysis. Chapter IV reports the results of the study. Chapter V consists of the discussion of the results and their relation to the effects of aging on motor preparation. Chapter VI consists of the conclusion, limitation of study, and recommendations for further studies.

CHAPTER II

Literature review

Chapter II provides a review of two models of motor preparation processes and introduces how aging would affect motor preparation processes, especially in the context of finger-tapping tasks. Variables, such as age, the responding hand, and task complexity that affect different stages of motor preparation, are reviewed. Plausible neural mechanisms underlying ageing effect on motor execution or performance are also explored.

Ageing Related Changes

Aging causes a series of changes across the human lifespan. The older brain works differently from the younger brain. One significant change of healthy aging is decreased volume of gray and white matter (e.g. Lemaître et al., 2005). Some studies have shown that normal aging is associated with declined speed in executive processes and reduced sensorimotor functions (Heuninckx, Wenderoth, & Swinnen, 2008). Results from a recent study which examined stimulus-locked ERP showed that the prefrontal cortex (PFC) is over recruited in motor preparation (Berchicci, Lucci, Pesce, Spinelli, & Di Russo, 2012). A hyperactive PFC suggests that older people tend to rely more on cognitive control processes in motor preparation than their younger counterparts (Seidler et al., 2010), resulting in reduced speed of information processing since the online cognitive resources for information processing, storing, and retrieval were

deprived.

There are two possible hypotheses generated according to observed phenomenon: the compensation hypothesis and the dedifferentiation hypothesis (Park & Reuter-Lorenz, 2009). The compensation hypothesis suggests that recruitment of additional brain regions (or over-activation) would compensate for deficits. The dedifferentiation hypothesis suggests that neural specialisation would be reduced due to over-activation of the required brain regions; this change would decrease the distinction in neural representation. Research on older people has shown increased bi-hemispheric activation during motor tasks; in contrast, younger people showed activation in the contralateral hemisphere. Similar findings were found in the primary motor cortex when older and younger subjects performed tasks involving unilateral hand movements(Ward & Frackowiak, 2003; Ward, Swayne, & Newton, 2008).

In cognitive tasks, performances were comparable between older and younger adults; nevertheless, older adults showed significantly slower RT than younger adults suggesting that aging has an impact on the sensorimotor system.

The Stages for Motor Preparation

Voluntary movements can be categorized into internally driven and externally-triggered movements depending on the mode of initiation. Previous studies have indicated that motor preparation can be separated into three different stages: stimulus processing, response selection, and motor response generation (Falkenstein, Yordanova, & Kolev, 2006; Kolev, Falkenstein, &

Yordanova, 2006; Yordanova, Kolev, Hohnsbein, & Falkenstein, 2004) (Figure 2.1). Although the three stages of motor preparation are presented as a cascading structure (Roggeveen, Prime, & Ward, 2007), they overlap; one stage may begin before the completion of the previous stage.

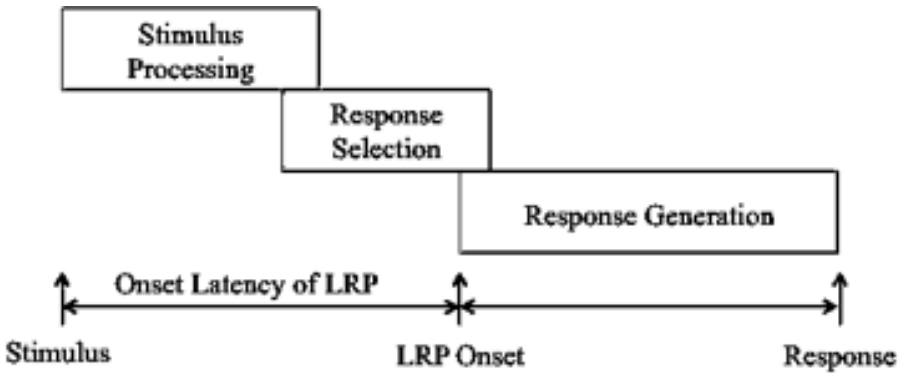


Figure 2. 1 Schematic illustration of the three stages of motor preparation. The time from stimulus onset to LRP onset contains the stimulus processing and response selection. The time from LRP onset to response is the process of response generation.

Stimulus Processing

The stimulus processing stage can be further divided into stimulus perception and stimulus classification. Stimulus perception is recognition of features of the stimulus which is associated with early components, such as P1 and N1 (e.g. Regan, 1989). The differences in the amplitude and latency of these components can be used to examine between- or within-subjects effects in. After

stimulus detection, stimulus classification occurs. P3 is associated with this classification process which was signified as a large positive-going central-parietal distributed waveform (Polich, 1998); P3 also reflects the attentional level involved in updating information contained in the stimulus. P3 latency has been reported as an indicator for the speed of classification task-related stimulus processes (Polich, 1998, 2007).

Response Selection and Motor Response Generation

The selection of motor response follows classification of the incoming stimulus. LRP has been used to reflect the time course of response selection (Coles, 1989). LRP is derived by means of the differences in neural activities elicited between the contralateral and ipsilateral motor-related brain regions. In general, the contralateral hemisphere at the sensorimotor cortex generate stronger activities than the ipsilateral hemisphere preceding the execution of hand movements. The onset of the inter-hemisphere difference therefore would be associated with initiation of the movements after response selection.

Cognitive-related Components

The ERP waveform consists of two major types of sensory potentials elicited by physical stimuli that are presented by positive- and negative polarities. Specific positive- or negative-going shifts occur when the subject is asked to perform specific cognitive tasks (see a review for Onofrj, Thomas, Iacono, D'Andreamatteo, & Paci, 2001).

P1 and N1

P1 and N1 are early components that reflect the initial steps of stimulus processing. For visual stimuli, the P1 and N1 would be elicited from bilateral occipital regions, such as at the O1 and O2 electrode sites.

P3

P3 or P300, which peak between 300 to 500 ms time window, is a late positive wave found to reflect processing of meaningful visual or auditory stimuli (e.g. Goodin, Squires, Henderson, & Starr, 1978; Pfefferbaum, Ford, Roth, & Kopell, 1980; Sutton, Braren, Zubin, & John, 1965). From an inhibition hypothesis perspective, the elicitation of P3 is associated with attention and memory-related operations due to brain regulations (Polich, 2007). In particular, it is related to rapid inhibition which is involved in on-going tasks. P3 was also found to be related to an increase in attention during stimuli detection (Knight, 1997; Soltani & Knight, 2000). Previous studies have reported decreases in amplitude of P3 among older adults (Craik & Byrd, 1982; Li, Gratton, Fabiani, & Knight, 2013; Onofrj et al., 2001; Salthouse, Babcock, & Shaw, 1991). Police (1997) revealed that the decrease in the amplitudes among older adults occurred in the midline electrodes, such as Fz, Cz, and Pz, in response to visual stimuli (Figure 2.2); in contrast, other studies reported increases in amplitudes of P3 over the frontal regions, suggesting that older people require greater activity in the frontal lobe for compensating declined cognitive functions, such as working memory (Linden, 2005; Onofrj et al., 2001; Polich, 2007). P3 has been reported

to be related to the allocation of attentional resources (Figure 2.3). Less positive-going and longer latencies of P3 were associated with increases in attentional resources.

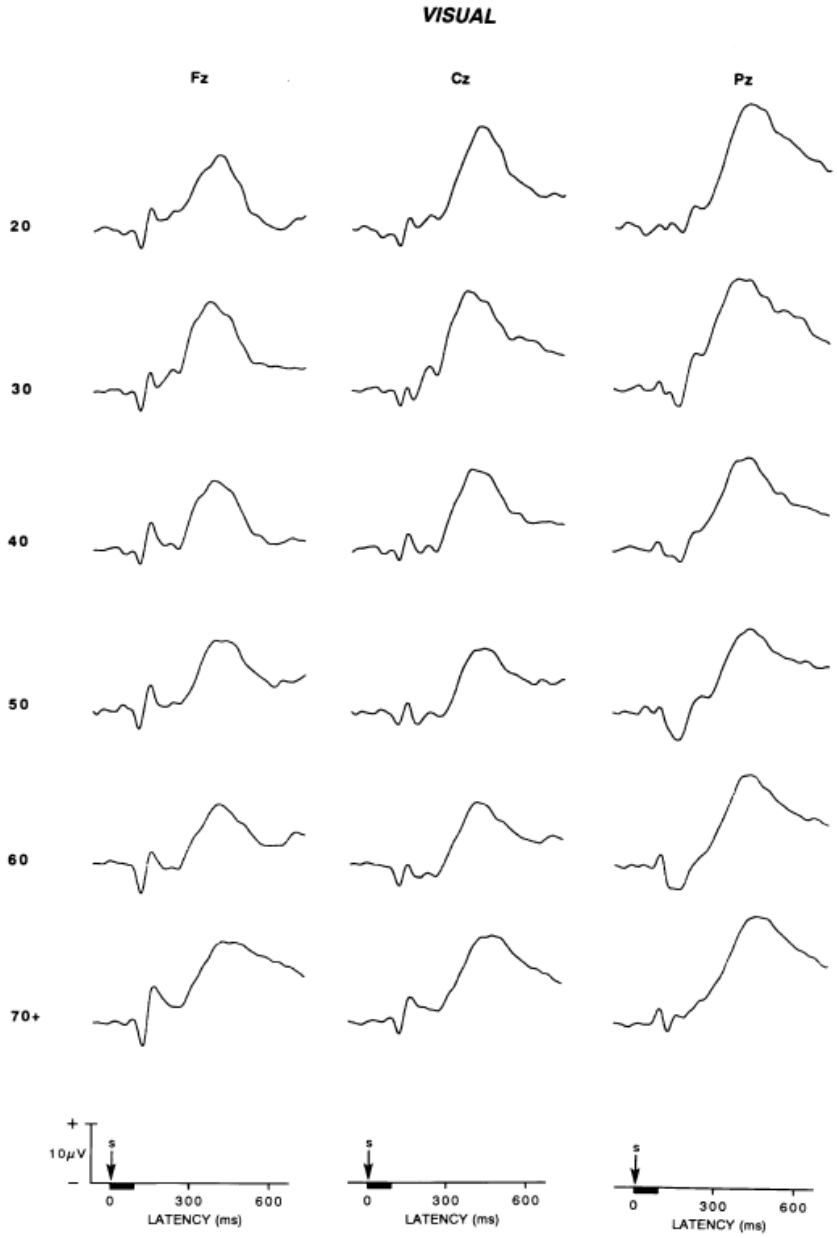


Figure 2.2 Modulation of P3 (less positive-going) with age at Fz, Cz, and Pz with visual stimuli. Time '0' means stimulus onset. From John Polich (1997) with kindly permission from ELSERIER Limited (See Appendix VI).

Bereitschaftspotential or Readiness Potential

What is Bereitschaftspotential?

The Bereitschaftspotential (BP) was firstly reported by Kornhuber and Deecke (1964) which represents the neural processes preceding execution of voluntary movements. The BP, also known as readiness potential (RP), is a slow negative-going wave elicited around 1500 to 2000 ms before movement onset (Onofrj et al., 2001; Shibasaki & Hallett, 2006); it was revealed to distribute widely over the scalp regardless of which body part executing the movement (Shibasaki & Hallett, 2006). Its topography is bilateral and symmetrical over the scalp that peaked at the precentral-patietal regions. Different movement conditions and the variability of subjects would significantly influence BP's onset latency and amplitude; these included intention level, preparation status, skill level, movement selection mode, and learning.

What Is Lateralized Readiness Potential?

LRP is readiness potential characterized by its lateralization feature. It was found to elicit in the contralateral sensorimotor regions when performing unilateral hand movements (Coles, Gratton, & Donchin, 1988); it is asymmetrically distributed and can be considered as an index of motor-related activations specific to the hands. LRP is derived by subtracting the potential recorded from C4 from that of C3 for left-hand responses, or the potential recorded from C3 from that of and C4 for right-hand responses. The primary motor cortex was proposed to be the source of generating LRP (Coles et al.,

1988). This proposition was supported by the evidence gathered using depth electrodes and magnetocephalogram (Eimer, 1998; Miller & Hackley, 1992).

Previous studies have employed LRP for two purposes: to capture motor preparation processes and to evaluate the time course of motor-related processing from the onset of stimuli to movement execution (RT interval) (Smulders, Miller, Luck, & Kappenman, 2012). LRP is captured using externally cues rather than self-paced (Shibasaki & Hallett, 2006). LRP amplitude can be influenced by factors such as characteristics of upcoming movements (including body parts, movement direction, movement extent, and force to perform) and complexity of the response (Hackley & Miller, 1995).

There are two types of LRP: stimulus-locked LRP (s-LRP) and response-locked LRP (r-LRP, Figure 2.3a and 2.3b). As described previously, the processes between detecting a stimulus to making proper and specific response can be separated into modality perception, response selection and motor execution, and these stages are overlapping to some extent. LRP may be used as an indicator of the different stages (Roggeveen et al., 2007). The time between the beginning to the stimulus and the onset of the s-LRP represents the first two processing stages: stimulus perception and response selection. The time between the beginning to the stimulus and the onset of the s-LRP represents the first two processing stages: stimulus perception and response selection. The duration from the beginning of r-LRP to the onset of motor response represents the motor generation stage containing motor programming and motor execution. Some studies used s-LRP and r-LRP to compare differences among different groups of

subjects doing the same task, or the same group of subjects performing different tasks (Baker, Piriyapunyaporn, & Cunnington, 2012; MacDonald, Nyberg, Sandblom, Fischer, & Bäckman, 2008).

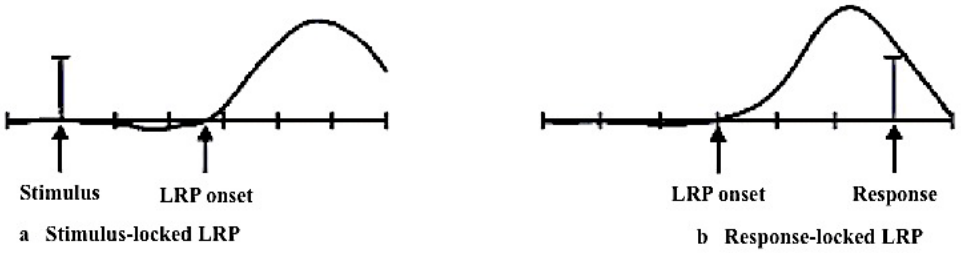


Figure 2.3 Stimulus-locked LRP (s-LRP) and response-locked LRP (r-LRP). From Roggeveen et al. (2007) with kindly permission from Oxford University Press (See Appendix VI).

Stimulus-locked LRP

The s-LRP is used to investigate perceptual processing of the perceived stimulus and the response selection informed by perception. The onset of the s-LRP indicates motor activity in motor-related region to select one of the choices (left vs. right). The time interval from target presentation to LRP onset indicates the amount of time required for the brain to process and analyze the stimulus related information and to make the choice corresponding to the target stimulus.

Response-locked LRP

Unlike the s-LRP, the r-LRP can be used to compare differences between two hemispheres in programming and executing a given motor task. The time

interval between the onset of the r-LRP and the motor execution reflects the required time for planning and initiating the motor response (Baker et al., 2012).

The Effects of Variables on LRP

Different experimental variables affect the stimulus to LRP (S→LRP) interval, LRP to response (LRP→R) interval, or both (Figure 2.4). The experimental variables acting on LRP→R interval include: (1) complexity of required response (e.g. Smulders, Kok, Kenemans, & Bashore, 1995); (2) precueing of movement parameters (e.g. Leuthold, Sommer, & Ulrich, 1996); and (3) pressure from time limitation (e.g. van der Lubbe, Jaśkowski, Wauschkuhn, & Verleger, 2001). There are two factors which will affect the S→LRP interval, the manipulation of foreperiod, such as the inter-trial interval (e.g. MÜller- Gethmann, Ulrich, & Rinkenauer, 2003) and the of stimulus properties (e.g. Hackley & Valle-Inclán, 1999), which is represented by the information contained in the stimulus, such as color, distribution, numbers of configuration, and types of stimuli.

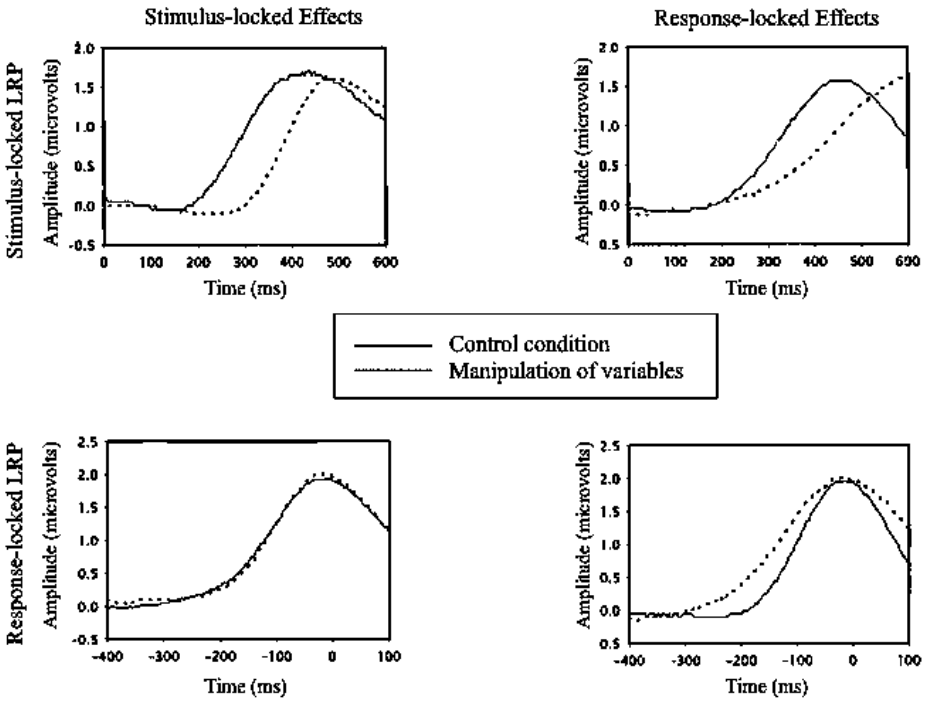


Figure 2.4 Graphic illustration of variables influences on S→LRP interval (left panel) in stimulus-locked LRP (upper panel) and LRP→R interval (right panel) in response-locked LRP (lower panel). From Mordkoff and Gianaros (2000) with kindly permission from John Wiley and Sons (See Appendix VI).

Age-Related Changes of Electrophysiological Components

Studies using ERP or LRP have suggested that both frontal and delayed parietal distributed perceptual and cognitive processes, which are involved in stimulus processing and response selection might contribute to the slowness which is reflected by prolonged RT (Mordkoff & Gianaros, 2000). Some studies have suggested that decreased functional regulation in the contralateral motor cortex during motor response generation contributes to the prolonged RT in older than younger group and this deficit becomes more obvious when task

complexity increased (e.g. MÜller- Gethmann et al., 2003). Since the age-related slowness of RT is increased with task complexity, this effect is called "the complexity effect" (Craik & Byrd, 1982; Kornhuber & Deecke, 1964; Shibasaki & Hallett, 2006). A more recent study showed that older adults recruit prefrontal areas when performing tasks regardless of task complexity (Falkenstein et al., 2006; Kolev et al., 2006; Yordanova et al., 2004). On the other hand, not only the task complexity has effects on the LRP, but also the sequence length of the required movements involved in the task.

A study using sequences of different movement lengths (1 vs. 3) showed that the influence of sequence length does not affect the onset latency of s-LRP but does affect r-LRP (see Eimer, 1998 for a review). These results suggest that the duration of motor processes associated with response execution increased with sequence length of movement required, which means when the first action was activated, the programming of the whole motor sequence for response execution was still ongoing; this is called "the sequence length effect," which refers to different sequence length of the required movement has effects on the onset latency of r-LRP (Craik & Byrd, 1982). Some recent studies support this idea (Smulders et al., 2012), but this sequence length effect can be seen only in blocked design but not in mixed condition (Schröter & Leuthold, 2008); a possible explanation for this effect is that the mixed design blocks involved a selection between two hands, so the effect of sequence length might covered by the selection between hands (Leuthold & Schröter, 2011; Schröter & Leuthold,

2008, 2009). Thus far, there have not been any neuroimaging studies which have investigated the sequence length effect associated with aging.

Previous studies have investigated motor planning by means of movement-related cortical potentials, and reported that older adults had RP with lower amplitude and extended onset latency than younger adults (Smulders et al., 1995); however, two studies found no difference between the two age groups. Some studies using transcranial magnetic stimulation (TMS) have found that the intracortical inhibitory circuits have less excitability in older than young groups (Coles et al., 1988); older adults also have decreased amplitude of motor evoked potential (MEP) (Coles et al., 1988; Eimer, 1998).

As task-related interhemispheric inhibition is reduced with aging, this may explain the bilateral activation observed in older people as demonstrated by neuroimaging studies (Coles, 1989; Eimer, 1998). EEG studies have shown that older people display a larger amplitude, despite showing no difference in s-LRP onset latency (Coles, 1989; Eimer, 1998). No study was performed to compare the differences of unilateral movements between left and right hands, as well as bilateral movement using the same sequence length. The mechanism of diminished interhemispheric inhibition in older adults needs to be further investigated.

Objectives of Current Study

Previous electrophysiological studies have compared stimulus processing, sensorimotor processing, and motor execution-related processing in

older and young group using various types of tasks. Although some of the studies aimed to examine the underlying mechanism of how different variables and age influence the motor preparation processes, but the interaction effects between different variables have not yet to be examined.

The current study was designed to explore changes in neural processes associated with aging and to discover how the different variables affect the different stages of motor preparation. The present study is a pilot study of aging-related effects on the process of motor preparation. These findings may be used to explore the differences in the processes of motor preparation and execution in different pathological conditions.

CHAPTER III

METHOD

This chapter describes the methods used to investigate the motor preparation process underlying finger-tapping tasks. The subjects, study design, experimental procedure, assessment instruments, data collection, and data analysis are detailed.

Subjects

There were 41 participants including 20 younger [8 female, age (mean±SD) 24.1±3.6 years] and 21 older adults (63.4±3.1 years). All subjects were healthy without history of neurological, psychiatric, or chronic somatic problems; they had normal or corrected to normal vision, and were right-handed according to the Annett handedness inventory. The subjects were recruited by posting recruitment notices at the university campus and one elderly center, which contained a brief introduction of the study and procedure. Potential subjects interested in the experiment called the investigator to register. All the potential subjects were screened by the recruitment criteria mentioned above. The purpose of the current study was explained in the informed consent form (see Appendix IV), which was given to the subjects to read before the experiment. Due to the differences in time spent in the study, each elderly and younger subject received HK$200 and HK$150, respectively, as compensation of the time and travelling fees associated with participating in the study.

All older participants were assessed by the Mini-mental State

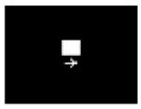
Examination Cantonese version (Chiu, Lee, Chung, & Kwong, 1994). Older participants who scored lower than 27 were excluded from the study. The mean MMSE score for the older participant group was 29.1 (SD=1.4). The younger participants consisted of undergraduate students from The Hong Kong Polytechnic University. The older participants consisted of retired volunteers from local communities of the Hong Kong Shatin Elderly Center. Informed consent was obtained from all participants according to the Declaration of Helsinki and the study received prior approval by the Ethical Committee of Department of Rehabilitation Sciences, The Hong Kong Polytechnic University.

General Description of the Tasks

The experimental tasks used in current study were based on the finger-tapping paradigm. Each participant was asked to complete 10 blocks of finger-tapping trials with the index and middle fingers of the left, right, or both hands depending on the different conditions set for each task trial. There were eight blocks of the choice-reaction task condition (CRT) followed by two blocks of the simple-reaction task condition (SRT). In the CRT condition, the subject was required to respond corresponding to the movement specifications represented by different visual cue cues in each trial; in contrast, in the SRT condition, the subject made the same movements across all trials. The purpose of the SRT condition was to set a baseline of response speed for each subject.

Visual Cues and Tapping Sequence

The visual cues were presented with Stim 2 software (NeuroScan Inc., Herndon, VA, USA). They are composed of a white geometric shape on top of an arrow against a black background (Figure 3.1) displayed through a 15" Cathode Ray Tube monitor. The shapes can be one of the four configurations: circle, square, diamond, or triangle. Each configuration refers to one tap with left or right index finger (circle), four taps with left or right index finger (square), four taps with alternate index and middle fingers of the left or right hand, (diamond), or four taps with alternate left and right index fingers (triangle) (Table 3.1). The arrow under the shape indicates the side of the hand initiating the movement. When visual cues appeared on the screen at the beginning of a trial, the subject would decide on the tapping sequence and the left or right index finger which initiated the tapping. The labels of the fingers which taps on a response pad are: the left index (LI), left middle (LM), right index (RI), and right middle (RM). The subject then began tapping according to the sequence indicated by the visual cue. The subject was instructed to tap as fast as they could perform each sequence fluently. In the SRT condition, the response was different from that in the CRT condition. The subject was required to make one tap by the left or right index finger according to the direction of the arrow appearing on the visual cues; for example, if SL was presented (Figure 3.1), the subject would tap once with the left index finger.

Cues	Orders	Responding Hand and Tapping Sequences			
					
		LI	LM	RI	RM
	1st	¢			
	2nd				
	3rd				
	4th				
	1st			¢	
	2nd				
	3rd				
	4th				
	1st	¢			
	2nd	¢			
	3rd	¢			
	4th	¢			
	1st			¢	
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	4th			¢	
	1st			¢	
	2nd	¢			
	3rd			¢	
	4th	¢			

Table 3. 1 Summary tapping sequences contained in the eight visual. The upper configuration of the cues indicates the tapping sequence, and the arrow below represents the responding hands. 1st, 2nd, 3rd and 4th indicate the sequence of the tapping contained in each of the visual cues.

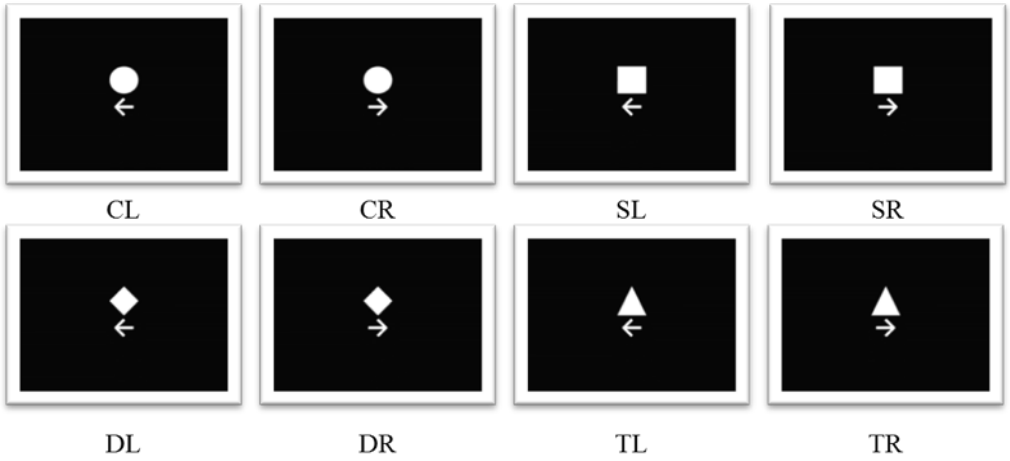


Figure 3.2 Eight configurations of visual cues used in current tasks. The upper configuration of the cues indicates the tapping sequence, and the arrow below represents the responding hands. 1st, 2nd, 3rd and 4th indicate the sequence of the tapping contained in each of the visual cues.

Procedures

The participant completed a training session in which he or she learned the tapping sequence represented by each of the eight visual cues. The familiarization process included recognition of the configurations presented in the visual cues and association of the configurations with the movement sequences. For the CRT condition, the subject practiced on two blocks of 30 trials. If the subject did not reach 90% of accuracy in the performing the tapping sequence, he or she continued to complete an additional block of 30 trials; no training practice was provided for the SRT condition. Once the participant reached the 90% accuracy benchmark, the subject proceeded to the tapping tasks.

For the CRT condition, a trial began with a fixation cross presented for 500 ms in the centre of the screen of the computer monitor (Figure 3.2). The visual cue with a specific shape configuration and directional arrow then appeared for a maximum of 4000 ms on the screen (Figure 3.1). The subject was required to respond as quickly as possible by tapping on buttons of the response pad with fingers according to the tapping sequence and side of hand represented by the visual cue (Figure 3.3). Depending on the time for the response, the visual cue disappeared once when the first tap was made and hit on the response pad. If no response was detected, the visual cue would stay on the screen for 4000 ms and the trial would be ended. The trial was ended with presentation of a black screen for a variable period of time ranging from 1440 to 2160 ms in order was to minimize the anticipation leading to the induction of anticipatory potentials. There were 15 trials with each configuration, giving a total of 120 CRT trials in each block (eight blocks in all). Similarly, there were 15 trials with each configuration, giving a total of 120 SRT trials in each block (two blocks in all). The eight visual cues for both CRT and SRT conditions were organized in a pseudo-randomized sequence. The sequence of the CRT and SRT blocks were the same across subjects. The total time for completion of all the 10 blocks for each subject was approximately 50 to 70 minutes and there was a short break between each block.

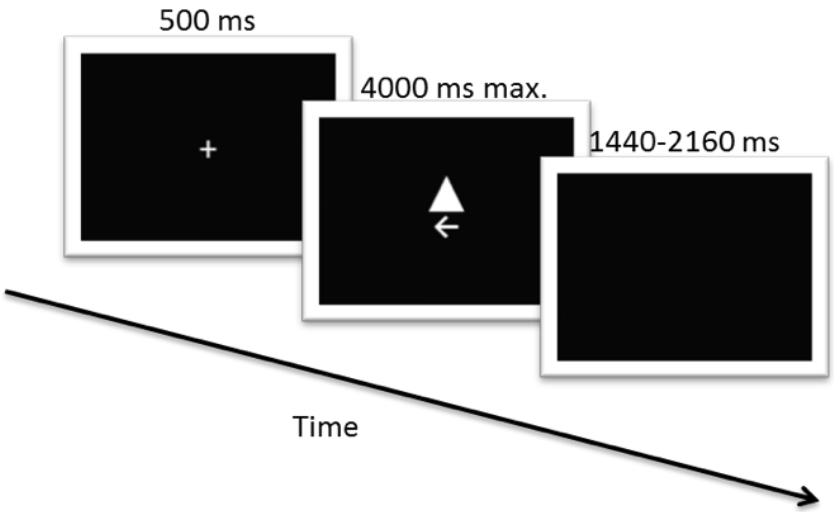


Figure3. 3 A typical trial in both training and experimental sessions. If there was no response detected, the visual cue would present on the screen and last for 4000 ms. Once there was a response detected, no matter the correctness of the response, the cue would have disappeared.

Experimental settings

The experimental tasks were conducted in a sound-attenuated chamber. For EEG recordings, a 64-channel EEG Neuroscan Quick cap with Ag/AgCl electrodes were was mounted on the subject's scalp (Neuroscan). Participants were seated comfortably in an armchair with the arms rested on a desk (Figure 3.3). The computer monitor was placed 65 to 75 cm in front of the subject. The response pad was placed in front of the subject on the desk. The subject positioned the left and right index and middle fingers on buttons of the response pad according to the sequence: left middle finger (#1 button), left index finger (#2 button), right index finger (#3 button), and right middle finger (#4 button)

(Figure 3.3).

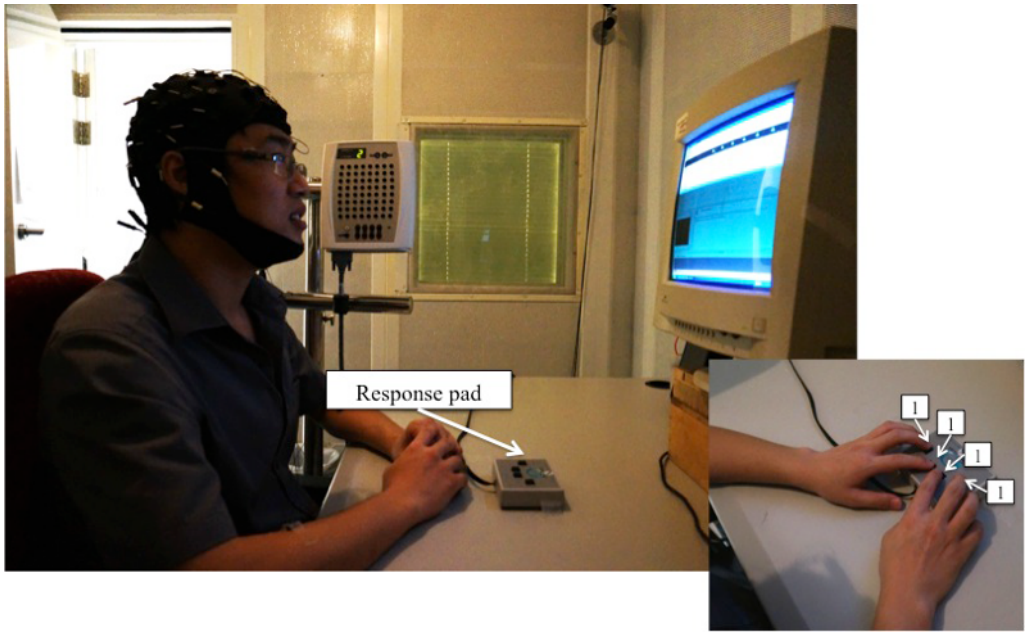


Figure 3. 4 The response pad was placed in front of the subject on the desk. The buttons on the response pad were label with #1 to #4. The subject made response by pressing on the corresponding buttons with the left middle finger, left index finger, right index finger, and right middle finger.

EEG Settings

Subject's EEG was recorded with SynAmps2 amplifier (NeuroScan Inc., Sterling, VA). Figure 3.4 shows the overview of SynAmps2 and Stim2 system for EEG data recording and cues delivering respectively. The stimulus presented on the CRT monitor, and the subject responded to the cues with specific tapping sequences.

The distance between the nasion (the depression part between forehead and nose) and inion (the bony protuberance at the back at the occipital region of the

head) of the subject was measured to guide the choice of the size of the cap. In order to locate the Cz electrode on the cap, two distances were measured: between the nasion and the inion and between the left and right periauricular points (the points just at the upper margin of the auricle) (Figure 3.5). The cross at the mid-point of these two distances set the location for the Cz electrode. The linked mastoids were used as references. AFz was used as the ground electrode. Two pairs of electrodes were used to monitor eye movements and ocular artifacts. For the vertical electro-oculogram (VEOG), two electrodes (HEOU and HEOL) were placed supra- and infra-orbitally at the right eye (Figure 3.6). For the horizontal electro-oculogram (HEOG), the signal was recorded from left and right orbital rims of both eyes with the HEOL and HEOR electrodes (Figure 3.6).

In preparation of the cap, a syringe filled with Quikgel (manufactured by NeuroScan Inc., Hemdon, VA, USA) was used for injecting the conductive gel into each electrode. Curry 7 software (NeuroScan Inc., Hemdon, VA, USA) was used for online signal acquisition (Figure 3.7). Electrode impedances were set below 5 kΩ. The band pass for EEG recording was set between 0.01 and 30 Hz. The amplified signals were digitized at 1000 Hz. The band pass for EMG recording was set between 13 to 10 kHz.

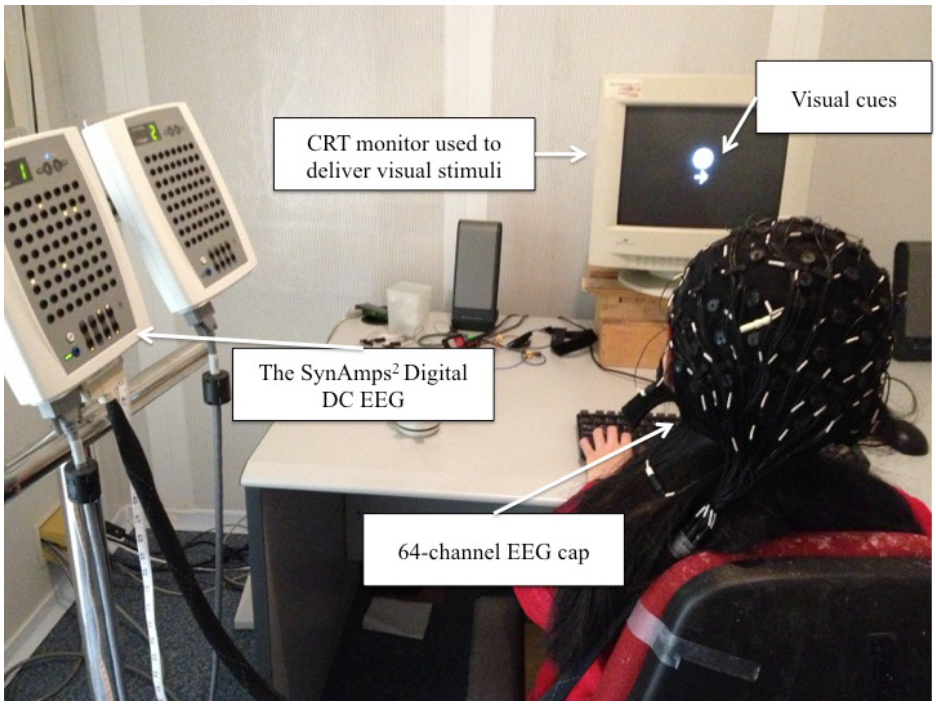


Figure 3. 5 General settings of the sound attenuated chamber. The 64-channel EEG cap was connected to SynAmps2 Digital DC EEG system. The amplified signals were transmitted and recorded by the software.

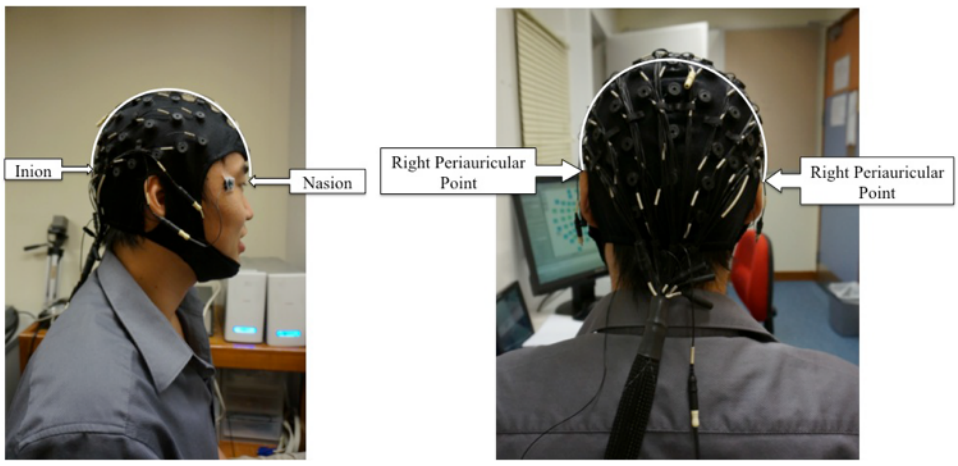


Figure 3. 6Method for positioning the cap. The measure of the anteroposterior distance over the scalp (left image) and left-right distance over the scalp (right image). The meet point of the two distances located the Cz electrode.

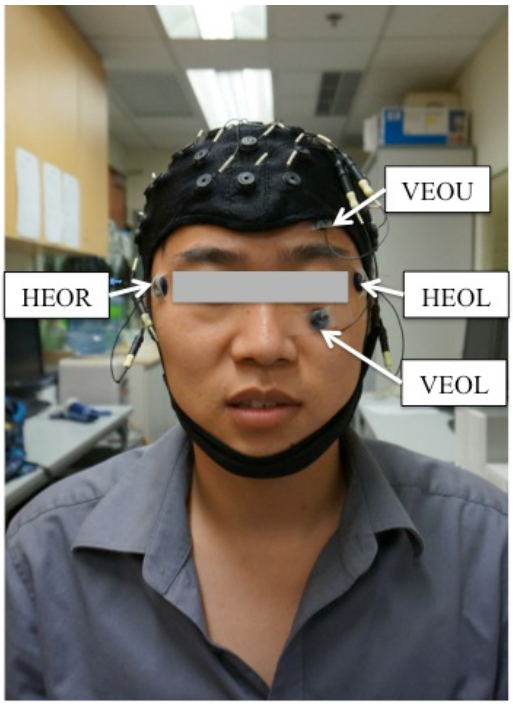


Figure 3. 7 Electrodes for captured signals associated with eye movements. The HEOR and HEOL were to capture the signals associated with horizontal eye movements, and the VEOU and VEOL were to capture the signals associated with vertical eye movements. HEOR: horizontal eletro-ocular right; HEOL: horizontal eletro-ocular left; VEOU: vertical eletro-ocular upper; and VEOL: vertical horizontal eletro-ocular upper.

Data Analysis

Behavioral data

Reaction time (ms, RT) of each trial of subject was measured from the onset of the visual cue to the time when the response pad was first pressed by the finger as stipulated in the visual cue. Mean RT was computed by collating the RT of all correct responses made by the subject. The RTs of trials of incorrect

responses or slower than 1300 ms were excluded from the analysis. The ACC of each of the CRT and SRT conditions was computed by dividing the number of trials with correct responses by the total number of trials for the condition.

Three-way repeated measures Analysis of Variance (ANOVA) with age (younger, older) as the between-subject factor and configuration (circle, square, diamond, triangle) and side (of hand; left, right) as the within-subject factors were conducted on the mean RT and ACC. To further evaluate subject's performance on the finger-tapping task, the time index (TI) [TI = mean RT/ mean ACC] was applied to the analyses; the TI was meant to minimize the speed-accuracy trade-off (SAT). The TI was computed for each of the visual cue conditions. Post-hoc comparisons on the two age groups, four visual cue conditions, and two sides of hand used t-tests or paired t-tests were used when significant interaction effects were found.

ERP and LRP

For ERP, epochs from 200 ms before (or -200 ms) and 1200 ms after the cue onsets were extracted for each of the four configuration conditions. The mean amplitudes of electrical activities between -200 ms and 0 ms at the onset of the visual cue formed the baseline. The P1, N1, and P3 components were identified using the peak amplitude method. The P1 and N1 signals elicited from the visual cues were obtained from the O1 and O2 sites. The P1 was identified as the most positive peak within the 40 to 140 ms time-window. The N1 was identified as the most negative peak within the 120 to 200 ms time-window

(Berchicci, Lucci, Pesce, Spinelli, & Di Russo, 2012; Falkenstein, Yordanova, & Kolev, 2006; Kolev, Falkenstein, & Yordanova, 2006; Salthouse, Babcock, & Shaw, 1991). The P3 was identified as the most positive deflection within the 260 to 700 ms time-window. The signals elicited at the midline electrodes, CPz was extracted. Three-way repeated measures ANOVA with age (younger, older) as the between-subject factor and Configuration (circle, square, diamond, triangle) and Site (O1, O2) as the within-subject factor was conducted on the left-right average amplitudes and latency of the P1 and N1 components. The reason for taking the average of the right and left sides was that previous literature did not reveal laterality differences. Three-way repeated measures ANOVA with Age x Configuration x Side (of hands; left, right) on amplitudes and latencies of P3 elicited at CPz site. The reason for selecting the CPz site was based on previous literature. Post-hoc comparisons were then conducted using t-tests or paired t-tests for significant interaction effects. The alpha level was set at 0.0125 after the Greenhouse-Geisser correction for all the post-hoc comparisons.

The LRP was defined from two different perspectives: cue-locked (s-LRP) and response-locked (r-LRP). The LRP reflects the difference between contralateral and ipsilateral potentials at the motor-related regions over scalp area, which is highly associated with activities of the corresponding hand. Right-hand responses corresponded to C3 minus C4 signals while left-hand responses corresponded to C4 minus C3 signals. Similarly, the baseline signals were those extracted from -200 ms to 0 ms at the onset of the visual cues. Latency of the s-

LRP was recorded when the negative waveform first crossed the x-axis. Time 0 of s-LRP was the onset latency of presentation of the visual cue. The r-LRP was obtained from contralateral motor cortex (C3 and C4).

In order to correct for the contamination effect of the event-related potentials, the baseline was defined as the electrical activities captured from -1200 ms to -1000 ms preceding the onset of execution of the response. The time '0' for r-LRP was defined as the onset latency when the first finger pressed on the button of the keypad in correct trials. Latency of s-LRP was defined as the negative-going waveform first cross the x axis. Analyses of s-LRP and r-LRP followed the statistical model used for that for P3, i.e. Age x Configuration x Side. The same alpha level was adopted for determining significance of all comparisons.

CHAPTER IV

Results

Performances in Finger Tapping Tasks

Table 4.1 summarizes the behavioral results of the finger tapping task. The reaction time was extracted for analysis only from the trials where tapping sequences were correctly performed (Figure 4.1). The interaction effect was significant for Configuration x Age [$F(3, 117)=9.31$, $p<0.001$] and Age x Side [$F(1, 39)=4.17$, $p=0.048$]. There were no significant interaction effects for Configuration x Side [$F(3, 117)=1.11$, $p=0.343$] or Configuration x Side x Age [$F(3, 117)=0.26$, $p=0.698$]. Post-hoc comparison indicated that among the younger group, the RT for the Diamond sequence was the longest (604.8 ± 109.2 ms) and that for the Circle sequence was the shortest (514.2 ± 65.0 ms). In contrast, among the older group, the RT for the Triangle sequence was the longest (990.9 ± 239.4 ms) and that for the Circle sequence was the shortest (732.6 ±150.2 ms). Figure 4.1 A shows the reaction time of four configurations for the different age groups. There were no significant differences between left (younger: 570.1 ± 91.9 ms; older: 576.3 ± 91.0 ms) and right hand-initiated (younger: 879.1 ± 192.4 ms; older: 850.6 ± 163.1 ms) tapping sequences in either the younger [$F(1, 19)=1.58$, $p=0.224$] or older [$F(1, 20)=3.21$, $p=0.088$] group (Figure 4.1 B). The main effects of Configuration [$F(3, 117)=40.79$, $p<0.001$] and Age [$F(1, 39) = 44.36$, $p<0.001$] on the RT were significant. The older subjects performed significantly slower than the younger subjects, reflected in

their RTs [older group (874±183.5 ms), younger group (562±88.9 ms)] [F(1,39)=42.95, p<0.001].

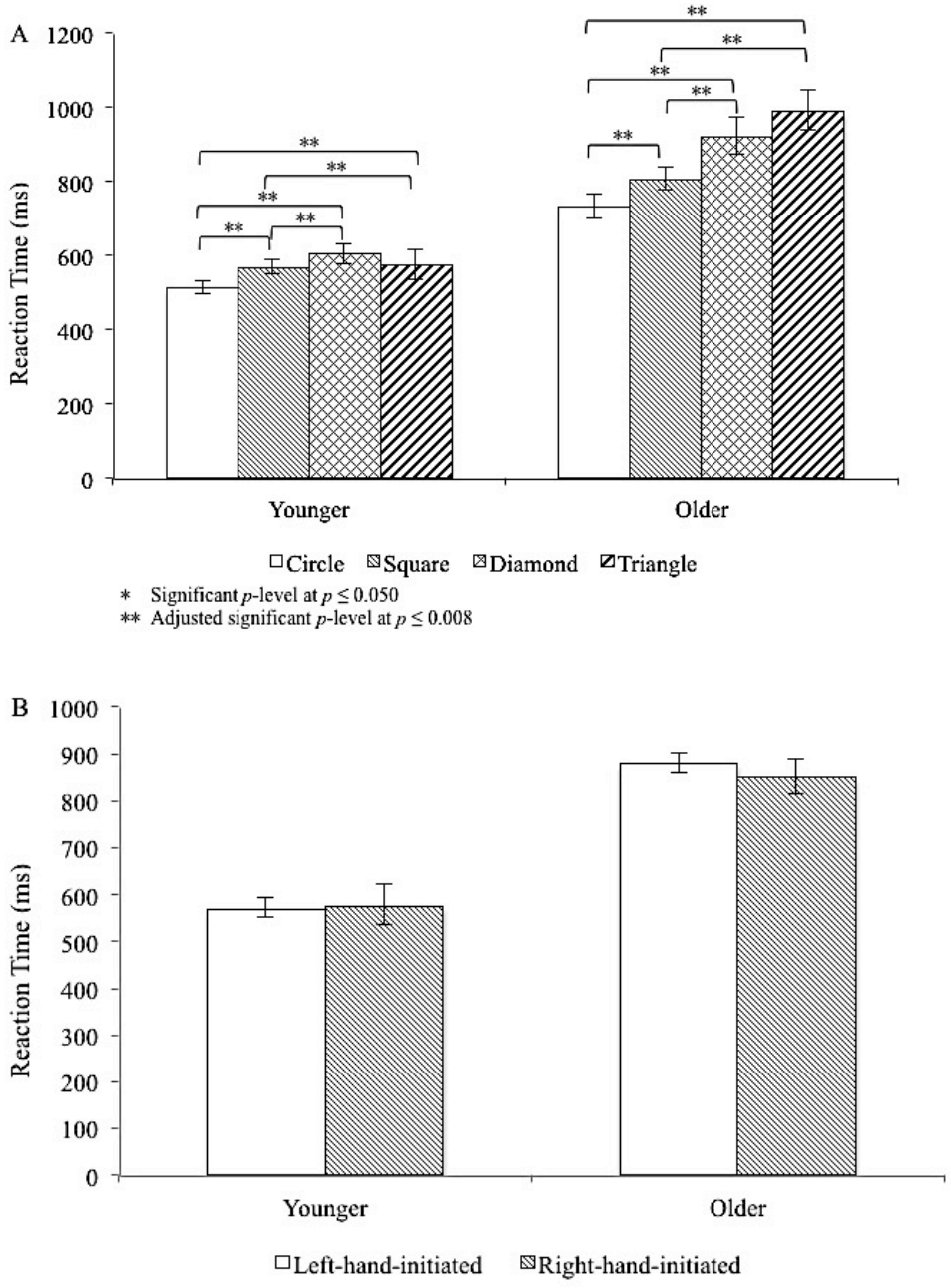


Figure 4.1 (A) results of reaction time in the four configurations of the different age groups; (B) results of reaction time of the younger and older groups for left and right hand-initiated sequences.

In terms of the accuracy rate, no significant interaction effects among the factors were found (all *p*s>0.061). The Configuration [F(3,117)=16.24, *p*<0.001] and Age [F(1,39)=7.52, *p*=0.009] effects on accuracy rate were significant however, while the Side effect was not statistically significant [F(1,39)=1.19, *p*=0.283]. The younger group (0.985±0.013) showed a significantly higher accuracy rate than the older group (0.961±0.037). Figure 4.2 shows the accuracy rate results in a bar chart.

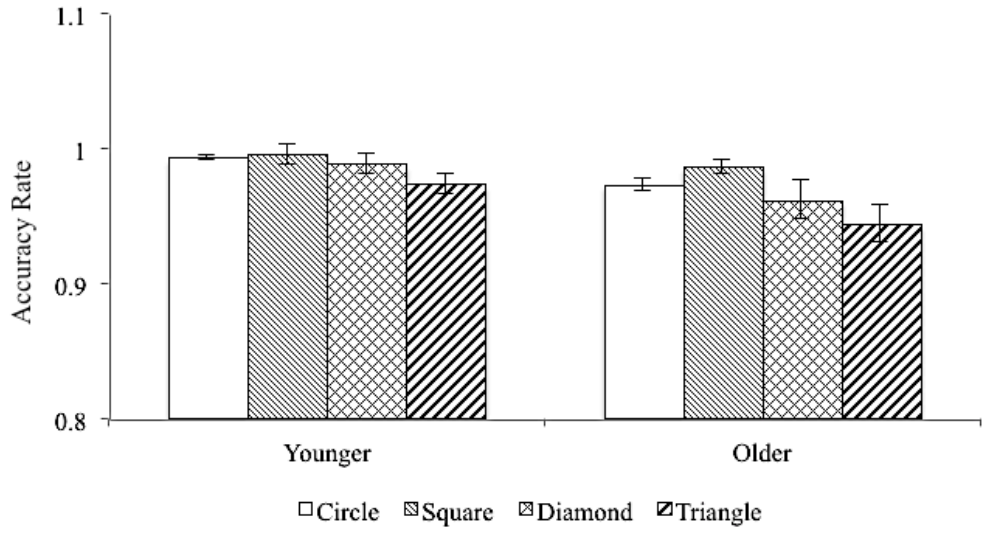
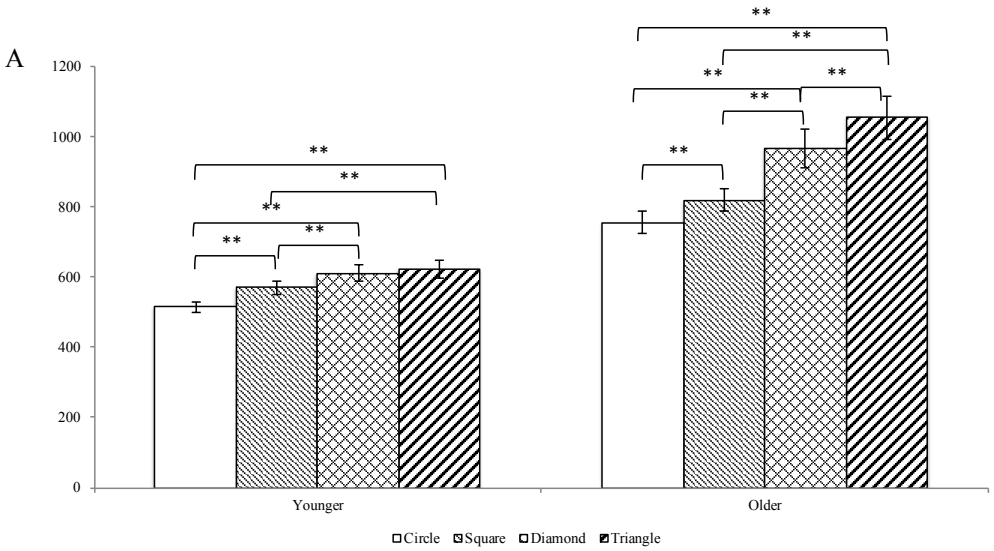


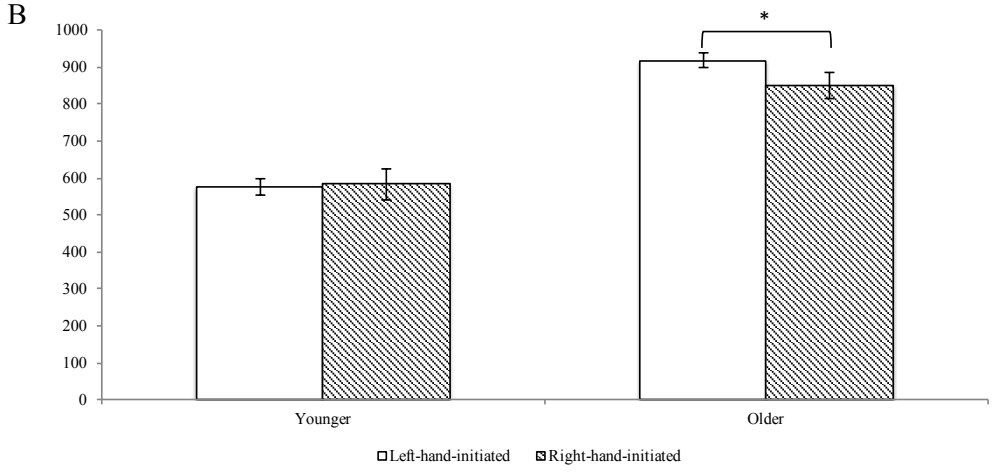
Figure 4.2 Accuracy rate results of the different age groups in the four configurations.

For the Time Index, the Age x Configuration [F(3,117)=11.25, *p*<0.001] and Age x Side [F(1,39)=4.24, *p*=0.046] interaction effects were significant. Post-hoc comparison suggested that, for the older group, the Time Index for the Triangle sequence was the longest, and significantly different than the three other sequences [F(1,20)=5.7 to 48.6, *p*<0.05]. For the younger group, the Time

Index for the triangle sequence was the longest and significantly different than those for the Circle and Square sequences [$F(1, 19)=23.9$ to 81.1, $p<0.001$]; no significant differences were found in the Time Indexes for the Diamond and Triangle sequences [$F(1,19)=3.6$, $p=0.073$] (Figure 4.3 A). The Time Index was shorter for the right hand-initiated sequence (882±175.9) than the left sequence (917±200.5) in the older group [$F(1, 20)=4.83$, $p=0.047$]; in the younger group, this pattern was reversed (left: 576±90.3 ms; right: 583±89.1 ms), but this difference did not reach statistical significance [$F(1, 19)=1.51$, $p=0.235$] (Figure 4.3 B). The Time Index of the left hand-initiated taps was longer than that of the right hand-initiated taps. The age effect on Time Index was found to be statistically significant [$F(1,39)=49.51$, $p<0.001$]. The Time Index of the younger group was significantly lower than that of the older group.



* Significant p-level at $p \leq 0.050$
** Adjusted significant p-level at $p \leq 0.008$



* Significant p-level at $p \leq 0.050$

Figure 4.3 A: the Time Index of both younger and older groups in four different configurations; B: comparison of left- and right-hand Time Indexes of both younger and older groups.

For the simple reaction tapping condition, the Age [$F(1,39)=28.10$, $p<0.001$] and Side [$F(1,39)=9.56$, $p=0.004$] effects were statistically significant. There was no significant interaction effect for Age x Side [$F(1,39)=1.69$, $p=0.201$]. The mean reaction time for the left-handed taps (older: 400±88.5 ms; younger: 268±63.6 ms) was significantly longer than that of the right-handed taps (older: 376±96.2 ms; younger: 258±51.8 ms) in both younger and older groups. The younger group (263±59.3 ms) also performed significantly faster than the older group (388±86.7 ms).

Table 4.1 Mean reaction time, accuracy rate, and time index for the first tap of the four movement sequences of the older and younger groups.

		Circle (SD)	Square (SD)	Diamond (SD)	Triangle (SD)	Mean (SD)
(A) Mean RT (ms)						
	L	502.6 (66.4)	572.1 (88.2)	604.6 (114.6)	600.7 (110.0)	570.0 (91.9)
Younger	R	522.7 (77.9)	564.7 (83.3)	605.1 (111.2)	613.6 (107.9)	576.3 (91.0)
	Mean	514.2 (70.1)	567.4 (84.3)	604.8 (112.1)	573.9 (172.3)	565.1 (92.9)
	L	740.7 (156.6)	828.9 (148.2)	936.3 (313.8)	1010.4 (253.0)	879.1 (192.4)
Older	R	729.2 (134.8)	784.7 (129.9)	916.3 (202.2)	972.2 (232.9)	850.6 (163.1)
	Mean	732.6 (143.7)	806.5 (137.1)	921.9 (219.8)	990.9 (239.4)	870.5 (174.4)
(B) Mean ACC						
	L	>0.99 (0.01)	>0.99 (0.01)	0.99 (0.01)	0.97 (0.03)	0.99 (0.01)
Younger	R	>0.99 (0.02)	>0.99 (0.01)	0.98 (0.02)	0.97 (0.02)	0.99 (0.01)
	Mean	>0.99 (0.01)	>0.99 (0.01)	0.99 (0.02)	0.97 (0.02)	0.99 (0.01)
	L	0.97 (0.04)	0.99 (0.02)	0.96 (0.04)	0.93 (0.05)	0.96 (0.03)
Older	R	0.97 (0.05)	0.98 (0.02)	0.96 (0.08)	0.96 (0.04)	0.97 (0.05)
	Mean	0.97 (0.05)	0.99 (0.02)	0.96 (0.06)	0.94 (0.04)	0.97 (0.04)
(3) Mean TI						
	L	504.8 (66.9)	574.2 (89.4)	610.3 (112.1)	616.3 (105.4)	576.4 (90.3)
Younger	R	525.4 (76.0)	565.6 (81.7)	611.4 (104.1)	629.5 (111.6)	583.0 (89.1)
	Mean	515.1 (69.0)	569.9 (84.5)	610.8 (107.5)	622.9 (106.5)	580.2 (89.8)
	L	761.2 (158.3)	844.7(149.2)	975.3(226.2)	1085.2(279.0)	916.6 (200.5)
Older	R	750.5 (143.2)	795.0(134.0)	959.5 (220.8)	1022.1 (263.4)	881.8(175.9)
	Mean	755.9(147.8)	819.9(138.9)	967.4(252.0)	1053.6(266.6)	899.2(183.5)

Results of EEG Data

P1-N1 components

The electrodes involved in the P1-N1 components were O1 and O2. Figure 4.6 shows an example of the P1-N1 component elicited from O1 and O2 separately (See Appendix IX for the P1-N1 component of each of the four configurations). Table 4.2 shows the mean peak amplitude and latency of P1 and N1 elicited in the different configurations. For the P1 latency, Age x Configuration [$F(3,117 = 0.83$, $p = 0.447$], Age x Site [$F(1, 39) = 2.27$, $p = 0.140$], Configuration x Site [$F(3,117) = 0.70$, $p = 0.498$], and Age x Configuration x Site [$F(3,117) = 0.40$, $p = 0.665$] were statistically insignificant. Significant Site effects [$F(1,39) = 15.45$, $p < 0.001$] were found on the P1 latency, which was significantly longer at O1 (95.3±18.4 ms) than that at O2 (88.7±16.4 ms) (Figure 4.4). The Age effect [$F(1,39) = 1.86$, $p = 0.180$] was not statistically significant. For the P1 peak amplitude, the main and interaction effects were not significant at O1 and O2 (all ps>0.320; see Appendix Table A4 for details).

For the N1 latency elicited at O1 and O2, no significant interaction effects were revealed (all ps>0.098; see Appendix Table A5 for details). The Age effect was significant [$F(1, 39) = 9.18$, $p = 0.004$]; the older group (181.3±19.9 ms) showed longer N1 latency than the younger group (164.4±16.6 ms) (Figure 4.5). No significant interaction or main effects were revealed on the amplitudes of N1 (all ps>0.264; see Appendix Table A6 for details).

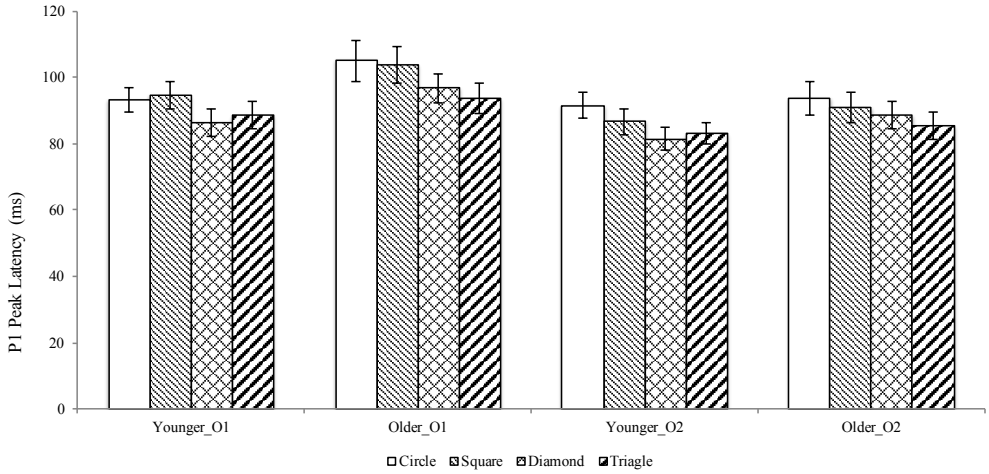


Figure 4.4 P1 peak latency of the four configurations for both younger and older groups at O1 and O2 sites.

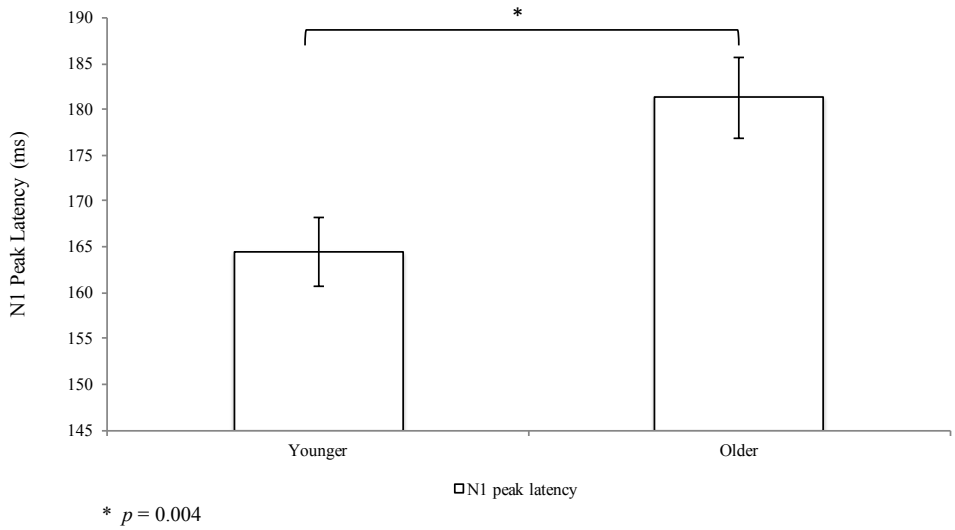
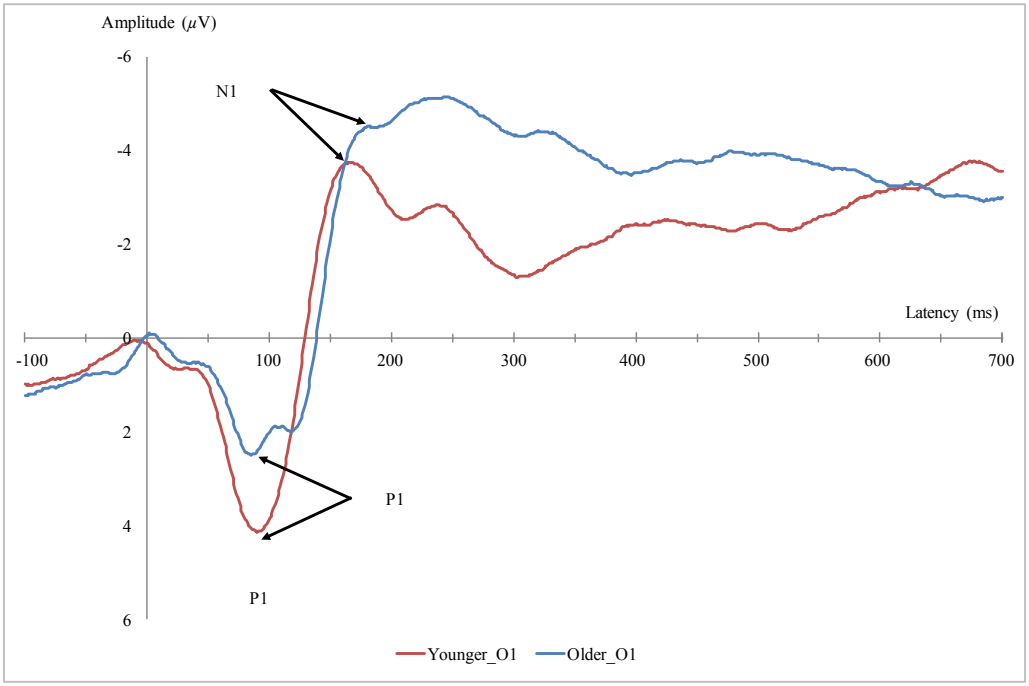


Figure 4.5 Comparison of N1 peak latency between the younger and older groups.



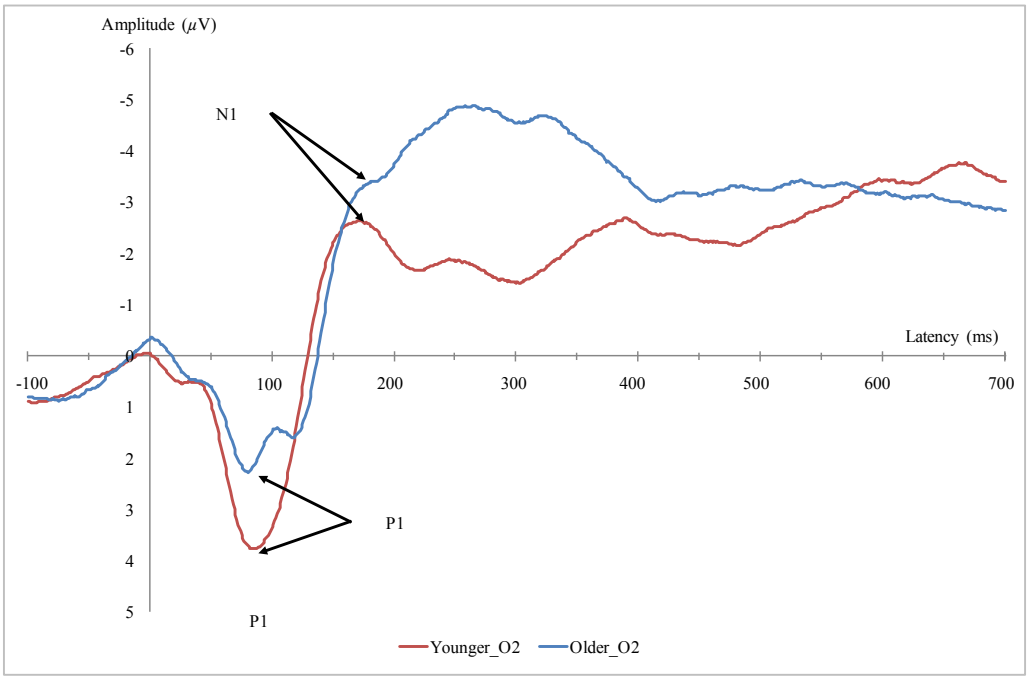


Figure 4.6 Grand-averaged waveform showing P1 and N1 elicited at O1 and O2 in the Circle condition for the younger and older groups. Red line: younger group; blue line: older group.

Table 4.2 Mean peak amplitude and latency of P1 and N1 elicited in different configuration conditions at O1 and O2 for the younger and older groups.

		Circle (SD)	Square (SD)	Diamond (SD)	Triangle (SD)	Mean (SD)
(A) Mean P1 peak latency (ms)						
	O1	93.3 (15.8)	94.4 (18.3)	86.4 (17.8)	88.7 (18.0)	90.7 (15.8)
Younger	O2	91.5 (17.0)	86.6 (17.8)	81.5 (14.6)	83.0 (14.2)	85.6 (14.5)
	Mean	92.4 (15.5)	90.4 (16.8)	83.9 (14.4)	85.8 (14.7)	88.1 (14.1)
	O1	104.9 (28.0)	103.7 (23.9)	96.7 (19.6)	93.7 (20.6)	99.7 (20.2)
Older	O2	93.8 (22.9)	91.0 (20.6)	88.5 (18.9)	85.4 (17.9)	89.7 (18.2)
	Mean	99.3 (22.2)	97.3 (20.4)	92.6 (17.4)	89.5 (17.3)	94.7 (18.1)
(B) Mean P1 peak amplitude (μV)						
	O1	4.30 (2.65)	4.39 (2.30)	3.83 (2.27)	4.04 (2.08)	4.14 (2.19)
Younger	O2	4.10 (2.51)	4.18 (2.43)	3.42 (2.40)	3.86 (2.34)	3.89 (2.38)
	Mean	4.20 (2.45)	4.28 (2.32)	3.62 (2.31)	3.95 (2.16)	4.02 (2.25)
	O1	3.72 (2.30)	3.90 (2.21)	3.53 (2.28)	3.43 (2.14)	3.64 (2.20)
Older	O2	3.25 (2.63)	3.01(3.14)	3.10 (2.57)	3.39 (2.40)	3.19 (2.58)
	Mean	3.49 (2.37)	4.46 (2.52)	3.31 (2.35)	3.41 (2.21)	3.42 (2.33)
(C) Mean N1 peak latency (ms)						
	O1	163.2 (13.3)	165.8 (18.5)	165.6 (15.8)	163.3 (19.5)	164.5 (15.8)
Younger	O2	164.4 (17.0)	166.0 (19.3)	164.0 (18.9)	163.4 (19.81)	164.4 (18.4)
	Mean	163.8 (14.1)	165.9 (18.3)	164.8 (16.7)	1163.3 (18.5)	164.4 (16.6)
	O1	182.2 (17.89)	183.9 (20.6)	181.3 (20.5)	183.9 (26.0)	182.8(19.7)
Older	O2	181.8 (21.39)	179.5 (22.6)	180.9 (21.4)	176.8 (24.5)	179.8 (20.7)
	Mean	182.0 (19.1)	181.7 (21.0)	181.1(20.7)	180.3 (24.4)	181.3 (19.9)

Table 4.2 Mean peak amplitude and latency of P1 and N1 elicited in different configuration conditions at O1 and O2 for the younger and older groups (cont.).

		Circle (SD)	Square (SD)	Diamond (SD)	Triangle (SD)	Mean (SD)
(D) Mean N1 peak amplitude (μV)						
	O1	-4.97 (3.44)	-4.50 (3.19)	-5.62 (3.75)	-4.98 (3.72)	-5.02 (3.43)
Younger	O2	-3.98 (3.17)	-3.76 (3.52)	-4.93 (4.08)	-4.46 (4.04)	-4.28 (3.63)
	Mean	-4.48 (3.14)	-4.13 (3.24)	-5.28 (3.80)	-4.72 (3.79)	-4.65 (3.43)
	O1	-5.90 (2.93)	-5.88 (2.93)	-5.62 (3.09)	-5.84 (2.92)	-5.84 (2.92)
Older	O2	-4.31 (2.83)	-4.62 (3.11)	-4.54 (2.85)	-5.40 (3.21)	-4.72 (2.56)
	Mean	-5.10 (2.69)	-5.25 (2.76)	-5.08 (2.73)	-5.69 (3.16)	-5.28 (2.59)

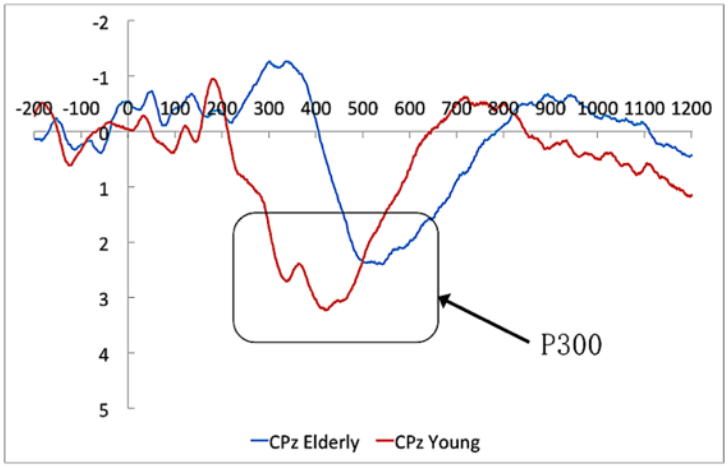
P3 Component

The electrodes involved in the P3 components were CPz. Figure 4.7 shows an example of the P3 component for both left-hand-initiated and right-hand-initiated tapping sequences (See Appendix X for the P3 component of each of the four configurations). No significant effects of Age x Configuration [$F(3,117)=2.77$, $p=0.061$], Age x Side [$F(1,39)=0.87$, $p=0.356$], Age x Configuration [$F(1,39)=1.64$, $p=0.192$], and Age x Configuration x Side [$F(1,39)=0.09$, $p=0.947$] were revealed on the latency of P3 elicited at CPz. The Configuration [$F(1,39)=3.04$, $p=0.046$] and Age [$F(1, 39)=7.56$, $p=0.009$] effects were also found to be significant on P3 latency at CPz (Figure 4.7 A). P3 latency was found to be longer for the Triangle condition than for the Circle [$F(1,39)=4.5$, $p=0.041$] and Square [$F(1,39)=4.1$, $p=0.049$] conditions, but not for the Diamond condition [$F(1,39)=1.1$, $p=0.308$]. The older group showed longer P3 latencies than the younger group (older: 502.0±77.8 ms; younger: 424.7±101.3 ms) (Figure 4.7 B). The Side effect [$F(1,39)=0.66$, $p=0.421$] on P3 latency was not statistically significant.

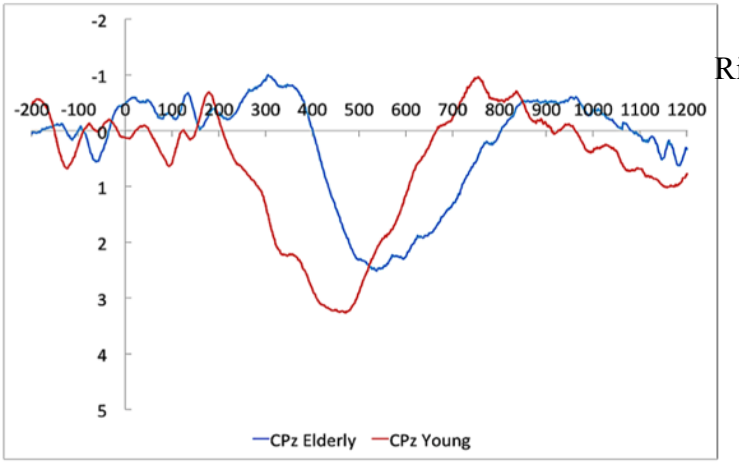
For the P3 peak amplitude, the Age x Side effects were statistically significant at CPz [$F(1,39)=4.74$, $p=0.036$] (Table 4.3). However, no significant effects were revealed for the other interaction effects: Age x Configuration [$F(3,117)=2.11$, $p=0.136$], Configuration x Side effects [$F(3,117)=0.25$, $p=0.854$], and Age x Configuration x Side [$F(3,117)=0.60$, $p=0.610$]. Post-hoc comparisons revealed that the amplitudes for the left hand-initiated movement

sequences (3.36 ± 1.81μV) were marginally more positive-going than those of the right hand (3.07±1.51μV) in the younger group [F(1,39)=3.79, p=0.066] (Figure 4.8 A). The Configuration [F(1,39)=23.17, p<0.001] and Age [F(1,39)=7.18, p=0.011] effects on the peak amplitude of P3 elicited at CPz were statistically significant. The P3 amplitudes of the left hand-initiated sequences (2.48±1.97μV) were less positive-going than those of the right hand-initiated sequences (2.44±1.67μV). The amplitudes of the older group (1.72±1.92μV) were significantly less positive-going than those of the younger group (3.22±1.63μV; see Figure 4.8 B). The P3 amplitudes were more positive-going for the Circle [F(1, 39)=10.9, p=0.002] and Square [F(1, 39)=10.4, p=0.003] than the Diamond condition. No significant Side effects were found [F(1,39)=0.01, p=0.995].

Figure 4.7 Grand-averaged P3 waveforms elicited at CPz in Circle configuration conditions for the younger and older groups. Red line: younger group; blue line: older group.



Left-hand-initiated



Right-hand-initiated

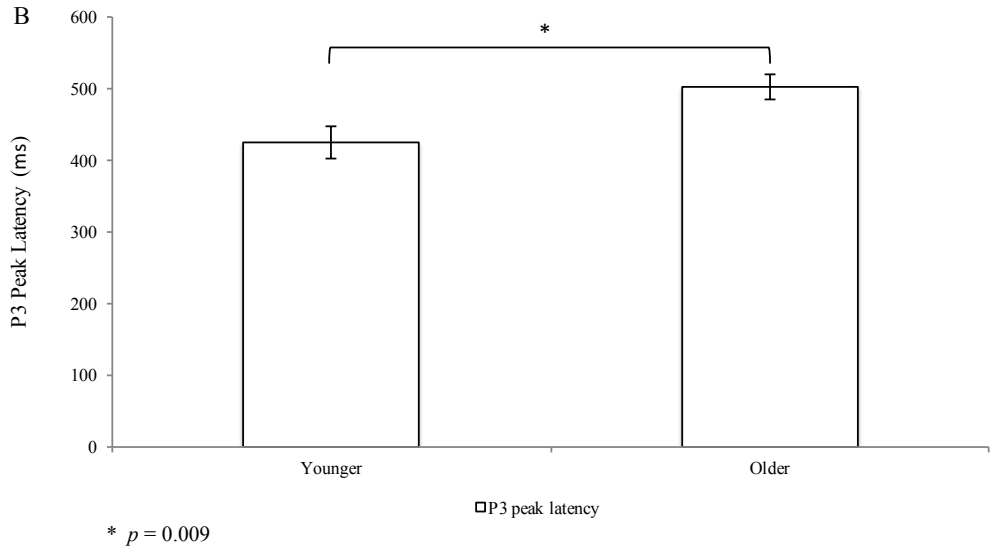
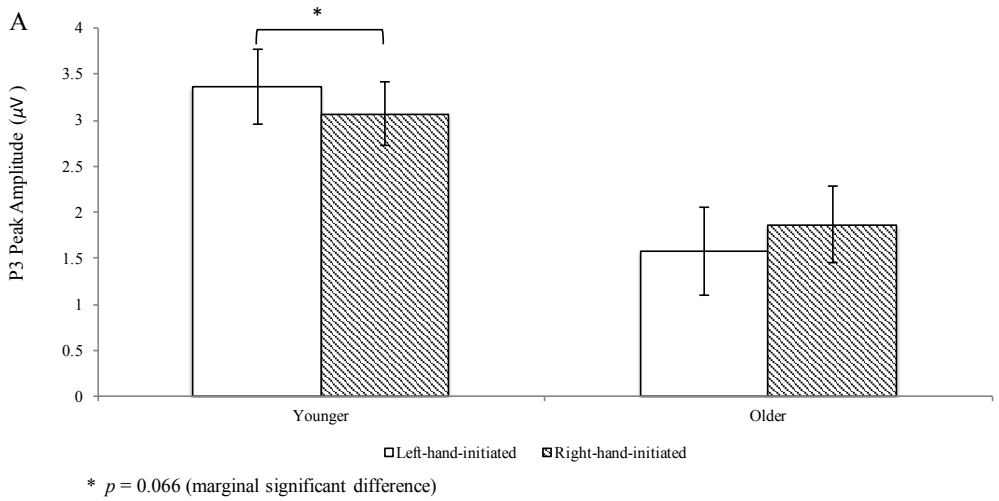


Figure 4.8 (A) P3 latency of different configuration conditions at CPz for the younger and older groups; (B) average P3 latency at CPz for the younger and older groups.



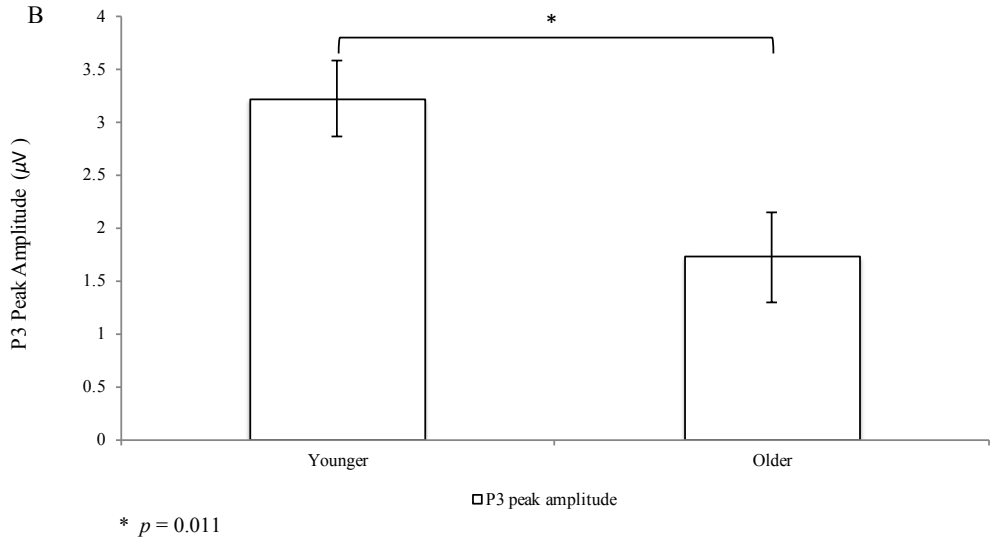


Figure 4.9 A: P3 peak amplitude of left and right hand-initiated tapping sequences for the younger and older groups at CPz; B: P3 peak amplitudes for the younger and older groups at CPz.

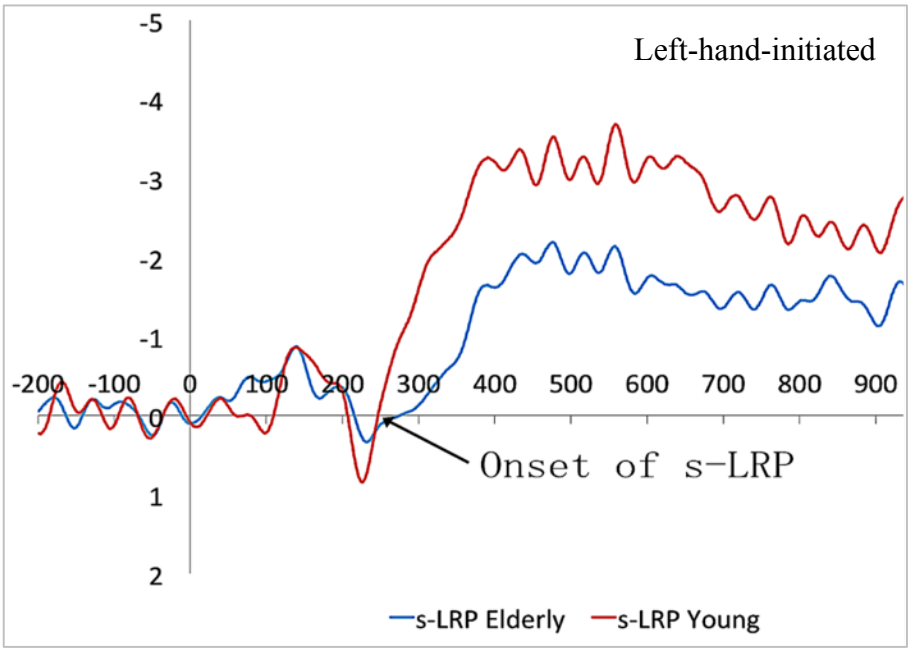
Table 4.3 Mean peak amplitude and latency of P3 elicited in different configuration conditions at CPz for the younger and older groups. L: left hand-initiated tapping sequences; R: right hand-initiated tapping sequences.

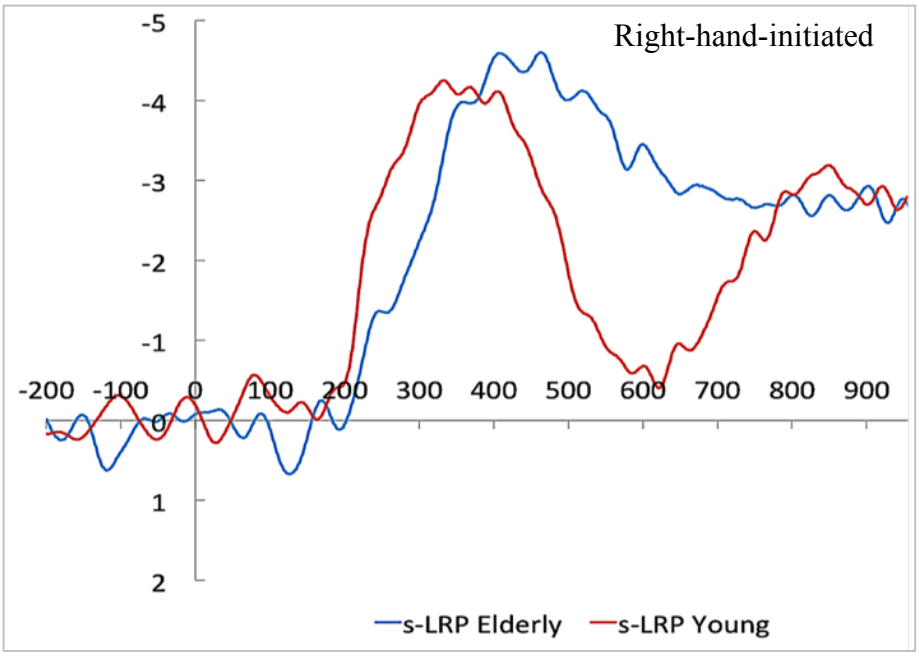
		Circle (SD)	Square (SD)	Diamond (SD)	Triangle (SD)	Mean (SD)
(A) Mean P3 peak latency (ms)						
	L	441.6 (94.6)	412.2 (116.6)	412.0 (139.8)	435.1 (142.2)	425.1 (105.4)
Younger	R	447.1 (99.6)	414.0 (117.9)	424.8 (131.1)	411.4 (135.1)	424.3 (100.2)
	Mean	444.1 (90.4)	413.1 (108.3)	418.4 (132.7)	423.2 (134.6)	424.7 (101.3)
	L	509.0 (139.2)	535.5 (104.2)	472.7 (116.3)	467.9 (111.3)	496.3 (80.9)
Older	R	533.0 (76.0)	539.9 (106.0)	506.7 (114.1)	451.6 (119.8)	508.8 (81.9)
	Mean	521.0 (89.9)	537.7 (98.4)	489.1 (97.7)	459.8 (106.9)	502.0 (77.8)
(B) Mean P3 peak amplitude (μV)						
	L	4.29 (1.84)	3.13 (2.06)	3.15 (1.82)	2.88 (2.17)	3.37 (1.81)
Younger	R	4.05 (1.56)	2.89 (1.64)	2.90 (1.76)	2.44 (1.92)	3.07 (1.51)
	Mean	4.17 (1.60)	3.01 (1.77)	3.02 (1.73)	3.07 (1.51)	3.22 (1.63)
	L	3.16 (2.03)	1.70 (2.26)	1.06 (2.67)	0.39 (3.03)	1.58 (2.14)
Older	R	3.22 (1.87)	2.11 (2.08)	1.36 (2.25)	0.79 (2.53)	1.87 (1.82)
	Mean	3.19 (1.79)	1.90 (2.10)	1.21 (2.39)	0.59 (2.72)	1.72 (1.92)

Response selection: s-LRP onset

Figure 4.10 shows an example of the s-LRP for both left-hand-initiated and right-hand-initiated tapping sequences (See Appendix XI for the s-LRP of each of the four configurations). The Age x Configuration [$F(3,117)=0.14$, $p=0.918$], Age x Side [$F(1,39)=0.25$, $p=0.617$], Configuration x Side [$F(3,117)=0.40$, $p=0.734$], and Age x Configuration x Side [$F(3,117)=0.94$, $p=0.415$] effects on the onset latencies of s-LRP were not statistically significant (Figure 4.9 and Table 4.4). The Age [$F(1, 39)=1.08$, $p=0.304$], Side [$F(1, 39)=0.79$, $p=0.378$], and Configuration [$F(3, 117)=0.38$, $p=0.734$] effects were also statistically insignificant. Figure 4.10 shows the mean onset latencies and mean peak amplitudes on s-LRP for both groups in bar chart form.

Figure 4.10 Grand-averaged s-LRP in Circle configuration conditions for the younger and older groups. Red line: younger group; blue line: older group.





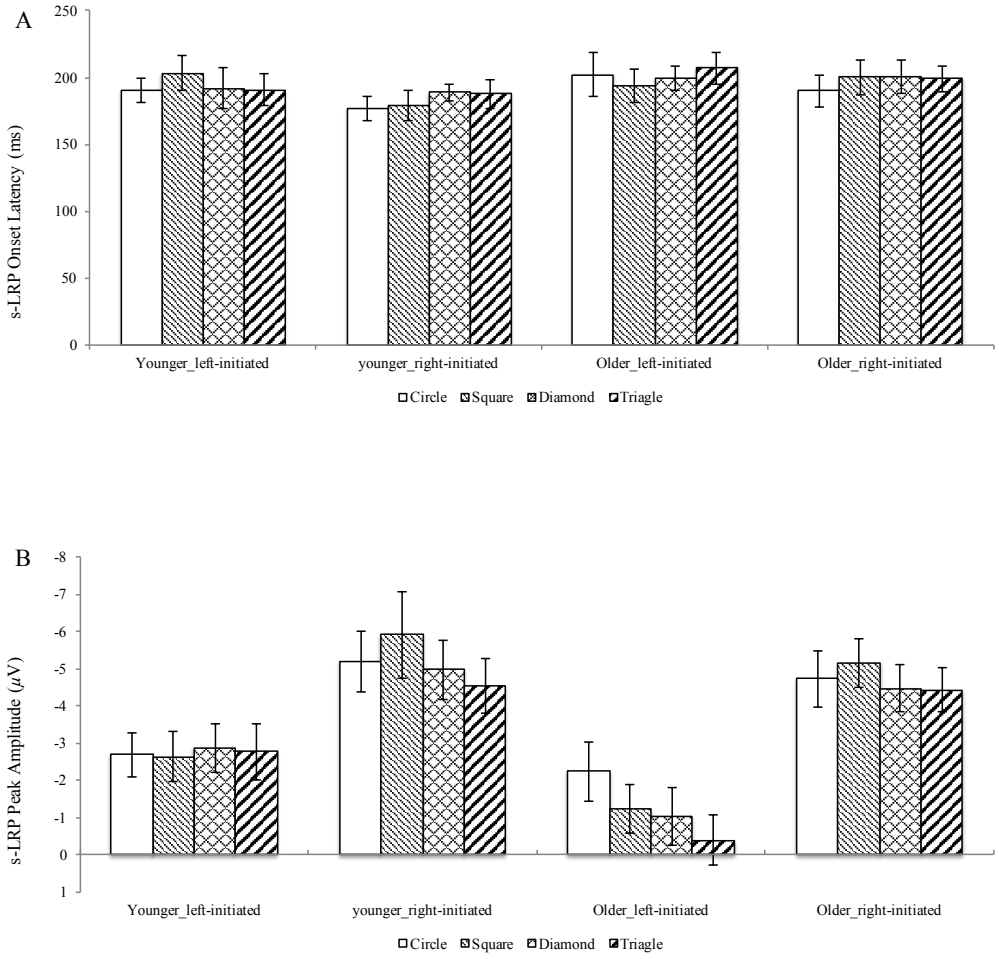


Figure 4.11 (A) mean onset latency of s-LRP and (B) mean peak amplitude of s-LRP of four configuration conditions for both left and right hand-initiated tapping sequences in the older and younger groups.

For the s-LRP peak amplitude, the Age x Configuration [$F(3,117)=1.36$, $p=0.261$], Age x Side [$F(1,39)=0.42$, $p=0.521$], Configuration x Side [$F(3,117)=1.75$, $p=0.172$], and Age x Configuration x Side [$F(3,117)=1.94$, $p=0.139$] effects were not statistically significant. The Configuration [F(3,

117)=4.65, p=0.005] and Side [F(1, 39)=13.1, p=0.001] effects were statistically significant. The amplitudes elicited in the Circle [F(1, 40)=10.67, p=0.002] and Square [F(1, 40)=10.73, p=0.002] configuration conditions were significantly more negative-going than that in the Diamond condition. The mean amplitudes elicited in the right hand-initiated tapping sequences were significantly more negative-going than those elicited in the left hand-initiated tapping sequences (left: -2.08±2.92 μV; right: -4.93±3.21 μV).

Table 4.4 Mean onset latencies and mean peak amplitude of s-LRP elicited in different configuration conditions for the younger and older groups. L: left hand-initiated tapping sequences; R: right hand-initiated tapping sequences.

		Circle (SD)	Square (SD)	Diamond (SD)	Triangle (SD)	Mean (SD)
(A) Mean s-LRP onset latency (ms)						
	L	190.9 (40.8)	203.1 (58.7)	191.9 (67.2)	190.9 (54.2)	194.2 (40.3)
Younger	R	177.0 (40.3)	178.9 (51.3)	188.8 (27.1)	187.8 (47.8)	183.1 (36.0)
	Mean	183.9 (25.7)	191.0 (41.0)	190.4 (42.6)	189.3 (41.6)	188.6 (30.8)
	L	201.9 (73.1)	194.0 (53.7)	199.6 (42.6)	207.1 (54.9)	200.6 (41.9)
Older	R	190.0 (54.7)	200.4 (58.1)	200.7 (56.9)	199.1 (44.6)	197.5 (44.9)
	Mean	195.2 (44.4)	197.2 (40.9)	200.1 (41.8)	203.1 (42.8)	199.1 (33.3)
(B) Mean s-LRP peak amplitude (μV)						
	L	-2.69 (2.69)	-2.64 (2.99)	-2.87 (2.92)	-2.77 (3.29)	-2.74 (2.86)
Younger	R	-5.20 (3.69)	-5.92 (5.23)	-4.98 (3.54)	-4.54 (3.35)	-5.16 (3.66)
	Mean	-3.94 (1.79)	-4.28 (2.72)	-3.92 (1.68)	-3.66 (1.56)	-3.95 (1.82)
	L	-2.24 (3.57)	-1.23 (2.92)	-1.02 (3.46)	-0.40 (2.94)	-1.22 (2.86)
Older	R	-4.73 (3.36)	-5.14 (2.91)	-4.47 (2.83)	-4.43 (2.68)	-4.69 (2.79)
	Mean	-3.49 (2.07)	-3.19 (1.30)	-2.74 (1.62)	-2.42 (1.42)	-2.96 (1.36)

Motor related processes: r-LRP

Figure 4.12 shows an example of the mean onset latencies and peak amplitudes of r-LRP for the left hand- and right hand-initiated-response of the younger and older groups. For the r-LRP onset latency, only the Side x Age [$F(1, 39)=5.21$, $p=0.028$; see Figure 4.12] effect was statistically significant, whereas the Age x Configuration [$F(3, 117)=51.14$, $p=0.331$], Configuration x Side [$F(3, 117)=0.25$, $p=0.853$], and Age x Configuration x Side [$F(3, 117)=1.04$, $p=0.374$] effects were all statistically insignificant. Post-hoc comparisons revealed that the onset latency for the r-LRP was significantly shorter in the left hand-initiated (-764.6±116.6 ms) than in the right hand-initiated response condition (-692.6 ± 140.8 ms) in the younger group [$F(1, 19)=7.01$, $p=0.016$]. On the other hand, in the older group, no significant differences in the onset latency of r-LRP were found between the left and right hand conditions [$F(1, 20)=0.19$, $p=0.670$; left-initiated: -777.4±100.5 ms; right-initiated: -787.7±136.1 ms]. The Age [$F(1, 39)=2.45$, $p=0.125$], Configuration [$F(3, 117)=0.42$, $p=0.689$] and Side [$F(1, 39)=2.92$, $p=0.095$] effects on the onset latency of r-LRP were all statistically insignificant.

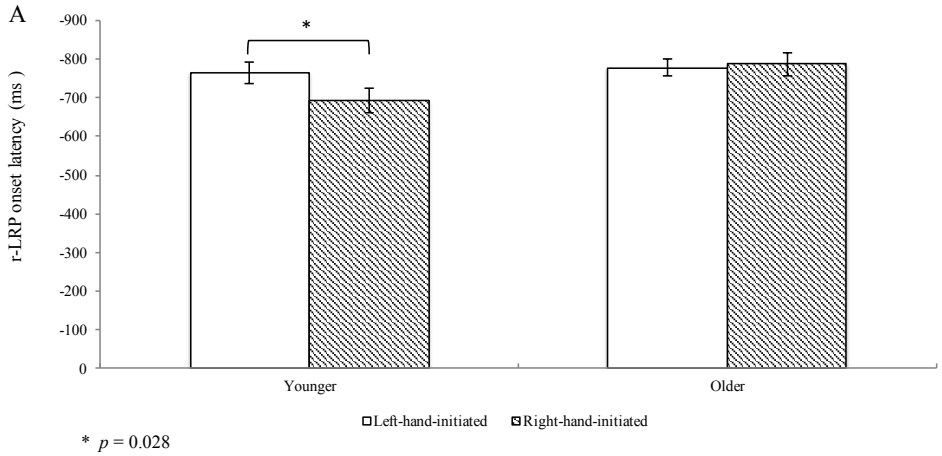


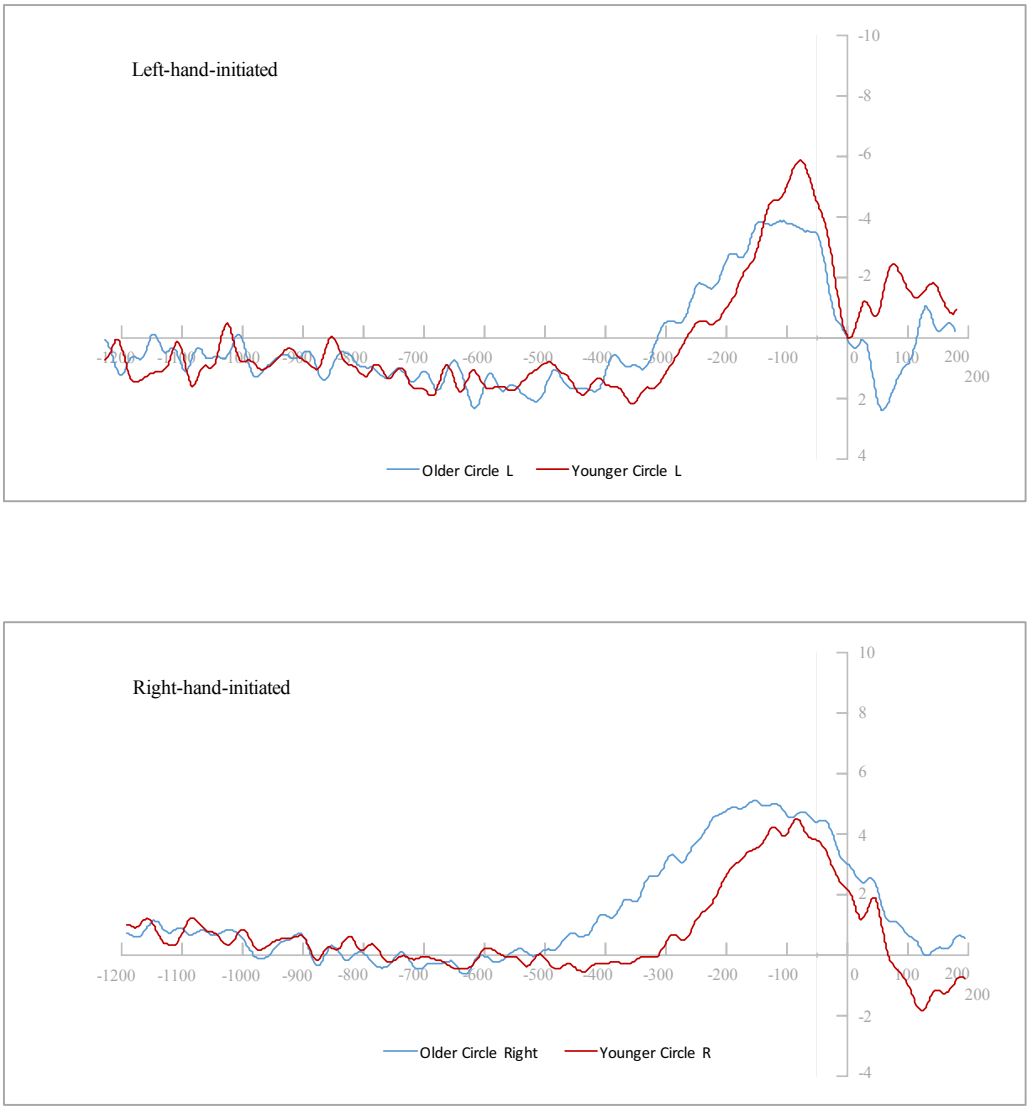
Figure 4.12 Mean latency of r-LRP for left and right hand-initiated response conditions for the younger and older groups.

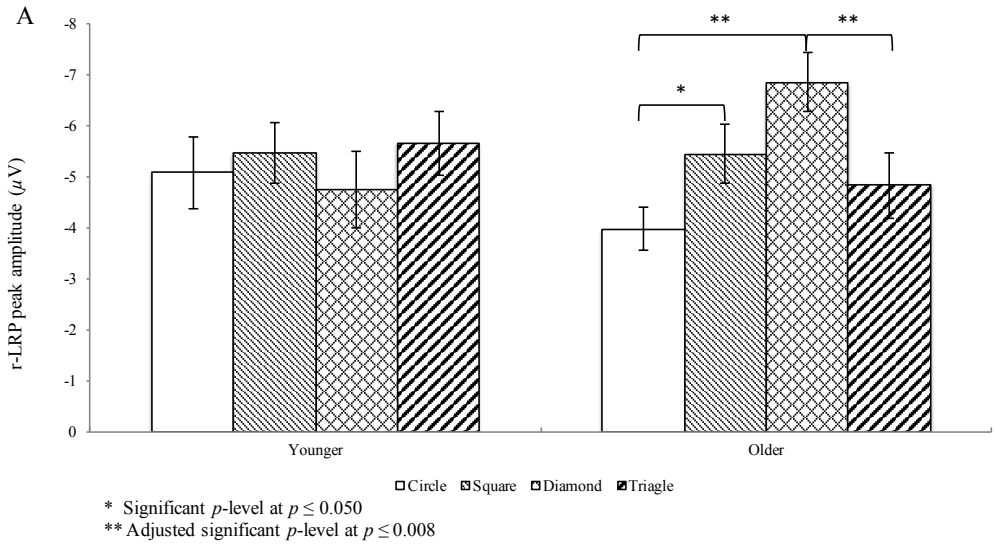
For the peak amplitude of r-LRP, the Configuration x Age [F(3, 117)=3.31, p=0.026] and Configuration x Side [F(3, 117)=5.84, p=0.001] effects were statistically significant (Figure 4.13 A and B). The Age x Side [F(1, 39)=2.45, p=0.126] and Age x Configuration x Side [F(3, 117)=0.40, p=0.750] effects were not statistically significant. The Side effects [F(1, 39)=11.84, p=0.001] were statistically significant but the Age [F(1, 39)=0.009, p=0.925] and Configuration [F(3, 117)=1.81, p=0.155] effects on the peak amplitude of the r-LRP were not statistically significant.

Post-hoc comparison revealed that the mean peak amplitudes of r-LRP were significantly more negative-going in the right hand-initiated response condition (-6.48±3.27μV) than those in the left hand-initiated response condition (-4.03 ± 2.29μV). For the younger group, no significant differences on the peak amplitudes were elicited in the different configuration conditions [F(3, 57)=0.42,

p=0.704; Circle: -5.08±3.16 μV; Square: -5.46±2.64 μV; Diamond: -4.74±3.34 μV; T:-5.65±2.84 μV]. In contrast, for the older group, the peak amplitude of the Circle condition (-3.98±1.90 μV) was more negative-going than that of the Square [-5.45±2.58 μV; F(1, 20)=4.02, *p*=0.050] and Diamond (-6.85±2.60 μV) [F(1, 20)=20.22, *p*<0.001] conditions, and the peak amplitude of the Diamond condition was more negative-going than that of the Triangle condition (-4.83±2.90 μV) [F(1, 20)=15.31, *p*=0.001]. For the left hand-initiated response condition, no significant differences in the peak amplitudes of r-LRP were found among the four configuration conditions [F(3, 117)=1.15, *p*=0.332; Circle: -4.40±4.07 μV; Square: -3.16±4.20 μV; Diamond: -4.08±3.25 μV; Triangle: -4.48±4.17 μV]. For the right hand-initiated response condition, the peak amplitude of the Circle condition (-4.63±3.10 μV) was less negative-going than that of the Square [-7.76±4.85 μV; F(1, 39)=11.68, *p*=0.001] and Diamond conditions [-7.57±5.08 μV; F(1, 39)=15.13, *p*<0.001], and the peak amplitude of the Triangle condition (-5.98±4.81 μV) was more negative than that of the Square [F(1, 39)=5.41, *p*=0.025] and Diamond conditions [F(1, 39)=4.27, *p*=0.045].

Figure 4.12 Grand-averaged r-LRP in Circle configuration conditions for the younger and older groups. Red line: younger group; blue line: older group.





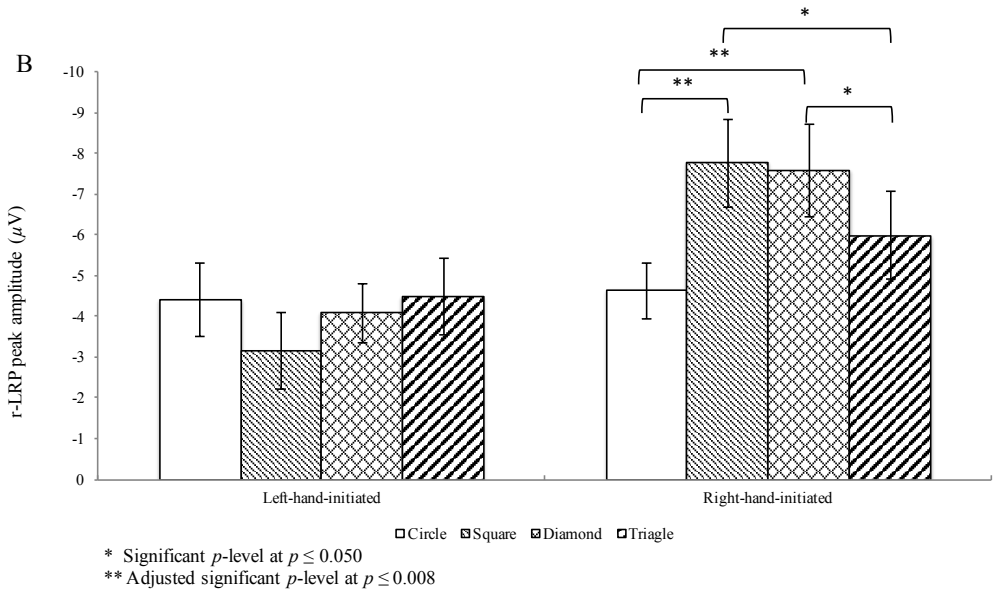


Figure 4.13 (A) mean peak amplitude of r-LRP in the four configuration conditions for the younger and older groups; (B) mean peak amplitude of r-LRP in the four configuration conditions for the left and right hand-initiated response conditions.

Table 4.5 Mean onset latencies and mean peak amplitudes of r-LRP in different configuration conditions for the younger and older groups.

		Circle (SD)	Square (SD)	Diamond (SD)	Triangle (SD)	Mean (SD)
(A) Mean r-LRP onset latency (ms)						
	L	-761.7 (188.9)	-794.7 (127.0)	-783.3 (177.2)	-718.9 (287.1)	-764.6 (116.6)
Younger	R	-724.1 (204.7)	-699.4 (249.9)	-677.2 (177.4)	-669.7 (206.6)	-692.6 (140.8)
	Mean	-742.9 (133.8)	-747.0 (166.2)	-730.2 (156.5)	-692.3 (227.6)	-728.6 (114.0)
	L	-772.7 (149.5)	-781.9 (143.9)	-765.9 (157.7)	-789.0 (162.6)	-777.4 (100.5)
Older	R	-724.3 (215.6)	-823.0 (166.2)	-783.7 (224.6)	-819.7 (138.3)	-787.7 (136.1)
	Mean	-748.5 (165.0)	-802.4 (132.7)	-774.8 (141.4)	-804.3 (109.9)	-782.5 (106.4)
(B) Mean r-LRP peak amplitude (μV)						
	L	-5.85 (4.58)	-3.82 (2.97)	-3.40 (3.03)	-5.21 (3.03)	-4.57 (2.02)
Younger	R	-4.30 (3.48)	-7.09 (4.81)	-6.08 (4.76)	-6.09 (5.36)	-5.89 (3.49)
	Mean	-5.08 (3.16)	-5.46 (2.64)	-4.74 (3.34)	-5.65 (2.84)	-5.23 (1.76)
	L	-3.02 (3.01)	-2.53 (5.10)	-4.73 (3.38)	-3.79 (5.01)	-3.52 (2.46)
Older	R	-4.94 (2.74)	-8.38 (4.93)	-8.98 (5.08)	-5.88 (4.53)	-7.04 (3.02)
	Mean	-3.98 (1.90)	-5.45 (2.58)	-6.85 (2.60)	-4.83 (2.90)	-5.28 (1.57)

Correlation and Regression Analysis of Different EEG components and Reaction Time

Correlation and single/multiple regression analyses were conducted to examine the relationship between P1 peak latency, and/or N1 peak latency, and/or P3 peak latency, and/or r-LRP onset latency, and/or s-LRP onset latency for different finger tapping conditions.

For left-hand initiated Circle conditions, reaction time was positively and significantly correlated with N1 peak latency (r=0.513, p=0.001). A significant regression equation was found (p = 0.001), with an R^2 of 0.264. Participants' predicted response time is equal to -197.021 + 4.750 (N1). N1 peak latency (p = 0.001) was significant predictor of response time (Table 4.6). For right-hand initiated Circle conditions, reaction time was positively and significantly correlated with N1 peak latency (r= 0.490, p = 0.001). A significant regression equation was found (p = 0.0011), with an R^2 of 0.240. Participants' predicted response time is equal to -49.244 + 3.975 (N1). N1 peak latency (p = 0.001) was significant predictor of response time (Table 4.7).

For left-hand initiated Square conditions, reaction time was positively and significantly correlated with N1 peak latency (r=0.457, p=0.003). A significant regression equation was found (p = 0.003), with an R^2 of 0.209. Participants' predicted response time is equal to 34.053 + 3.836 (N1). N1 peak latency (p = 0.003) was significant predictor of response time (Table 4.8). For right-hand initiated Square conditions, reaction time was positively and

significantly correlated with P1 peak latency (r=0.436, p=0.004). A significant regression equation was found (p = 0.004), with an R^2 of 0.190. Participants' predicted response time is equal to 116.404 + 3.211 (P1). P1 peak latency (p = 0.004) was significant predictor of response time (Table 4.9).

For left-hand initiated Diamond conditions, reaction time was positively and significantly correlated with P1 peak latency (r=0.384, p=0.013) and N1 peak latency (r=0.453, p=0.003), and negatively and significantly correlated with r-LRP onset latency (r=-0.309, p=0.050). A significant regression equation was found (p = 0.003), with an R^2 of 0.228. Participants' predicted response time is equal to -403.399 + 5.665(N1). N1 peak latency (p = 0.031) was significant predictor of response time, and P1 peak latency (p=0.409) was insignificant predictor of response time (Table 4.10). For right-hand initiated Diamond conditions, reaction time was positively and significantly correlated with P1 peak latency (r=0.355, p=0.023) and N1 peak latency (r=0.463, p=0.002). A significant regression equation was found (p = 0.005), with an R^2 of 0.291. N1peak latency (p=0.218), P1 peak latency (p=0.093), r-LRP onset latency (p=0.081) were insignificant predictors of response time (Table 4.11).

For left-hand initiated Triangle conditions, reaction time was positively and significantly correlated with N1 peak latency (r=0.463, p=0.002). A significant regression equation was found (p = 0.002), with an R^2 of 0.214. Participants' predicted response time is equal to -107.781 + 5.304 (N1). N1 peak latency (p = 0.002) was significant predictor of response time of response time (Table 4.12). For right-hand initiated Triangle conditions, reaction time was

positively and significantly correlated with N1 peak latency (r=0.485, p=0.001), and negatively and significantly correlated with r-LRP onset latency (r=-0.433, p=0.005). A significant regression equation was found ($p < 0.001$), with an R^2 of 0.361. Participants' predicted response time is equal to -339.880 + 4.466 (N1)-0.488 (r-LRP). N1 peak latency ($p = 0.003$) and r-LRP ($p = 0.010$) onset latency were significant predictors of response time (Table 4.13).

Table 4.6 Summary correlations and results from the single regression analysis of N1 and reaction time for left-hand initiated Circle conditions

EEG components	Correlation with reaction time		Single Regression Weights	
	r	*p*	b	β
P1 peak latency	0.159	0.322	/	/
N1 peak latency	0.513	0.001	-197.021	0.513
P3 peak latency	0.146	0.363	/	/
r-LRP onset latency	0.078	0.627	/	/
s-LRP onset latency	0.061	0.717	/	/

Table 4.7 Summary correlations and results from the single regression analysis of N1 and reaction time for right-hand initiated Circle conditions

EEG components	Correlation with reaction time		Single Regression Weights	
	r	*p*	b	β
P1 peak latency	0.235	0.139	/	/
N1 peak latency	0.490	0.001	-49.244	0.490
P3 peak latency	0.188	0.239	/	/
r-LRP onset latency	0.075	0.641	/	/
s-LRP onset latency	0.000	1.000	/	/

Table 4.8 Summary correlations and results from the single regression analysis of N1 and reaction time for left-hand initiated Square conditions

EEG components	Correlation with reaction time		Single Regression Weights	
	r	*p*	b	β
P1 peak latency	0.250	0.115	/	/
N1 peak latency	0.457	0.003	34.053	0.457
P3 peak latency	0.241	0.128	/	/
r-LRP onset latency	0.009	0.956	/	/
s-LRP onset latency	-0.120	0.454	/	/

Table 4.9 Summary correlations and results from the single regression analysis of N1 and reaction time for right-hand initiated Square conditions

EEG components	Correlation with reaction time		Single Regression Weights	
	r	*p*	b	β
P1 peak latency	0.436	0.004	116.404	0.436
N1 peak latency	0.249	0.117	/	/
P3 peak latency	0.300	0.056	/	/
r-LRP onset latency	-0.277	0.079	/	/
s-LRP onset latency	0.032	0.842	/	/

Table 4.10 Summary correlations and results from the multiple regression analysis for left-hand initiated Diamond conditions

EEG components	Correlation with reaction time		Multiple Regression Weights	
	r	*p*	B	β
P1 peak latency	0.355	0.023	2.184	0.143
N1 peak latency	0.463	0.002	5.655	0.383
P3 peak latency	0.238	0.134	/	/
r-LRP onset latency	-0.095	0.555	/	/
s-LRP onset latency	0.003	0.983	/	/

Table 4.11 Summary correlations and results from the multiple regression analysis for right-hand initiated Diamond conditions

EEG components	Correlation with reaction time		Multiple Regression Weights	
	r	*p*	b	β
P1 peak latency	0.384	0.013	2.689	0.210
N1 peak latency	0.453	0.003	3.461	0.293
P3 peak latency	0.198	0.215	/	/
r-LRP onset latency	-0.309	0.050	-0.300	-0.252
s-LRP onset latency	-0.065	0.687	/	/

Table 4.12 Summary correlations and results from the single regression analysis for left-hand initiated Triangle conditions

EEG components	Correlation with reaction time		single Regression Weights	
	r	*p*	b	β
P1 peak latency	0.185	0.246	/	/
N1 peak latency	0.463	0.002	5.304	0.463
P3 peak latency	0.126	0.432	/	/
r-LRP onset latency	-0.198	0.214	/	/
s-LRP onset latency	0.227	0.153	/	/

Table 4.13 Summary correlations and results from the multiple regression analysis for right-hand initiated Triangle conditions

EEG components	Correlation with reaction time		Multiple Regression Weights	
	r	*p*	b	β
P1 peak latency	0.266	0.092	/	/
N1 peak latency	0.485	0.001	4.466	0.422
P3 peak latency	0.195	0.221	/	/
r-LRP onset latency	-0.433	0.005	-0.488	-0.360
s-LRP onset latency	0.097	0.546	/	/

CHAPTER V

Discussion

This chapter summarizes findings of the study. The mental processes associated with four finger-tapping sequences (Circle: single tapping with one finger, Square: repeated tapping with one finger, Diamond: alternate finger-tapping with the same hand, and Triangle: alternate hand finger-tapping) with reference the behavioral and electrophysiological results are discussed. The age-related slowness revealed from the tapping sequences will be addressed. This chapter will end with implications of the results.

Summary of Results

The response times of older participants were in general slower than those of the younger participants. Among the configuration conditions, the alternate hand finger-tapping sequence (Triangle) were the longest for the older group, whereas alternate tapping of fingers with the same hand were the longest for the younger participants (Diamond). Older participants had significantly lower accuracy rates than their younger counterparts in all tapping sequences. The alternate hand finger-tapping (Triangle) had the lowest accuracy rate, followed by the alternate tapping of fingers with the same hand (Diamond), repeated-tapping with one finger (Square), and single-tapping with one finger (Circle). Both the younger and older groups shared similar pattern of the accuracy on the tasks. The time index, an index adjusted for task accuracy, suggested that older participants had lower performance (higher

time index) for the tapping initiated by the left hand than that for the right hand.

The major results on P1-N1are that the latency of N1 showed aging effect with the older participants had longer N1 latency than the younger participants at both O1 and O2 sites. Similarly, the older participants also had longer P3 latency than the younger participants at the CPz site. Differences in the P3 latencies at CPz were found across the four configuration conditions with the longest for the alternate hand finger-tapping and shortest for the one-finger repeated tapping and single-tap with one finger sequences. The older participants showed less positive-going P3 amplitudes at CPz in all configuration conditions than the younger participants. The most positive-going P3 amplitudes at CPz were found in the one-finger repeated tapping and single-tap with one finger sequences, whilst those in the alternate tapping of fingers with the same hand had the least positive-going amplitudes.

No significant aging effects were revealed in the s-LRP latency and amplitude. The alternate finger tapping with the same hand condition had the least negative-going s-LRP than the one-finger repeated tapping with the same hand and the single-tap with one finger sequences. Aging effect was revealed in influencing the latencies of r-LRP of the right- and left-hand initiated sequences between the older and younger groups. The left-hand initiated tapping sequences had shorter r-LRP latency than the right hand for the younger participants; which was not the case for the older participants. Aging effect was also revealed on the amplitudes of r-LRP across the four tapping sequences between the older and younger groups. The alternate finger-tapping with the same hand had the most negative r-LRP than the other three sequences for the older participants; whist this was not the case for the

younger participants.

As described in Chapter II, P1 and N1 are the components associated with processing of the visual cues which contains motor-related information in preparation for the subsequent finger-tapping responses. In this case, the cue contained the shape-and-arrow configuration based on which the motor actions associated with each finger-tapping sequence were made known to the participant. However, it is important to note that the P1 and N1 components were associated with the activities at the occipital sites (i.e. O1 and O2) but not the motor-related finger-tapping sequence conveyed by the shape-and-arrow configuration. Rather, the latter are the processes associated with the s-LRP elicited at the CPz site. The s-LRP is the component associated with the processes which paired up specific shape-and-arrow configuration presented in the visual cue with a specific finger-tapping sequence, and selected the appropriate motor sequence for execution. The P3 and r-LRP components reflected the processes associated with identification of the stimulus and generation of the movement sequences indicated by the shape-and-arrow cue, respectively; P3 was also found to relate to allocation of attention, and detection and classification of stimulus involving working memory.

Ageing Related Slowness

Behavioural response time

In general, older participants performed slower than the younger participants disregard the finger-tapping task conditions. The slowness among the older participants were further aggravated when the tapping movements involved more

than one fingers such as those in the alternate finger-tapping with the same hand or finger-tapping with alternate hands. Among the older participants, the alternate finger-tapping with the same hand had the longest response time, which was not the case for the younger participants. Tapping with more than one finger would involve more complex sensorimotor processes than tapping with one finger (single or repeated tapping). The increase complexity of the sensorimotor processes was found to be more vulnerable among the older than younger participants. Our findings concur with previous studies which reported that processing speed of sensorimotor transformation decreased with increasing age (Kok, 2000; Yordanova, Kolev, Hohnsbein, & Falkenstein, 2004). Results showed that for the younger group, the reaction time for Diamond conditions was longest whereas for the older group, the reaction time for Triangle conditions was longest. The latency differences compared between both group were enlarged for choice reaction task than simple reaction tasks. This is in line with previous studies (Anstey, Luszcz, & Sanchez, 2001; Deary, Johnson, & Starr, 2010; Yordanova, Kolev, Hohnsbein, & Falkenstein, 2004).

It is important to note that older participants had lower accuracy rates than the younger participants. Our findings are not consistent with those of Falkenstein et al. (2006) and Kolev et al. (2006) which did not reveal significant age effect. The discrepancies in the findings perhaps are attributable to the differences in the task designs. In this study, besides one tapping sequence (Circle, single-tap with index finger with alternate hand), the other three sequences required the participants to perform finger-tapping different from the tasks employed in Falkenstein and Kolev et al.'s studies. The four finger-tapping sequences were randomly presented to the

participants which further increased the difficulty level of the task. The increase in the task difficult is likely to contribute to the lower accuracy rates among the older than younger participants. Similarly, the task effects were found to affect the older more than the younger group. Adjusted for the accuracy rate (by using Time Index), the older participants consistently showed longer response times than the younger participants. It is noteworthy that the response times for the right-hand initiated tapping responses were shorter than those for the left-hand counterparts. This left-right discrepancy was not observed for the younger participants. Healthy ageing population is reported with a significant decreased in muscular performance. The changes of neuromuscular function that demonstrated by aged adults include a greater kinematic variability of simple movement, impaired performance of fine-motor tasks, a larger kinematic variability of simple movements, and increased postural instability (Grabiner & Enoka, 1995). The ageing related changed in neuronal mechanisms will be compensated by neuronal functional reorganisation and connectivity (Cabeza, 2001; Raz, 2000; Tsujii, Okada, & Watanabe, 2010). It focus on changes in functional hemispheric asymmetry when performing unilateral movement.

The results from regression analysis showed that the N1 peak latency was a significant predictors of reaction time for most of the conditions (except right-hand initiated finger tapping conditions). As discussed before, N1 components, which combined with P1 components, were associated with processing of the visual cues for interpretation of the motor-related information contained in the cues presented, that is, the shape-and-arrow configuration.

Previous studies studies (e.g. Falkenstein et al., 2006; Jong, Kok, & Rooy, 1988; Kolev et al., 2006; Van der Lubbe & Verleger, 2002) already confirmed that N1 peak latency, which represents early sensory processing will be delayed in older group. Even thought the results of s-LRP onset latency analysis showed there were no influence of N1 on s-LRP, which represents shape-and-arrow configuration with specific motor sequences, and the response selection processing, the N1 could be the predictor of reaction time.

P1-N1 component – Visual processing

The prolonged N1 latency at occipital areas (i.e. O1 and O2) among the older participants suggested possible delays in early processing of visual stimuli among this group. In this study, the visual cues were the four figure-and-arrow symbols (denoting finger-tapping configurations) indicating specific tapping sequences. Our findings on the age-related delay in the N1 peak latency are consistent with the results reported in previous studies (e.g. Falkenstein et al., 2006; Jong, Kok, & Rooy, 1988; Kolev et al., 2006; Van der Lubbe & Verleger, 2002). Previous study suggested that P1 and N1 components were related to perceptual sensitivity of the visual system for detecting features of the incoming stimuli (Hillyard, Mangun, Woldorff, & Luck, 1995). Although the P1-N1 component was regarded as a complex, the N1 was further separated from the P1 which was associated with orienting of attention to the task relevant stimulus (Luck, Heinze, Mangun, & Hillyard, 1990). The current study revealed significant age-related effects on the N1 but not P1 component. This further suggested that the differences between the older

and younger participants on detecting of the figure-and-arrow symbols were more in the orienting of attention rather than the perceptual sensitivity processes. When compared with the younger participants, the delay N1 latency also suggested that the age-effect would have delayed the attention process among the older participants. It is likely that the intensity of the attention would not have differed between the two groups. The N1 component was previously suggested to relate to feature selection of the detected stimuli (Zanto, Toy, & Gazzaley, 2010). The delayed N1 latency in the older group indicated that there could have been a delay in the feature selection process when compared with the younger group. These results are somehow different from another study which reported age-effect on the P1 and N1 latencies without affecting stimulus detection accuracy (Curran, Hills, Patterson, & Strauss, 2001). The difference in findings for the P1 latency perhaps is related to the differences in the task design between Curran et al. and the current study. The task used in Curran's study is relatively easy as there were just two stimulus used in the task. The task design could have yielded early ceiling effects for both the younger and older groups, hence not showing between-group differences. Their results also suggested that the lower accuracy on the finger-tapping tasks by the older than younger participants would not have been due to the delay in orienting the attention to the visual stimuli.

P3 component – Attention and working memory

Similar to N1, there was a general delay in P3 latency among the older participants. Different from N1, the amplitudes of P3 at CPz for the older participants

were less positive-going than those for the younger participants. The between-group differences appeared to be similar across the four finger-tapping conditions. The result of delayed P3 latency at the centro-parietal regions are consistent with those revealed from previous studies (Falkenstein et al., 2006; Kolev et al., 2006; Polich, 1997a, 1997b; Yordanova et al., 2004). The P3 component is related to the allocation of attention and working memory processes associated with stimulus identification. In this study, it would be the attention and working memory for identification of the movement sequences indicated by the shape-and-arrow cue. The prolonged P3 latency found among older participants could have related to the slowness in retrieval process of the stimulus-related context from the long term to working memory (Polich, 2007). In this study, the finger-tapping task required the participant to extract the movement sequence information from the shape-and-arrow cues contained in the visual stimulus. In order to proceed with the task, the participant would have to retrieve from long-term memory the rule governing the specific movement sequence conveyed by the cue, which would involve access to memory, response selection, response maintenance in the working memory, and response execution; these suggested that older participants, when compared with their younger counterpart, would require more effort on their attention and memory processes when performing on the movement sequences (Falkenstein et al., 2006; Kolev et al., 2006; Yordanova et al., 2004). The older participants would have also needed more time to identify the stimulus, generate and select response for leading to execution of the movement patterns (Kolev et al., 2006; Yordanova et al., 2004). Current results also showed a general less positive-going P3 amplitude at CPz for

the older than younger participants. These results suggested that older participants would have more problems with performing on the finger-tapping tasks (Grabiner & Enoka, 1995; Morrison & Newell, 2012). They offer an explanation on the lower accuracy rates on the tasks for the older (Hamacher, Singh, Van Dieen, Heller, & Taylor, 2011) than younger participants.

s-LRP component – Association and selection of motor sequence

Despite the delays in early visual sensory processing among the older participants, no between-group differences were revealed in the latency and amplitudes of the s-LRP. In this study, the onset of the s-LRP was derived from the time point when the waveform curve crossed the time axis followed by a negative-going waveform. The results indicated that the longer latencies of N1 and P1 did not influence elicitation of the s-LRP. Our findings concur with those revealed in previous studies which used a choice reaction task (Kenemans, Smulders, & Kok, 1995; Falkenstein et al., 2006; Kolev et al., 2006; Yordanova et al., 2004). They conclude that the response selection was also unaffected by ageing due to the onset latency of s-LRP was not delayed in older group. It is worthy to point out that there were no significant difference on the onset latency between younger and older groups. The older subjects may re-organize their response selection process in order to compensate the visual processing delay represent by prolonged N1 latency (Cabeza, Anderson, Locantore, & McIntosh, 2002; Falkenstein et al., 2006; Reuter-Lorenz, 2002).

However, interpretation of the non-significant results should be with caution.

The non-significant s-LRP results could have been confounded by the training provided to all participants and the easiness of the tapping tasks. Participants received training on associating the visual cues with the movement patterns before performing on the experimental tasks. This training would decrease the difficulty of the task; the tasks used were not difficult enough to display age-related differences. The s-LRP results indicated that aging-effect would be less likely to affect the association of the shape-and-arrow configuration with the specific motor sequence as well as the response selection processes. Our findings concur with those reported in another study that increase in sequence length did not modulate the neural processes associated with movement selection (Schröter & Leuthold, 2008).

r-LRP component – Generation of movement sequences

The r-LRP is the component reflecting generation of response particularly leading to execution of the movement patterns; this process was found to follow the P3 as its onset latencies ranged from -823.0 to -669.7 ms. Results of the onset latencies of r-LRP for the younger participants showed that the initiation of movements by the right hand in general were significantly longer than those by the left hand. In contrast, no differences were revealed between the right- and left-hand initiated responses among the older participants. No between-group differences were found in the onset latencies of the r-LRP. The left-right influence does not seem to tie to the complexity of the task, however. The r-LRP onset time, the time duration from r-LRP onset to peak was longer for the left than the right-initiated condition for

the younger participants. This finding can be explained by the fact that the r-LRP amplitudes were significantly higher for the right-hand than left-hand initiated response irrespective to group membership. Response-related potential rising time was previously found to be due to the stronger neural facilitation from the contralateral hemisphere (Kolev et al., 2006). Other studies explained the increases in neural activities in the ipsilateral motor cortex could have been the result of inhibition of the ipsilateral motor cortex (Carbonnell, Hasbroucq, Grapperon, & Vidal, 2004; Taniguchi, Burle, Vidal, & Bonnet, 2001). In view of the right-handedness of the participants recruited in this study, stronger left hemisphere activities would have been expected from the current task (Hugdahl, 2000; Newton, Sunderland, & Gowland, 2005). The results on the latency and amplitude of the r-LRP suggested that the laterality effects observed among the younger participants did not seem to exist among the older participants.

The finger-tapping task involved top-down regulation processes as the visual cue stipulated different movement patterns to be performed by specific hands and fingers (Mesulam, 1998). Brunia (1999) suggested that the task-taking process in this study would require functional facilitation so that fast responses could be generated by the participants. The diminished laterality (shorter latency for the right-hand) among the older participants suggested that older age may have compromised this top-down regulation and functional facilitation when performing on the finger-tapping task. The r-LRP is an index of the difference in electrical activities between the ipsilateral and contralateral sensorimotor cortex. Previous studies have related the observable differences in r-LRP with insufficient regulation and hence activities

in the sensorimotor cortices prior to producing the motor responses related to the task (Yordanova et al., 2004). It is noteworthy that, among the older participants, the said decrease in regulation and facilitation appears to increase with the complexity of the task. But this was not the case for the younger participants. The most negative r-LRP was found in the tapping sequence involving alternate fingers with the same hand (Diamond) and the least negative r-LRP was in the single-tapping with one finger (Circle). The left-hand-initiated responses were in general with more negative r-LRP than the right-hand-initiated responses, which indicated the decrease in regulation and facilitation.

Effects on Functional Cortical Regulation in Sensorimotor Tasks

The finger-tapping task involved top-down regulation processes as the visual cue stipulated different movement patterns to be performed by specific hands and fingers (Mesulam, 1998). Brunia (1999) suggested that the task-taking process in this study would require functional facilitation so that fast responses could be generated by the participants. The longer latency and reduced amplitude of r-LRP among the older participants suggested that age effects may have compromised this top-down regulation and functional facilitation when performing on the finger-tapping task. The r-LRP is an index of the difference in electrical activities between the ipsilateral and contralateral sensorimotor cortex. Previous studies have related the observable differences in r-LRP with insufficient regulation and hence activities in the sensorimotor cortices prior to producing the motor responses related to the task (Yordanova et al., 2004). It is noteworthy that the said decrease in regulation

and facilitation appears to increase with the complexity of the task. The most negative r-LRP was found in the diamond movement sequence among the older participants, of which the response was tapping with alternate fingers of the right hand.

Age-related functional dysregulation could go beyond the response-related processes, as previous studies indicated that it was found equally influencing other visuo-motor processes; for example, the amplitudes of N1 elicited at O1 and O2 among the older participants were found more negative-going than those of the younger participants. These results concur with previous studies which have identified age-related effects on early ERP components (Allison, Hume, Wood, & Goff, 1984; Falkenstein, Hohnsbein, & Hoormann, 1994; Kok, 2000; Kolev et al., 2006; Kolev, Yordanova, Basar-Eroglu, & Basar, 2002; Leuthold, Sommer, & Ulrich, 2004). The more negative-going N1 would reflect increase in attentional demand (Hillyard & Anllo-Vento, 1998; Luck, Woodman, & Vogel, 2000). Our results also concur with those reported in another study which proposed that the increase in amplitudes were associated with increase in attention on the motor-related cue stimuli visually presented to the participants (Yordanova et al., 2004).

The more positive-going amplitudes and longer latencies of centro-parietally distributed P3 in the right- than left-hand-initiated tapping sequence suggested possible age-related influences on the inter-hemispheric activities among the older participants; such age-related effects were intensified with increasing complexity of the finger-tapping task. These results suggested that the age effects could influence neural excitability affecting the left more than the right hemisphere.

Stimulus Type Effects

These results showed no significant differences in latencies in s-LRP across the four types of cue stimuli, suggesting that processes prior to generation of movement sequences would not have been affected by the characteristics of the stimuli, including sequence length (one versus four taps), sequence complexity (single versus alternate tapping), and side of hand
(unilateral versus bilateral). Our findings concur with those reported in another study that increase in sequence length did not modulate the neural processes associated with movement selection (Schröter & Leuthold, 2008).

Facilitation was found in the left-hand-initiated sequence among the younger participants. This result was supported by the earlier onset latency of the r-LRP for the left- than right-hand-initiated sequence. The facilitation identified for the younger group appears to reversed the older group; however, these suggested possible diminishing inter-hemispheric differences among the older participants, possibly due to the increased inhibitory control exerted by the opposite hemisphere (Carbonnell, Hasbroucq, Grapperon, & Vidal, 2004). The onset latency of r-LRP for older participants was found to be prolonged with the increase in complexity of the movement sequences, e.g. alternative tapping left and right hand fingers, which concurs with results of previous studies (Ghacibeh et al., 2007; Kobayashi, Hutchinson, Schlaug, & Pascual-Leone, 2003; Swinnen & Wenderoth, 2004; Verstynen, Diedrichsen, Albert, Aparicio, & Ivry, 2005; Ziemann & Hallett, 2001). The larger differences in the r-LRP amplitudes between the left- and right-hand-

initiated sequences indicated that the left-right difference was amplified by the effect of aging. Left-hand-initiated movement sequences involved activation of the right sensorimotor cortex, which would be inhibited by the left hemisphere. The reverse would apply to the left-hand-initiated movement sequence. The left-right differences were found largest in the simplest sequence (repetitive single finger-tapping and the smallest in the most complex sequence, alternate left and right finger-tapping). This can perhaps explain why the accuracy rates for the complex movement sequences were lower than those for the simple movement sequences.

CHAPTER VI

Conclusion

The present study utilised event-related potential and lateralised readiness potential to investigate the difference in neural processes associated with ageing during finger-tapping tasks.

There are three different stages of sensorimotor processing, which include stimulus processing, response selection, and response generation (Falkenstein, Yordanova, & Kolev, 2006; Kolev, Falkenstein, & Yordanova, 2006; Yordanova, Kolev, Hohnsbein, & Falkenstein, 2004); each stage is reflected by different electrophysiological indicators. The early ERP components studied in the sensorimotor processing stage included P1 and N1, which are associated with the stimulus processing stage. The differences in P1 latency between the age groups may suggest a delay in visual stimulus processing associated with ageing. The P3 ERP component is related to attention and memory-related operations (Polich, 2007), and the nature of P3 is summation of a serial of subcomponents. We found that the P3 latency was delayed in the aged group, but this may not contribute to behavioural slowness of older adults because we found no delay in the onset latency of s-LRP which is associated with information processing of the stimulus, the s-LRP results indicated that ageing related slowness would not affect the association of shape-and-arrow configuration with the specific finger tapping sequences, as well as the response selection processes. However, the delay in P3 latency may be related to slowness in memory refresh for received

stimulus context (Polich, 2007).

The delay in onset latency of r-LRP in the aged group compared to the young group suggests ageing may affect the motor response generation stage. Extra-neural activity from the contralateral motor cortex was needed for movement execution in the older participants. There are possible reasons to explain the decrease in amplitude of the r-LRP in the aged group, which include an increase in bilateral motor activities and a decrease in inter- and intra-hemispheric inhibition. The age-related difference in r-LRP onset latency may be caused by an increase in dysregulation function of higher control system, which would affect the stimulus perception and response selection stages. The task-related difference in LRP duration and amplitude might suggest a functional dys-facilitation in the contralateral motor cortex. Ageing effects also represented by a decline in intra-hemispheric inhibition and inter-hemispheric inhibition, especially during the performance of complex tasks.

The high resolution EEG enhanced the spatial characteristics and quantified the time course of neural processing; this approach was helpful to evaluate the central sensorimotor processing more precisely. The current study found that age-related slowness might occur at the motor response generation stage. Other mechanisms, such as delays in modality-specific perception, may also be affected by the ageing process. Functional dysregulation of the contralateral motor cortex and decreased intra- and inter-hemispheric inhibitions may contribute to the ageing related slowness.

Limitations of Current Study

This study is a follow-up of previous studies (Falkenstein et al., 2006; Kolev et al., 2006; Yordanova et al., 2004) and the results extend our understanding of the mechanism of age-related slowness in motor preparation and execution. There are a few limitations that might have confounded the findings, from which further studies may improve upon.

First, due to the nature of P3, the tasks used in the current study could not differentiate the sub-components of P3. If we could differentiate the P3 subcomponents affected by different task related variables, we could further understand in which sub-stages during the sensorimotor processing would be affected by ageing.

Second, we did not take into account the preceding experiences of the participants. The history of the participants, such as education levels, exercise levels, and occupation, could influence the sensorimotor processing during finger-tapping tasks. Previous published literatures rarely discuss those issues (refs). Those factors were not included in current study as well.

Third, we used the build-in function of Curry 7 software for artifact reduction, such as eye blinks. A covariance analysis is performed between the artifact channel and each EEG channel. Linear transmission coefficient were computed by software. Based on the coefficient, a proportion of the voltage is subtracted from each data point in the artifact interval. Currently, the independent component analysis (ICA) is used for disentangling the independent

neural source signals. By using this methods, it might be further decrease the influence of artifact. Further analysis should try to use ICA to see whether there are some difference in between.

Implications for Future Studies

A number of previous studies which examined how different factors, such as age, sequence length, sequence complexity, and responding hand, affect sensorimotor processing and at which stages of processing these factors would be involved. The current study further confirmed previous findings and provides further evidence to illustrate the influence of ageing on sensorimotor processes. Further neuroimaging studies should be used to study the spatial aspect of neural processes related to sequence movements. These studies can be useful for the study of certain neurological conditions regarding how these diseases may affect the sensorimotor processes of patients.

APPENDICES

List of Appendices

Appendix I Demographic information collecting form

Subject group Subject No.

基本資料
Demographic Information

姓名 Name	
聯絡電話 Contact No.	
性別 Gender	年齡 Age
職業 Occupation	教育水平 Educational Level
既往疾病史 Past Medical History	
是否服用藥物 Medication History	
是否接受過藝術方面訓練 Trained with any instruments or not	

Note

Appendix II Annett Handedness Questionnaire

Handedness
主要用手

請依據您的習慣來對以下各個項目進行判斷。

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

您用那隻手：

Which hand do you use:

To write a letter legibly? 你用邊隻手寫字?	L	R	E
To throw a ball to hit a target? 你用邊隻手拎住個波，掟向一個目標?	L	R	E
To hold a racket in tennis, squash or badminton? 你用邊隻手揸球拍打波?	L	R	E
To hold a match whilst striking it? 你劃火柴既時候用邊隻手拎住支火柴?	L	R	E
To cut with scissors? 你用邊隻手揸較剪?	L	R	E
To guide a thread through the eye of a needle? 你穿針既時候用邊隻手揸住條線?	L	R	E
At the top of a broom while sweeping? 揸掃把既時候，兩隻手你會用邊隻手揸上面?	L	R	E
At the top of a shovel when moving sand? 剷沙既時候，兩隻手你會用邊隻手揸上面?	L	R	E
To deal playing cards? 派啤牌時，你會用邊隻手派牌出去?	L	R	E
To hammer a nail into wood? 踏釘時，你用邊隻手揸鎚?	L	R	E
To hold a toothbrush while cleaning your teeth? 刷牙既時候，你用邊隻手揸牙刷?	L	R	E
To unscrew the lid of a jar? 開樽蓋嗰陣，你用邊隻手擰開個樽蓋?	L	R	E

If you use the RIGHT/LT HAND FOR ALL OF THESE ACTIONS, are there any one-handed actions for which you use the

LEFT /RT HAND? Please record them here. _____

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

Appendix III Mini-mental Status Examination (MMSE, Cantonese Version)

MINI –MENTAL STATE EXAMINATION (MMSE)
簡短智能測驗

姓名:_____性別/年齡:_____ 評估日期: _____ 評估員:_____

最高分數	分數	
5	( )	ORIENTATION 依家係乜野日子? (年份)、(季節)、(月份)、(幾號)、(星期幾)
5	( )	我地依家係邊度? (九龍/新界/香港)、(九龍/新界/香港既邊區) 、(邊條街/邊個屋村)、(中心名字)、(邊層樓)
3	( )	REGISTRATION 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，我會叫你再講番俾我聽。 〔蘋果〕、〔報紙〕、〔火車〕。依家請你講番呢三樣野俾我聽。 （以第一次講的計分，一個一分；然後重複物件，直至全部三樣都記得住）
5	( )	ATTENTION AND CALCULATION 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	( )	RECALL 我頭先叫你記住既三樣野係乜野呀?
9	( )	LANGUAGE a. 哩樣係乜野？ (鉛筆)(手錶) (2) b. 請你跟我講呢句話。 (媽丈買魚腸) (1) c. 依家檯上面有一張紙，用你既右手拿起張紙，用兩隻手一齊將張紙摺成一半，然後放番張紙係檯上面。 (3) d. 請讀出哩張紙上面既字，然後照住去做。(1) e. 請你講任何一句完整既句子俾我聽。 (1) 如:〔我係一個人〕、〔今日天氣好好〕 f. 哩處有幅圖，請你照住呢畫啦。 (1)

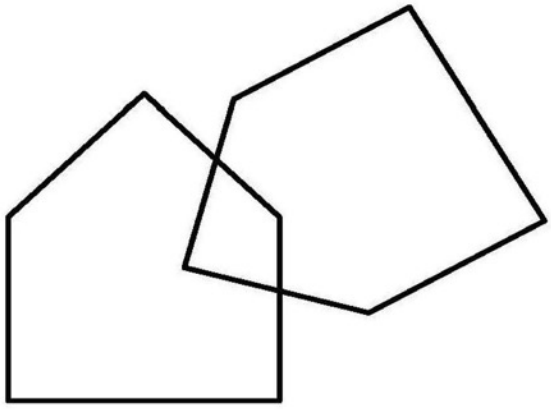
總分： _____/30

d. 請讀出哩張紙上面既字，然後照住去做。

拍手

e. 請你講任何一句完整既句子俾我聽。

f. 哩處有幅圖，請你照住呢畫啦。(畫在右邊空白位置)



＜問題完＞

Appendix IV Consent form used in this experiment

The Hong Kong Polytechnic University

Department of Rehabilitation Sciences

Research Project Informed Consent Form

Project title: Modulation of motor readiness potential using external cueing in patients with Parkinson's disease

Investigators: Prof. Chetwyn Chan, Dr. KH Ting, Ms. Wang Xin (1190)

Project information:

This study aims to understand the effects of visual cues on enhancing motor functions of patients with Parkinson's disease. It involves capturing the behavioral responses and electroencephalogram of patients and normal subjects.

In current study, you are invited to participate in a 3-hour finger tapping task. Your participation will have three parts. The first part involve you to be familiar with making responses with your left or right hand fingers according to different visual cues. After the training, you will prepare for the experiment session, including completing questionnaires and cap set-up for electroencephalogram signal collection. Then you will transfer to the experiment session which your performance will be recorded for further analysis. The study carries no risks to you.

The results will enable us to know the neural mechanism behind visual cues which inform design of clinical interventions for patients with Parkinson's disease.

You may approach the investigator for any clarification. During the experimental procedure, you can require for a rest if fatigue is experienced. Your participation in this study is entirely on a voluntary basis.

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 chief investigator, Prof. Chetwyn Chan at 2766 for any questions about this study. If I have complaints related to the investigator(s), I can contact Mr Leung Ka Yan, secretary of Departmental Research Committee, at 2766

I know I will be given a signed copy of this consent form.

Signature (subject): Date:

Signature (witness): Date:

香港理工大學康復治療科學系科研同意書

研究題目：視覺提示對柏金遜病人仕運動準備電位的影響
研究人員：陳智軒教授、丁建鴻博士、王欣小姐(1190　　)

科研內容：

此研究旨在瞭解視覺提示對促進柏金遜病患者運動表現的效果及影響。在實驗中，病人和年齡匹配正常人行為學的數據和腦電圖都將被採集。

此項研究大約需 3 個小時完成。這個實驗過程三部份組成。首先，您需要先熟悉使用您的左右手指依據不同視覺提示的要求來按鍵。在訓練之後，我們將正式進入到實驗階段。您需要完成一系列關於您背景信息和認知功能狀態的問卷。之後您需要清洗您的頭髮，并由我們為您佩戴上一頂用於收集您腦電波的帽子。最後，需要您根據之前練習時所學習的內容，來完成手指按鍵任務。與此前練習時不同的是，此時我們將會記錄您在按鍵過程中的腦電波變化情況。

您的參加完全自願，並且在實驗過程中，若感覺疲乏，您可以隨時要求停止實驗進行適當休息。

對項目參與人仕和社會的益處：

實驗的結果將會幫助我們瞭解在視覺提示情況下的神經機制，以便將來設計一些更適合於柏金遜患者的臨床治療方案。

潛在危險性：沒有

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，本人有權在任何時候、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以及本人的資料將不會洩露給與此研究無關的人員，我的名字或相片不會出現在任何出版物上。

本人可以用電話 2766　　來聯繫此次研究課題負責人陳智軒教授。若本人對此研究人員有任何投訴，可以聯繫梁先生（部門科研委員會秘書），電話：2766　　。本人亦明白，參與此研究課題需要本人簽署一份同意書。

簽名（參與者）：_____日期：_____

簽名（證人）：_____日期:_____

Appendix V Ethics approval for this study

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	31-Mar-2013

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 15-Mar-2013 to 28-Feb-2014:

Project Title:	Modulation of motor readiness potential using external cueing in patients with Parkinson's disease
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

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Appendix VII Abbreviations

EEG	Electroencephalography
ERP	Event related potential
LRP	Lateralized readiness potential
s-LRP	Stimulus-locked lateralized readiness potential
r-LRP	Response-locked lateralized readiness potential
PFC	Prefrontal cortex
RT	Reaction time
ACC	Accuracy
TI	Time index
MMSE	Mini-mental status examination
PMC	Premotor cortex
SMA	Supplementary motor area
CRT	Choice-reaction task
SRT	Simple-reaction task

Appendix VIII Tables of statistical results on behavior, latency, and amplitude comparison between younger and older groups

Table A1.1 Details of reaction time in choice-reaction task between groups.

Effect	df	F-value	*p*-value
Group	1,39	44.36	<0.001*
Configuration	3,117	40.79	<0.001*
Side	1,39	1.71	0.199
Group x Configuration	3,117	9.31	<0.001*
Group x Side	1,39	4.17	0.048*
Configuration x Side	3,117	1.11	0.343
Group x Configuration x Side	3,117	0.26	0.689

* Significant *p*-level at $p \leq 0.050$

Table A1.2 Details of the pair-wise post-hoc analysis of Configuration of reaction time between younger and older groups.

Effect			df	F-value	*p*-value
Younger Group					
Circle	<	Square	1,19	28.68	<0.001**
Circle	<	Diamond	1,19	36.03	<0.001**
Circle	<	Triangle	1,19	47.37	<0.001**
Square	<	Diamond	1,19	14.78	0.001**
Square	<	Triangle	1,19	16.87	0.001**
Diamond	N/A	Triangle	1,19	0.25	0.620
Older Group					
Circle	<	Square	1,20	39.98	<0.001**
Circle	<	Diamond	1,20	24.42	<0.001**
Circle	<	Triangle	1,20	48.66	<0.001**
Square	<	Diamond	1,20	12.53	0.002**
Square	<	Triangle	1,20	32.52	<0.001**
Diamond	N/A	Triangle	1,20	3.75	0.067

* Significant *p*-level at $p \leq 0.050$
** Adjusted significant *p*-level at $p \leq 0.008$

Table A3 Details of accuracy rate in choice-reaction task between younger and older groups.

Effect	df	F-value	*p*-value
Group	1,39	7.58	0.009*
Configuration	3,117	16.24	<0.001*
Side	1,39	1.19	0.283
Group x Configuration	3,117	1.38	0.258
Group x Side	1,39	1.64	0.208
Configuration x Side	3,117	2.98	0.062
Group x Configuration x Side	3,117	1.40	0.253

* Significant *p*-level at $p \leq 0.050$

Table A3.1 Details of time index in choice-reaction task between younger and older groups.

Effect	df	F-value	*p*-value
Group	1,39	49.51	<0.001*
Configuration	3,117	45.43	<0.001*
Side	1,39	1.97	0.168
Group x Configuration	3,117	11.25	<0.001*
Group x Side	1,39	4.24	0.046*
Configuration x Side	3,117	1.32	0.273
Group x Configuration x Side	3,117	0.84	0.398

* Significant *p*-level at $p \leq 0.050$

Table A3.2 Details of the pair-wise post-hoc analysis of Configuration of time index between younger and older groups.

Effect			df	F-value	*p*-value
Younger Group					
Circle	<	Square	1,19	41.07	<0.001**
Circle	<	Diamond	1,19	51.80	<0.001**
Circle	<	Triangle	1,19	81.09	<0.001**
Square	<	Diamond	1,19	18.06	<0.001**
Square	<	Triangle	1,19	23.88	0.001**
Diamond	N/A	Triangle	1,19	3.61	0.073
Older Group					
Circle	<	Square	1,20	60.75	<0.001**
Circle	<	Diamond	1,20	26.87	<0.001**
Circle	<	Triangle	1,20	48.62	<0.001**
Square	<	Diamond	1,20	15.59	0.001**
Square	<	Triangle	1,20	32.31	<0.001**
Diamond	<	Triangle	1,20	5.72	0.027*

* Significant *p*-level at $p \leq 0.050$
** Adjusted significant *p*-level at $p \leq 0.008$

Table A4 Details of P1 latency at electrode site CPz in choice-reaction task between younger and older groups.

Effect	df	F-value	*p*-value
Group	1,39	1.86	0.180
Configuration	3,117	1.01	0.109
Site	1,39	15.45	<0.001*
Group x Configuration	3,117	0.83	0.447
Group x Site	1,39	2.27	0.140
Configuration x Site	3,117	0.70	0.498
Group x Configuration x Site	3,117	0.40	0.665

* Significant *p*-level at $p \leq 0.050$
Site: electrode site O1 and O2

Table A5 Details of P1 latency at electrode site CPz in choice-reaction task between younger and older groups.

Effect	df	F-value	*p*-value
Group	1,39	0.39	0.534
Configuration	3,117	0.94	0.339
Side	1,39	0.61	0.440
Group x Configuration	3,117	0.97	0.331
Group x Side	1,39	0.85	0.364
Configuration x Side	3,117	1.03	0.316
Group x Configuration x Side	3,117	1.01	0.321

* Significant *p*-level at $p \leq 0.050$

Table A6 Details of N1 latency at electrode site CPz in choice-reaction task between younger and older groups.

Effect	df	F-value	*p*-value
Group	1,39	9,18	0.004*
Configuration	3,117	0.57	0.607
Side	1,39	2.20	0.147
Group x Configuration	3,117	0.09	0.943
Group x Side	1,39	0.99	0.326
Configuration x Side	3,117	1.23	0.301
Group x Configuration x Side	3,117	2.29	0.099

* Significant *p*-level at $p \leq 0.050$

Table A7 Details of N1 amplitude at electrode site CPz in choice-reaction task between younger and older groups.

Effect	df	F-value	*p*-value
Group	1,39	1.28	0.265
Configuration	3,117	1.02	0.320
Side	1,39	0.61	0.441
Group x Configuration	3,117	1.00	0.324
Group x Side	1,39	0.87	0.358
Configuration x Side	3,117	1.00	0.324
Group x Configuration x Side	3,117	0.98	0.328

* Significant *p*-level at $p \leq 0.050$

Table A8 Details of P3 latency at electrode site CPz in choice-reaction task between younger and older groups.

Effect	df	F-value	*p*-value
Group	1,39	7.56	0.009*
Configuration	3,117	3.04	0.046*
Side	1,39	0.66	0.421
Group x Configuration	3,117	2.77	0.061
Group x Side	1,39	0.87	0.356
Configuration x Side	3,117	1.64	0.192
Group x Configuration x Side	3,117	0.09	0.947

* Significant *p*-level at $p \leq 0.050$

Table A9 Details of P3 amplitude at electrode site CPz in choice-reaction task between younger and older groups.

Effect	df	F-value	*p*-value
Group	1,39	7.19	0.011*
Configuration	3,117	23.17	<0.001*
Side	1,39	0.00	0.995
Group x Configuration	3,117	2.11	0.136
Group x Side	1,39	4.74	0.036*
Configuration x Side	3,117	0.25	0.854
Group x Configuration x Side	3,117	0.60	0.610

* Significant *p*-level at $p \leq 0.050$

Table A10 Details of stimulus-locked LRP onset latency in choice-reaction task between younger and older groups.

Effect	df	F-value	*p*-value
Group	1,39	1.08	0.304
Configuration	3,117	0.38	0.734
Side	1,39	0.79	0.378
Group x Configuration	3,117	0.14	0.918
Group x Side	1,39	0.25	0.617
Configuration x Side	3,117	0.40	0.734
Group x Configuration x Side	3,117	0.94	0.415

Table A11.1 Details of stimulus-locked LRP peak amplitude in choice-reaction task between younger and older groups.

Effect	df	F-value	*p*-value
Group	1,39	3.94	0.054
Configuration	3,117	4.65	0.005*
Side	1,39	13.10	0.001*
Group x Configuration	3,117	1.36	0.261
Group x Side	1,39	0.42	0.521
Configuration x Side	3,117	1.75	0.172
Group x Configuration x Side	3,117	1.94	0.139

* Significant *p*-level at $p \leq 0.050$

Table A11.2 Details of the pair-wise comparison of Configuration of stimus-locked LRP peak amplitude.

Effect			df	F-value	*p*-value
Circle	N/A	Square	1,40	0.00	0.965
Circle	N/A	Diamond	1,40	3.38	0.730
Circle	<	Triangle	1,40	10.55	0.002*
Square	N/A	Diamond	1,40	2.76	0.105
Square	<	Triangle	1,40	10.69	0.002
Diamond	N/A	Triangle	1,40	2.32	0.135

* Significant *p*-level at $p \leq 0.050$

Table A12 Details of response-locked LRP onset latency in choice-reaction task between younger and older groups.

Effect	df	F-value	*p*-value
Group	1,39	2.45	0.125
Configuration	3,117	0.42	0.689
Side	1,39	2.92	0.095
Group x Configuration	3,117	1.41	0.331
Group x Side	1,39	5.21	0.028*
Configuration x Side	3,117	0.25	0.853
Group x Configuration x Side	3,117	1.04	0.374

* Significant *p*-level at $p \leq 0.050$

Table A13.1 Details of response-locked LRP peak amplitude in choice-reaction task between younger and older groups.

Effect	df	F-value	*p*-value
Group	1,39	0.01	0.925
Configuration	3,117	1.81	0.155
Side	1,39	11.84	0.001*
Group x Configuration	3,117	3.31	0.026*
Group x Side	1,39	2.45	0.126
Configuration x Side	3,117	5.84	0.001*
Group x Configuration x Side	3,117	1.40	0.750

* Significant *p*-level at $p \leq 0.050$

Table A13.2 Details of the pair-wise post-hoc analysis of Configuration of response-locked LRP peak amplitude between younger and older groups.

Effect			df	F-value	*p*-value
Younger Group					
Circle	N/A	Square	1,19	0.23	0.635
Circle	N/A	Diamond	1,19	0.10	0.735
Circle	N/A	Triangle	1,19	0.30	0.592
Square	N/A	Diamond	1,19	0.73	0.402
Square	N/A	Triangle	1,19	0.07	0.790
Diamond	N/A	Triangle	1,19	1.22	0.283
Older Group					
Circle	>	Square	1,20	4.02	0.500
Circle	>	Diamond	1,20	20.22	<0.001**
Circle	N/A	Triangle	1,20	1.51	0.233
Square	N/A	Diamond	1,20	3.88	0.063
Square	N/A	Triangle	1,20	0.50	0.489
Diamond	<	Triangle	1,20	15.31	0.001**

* Significant *p*-level at $p \leq 0.050$

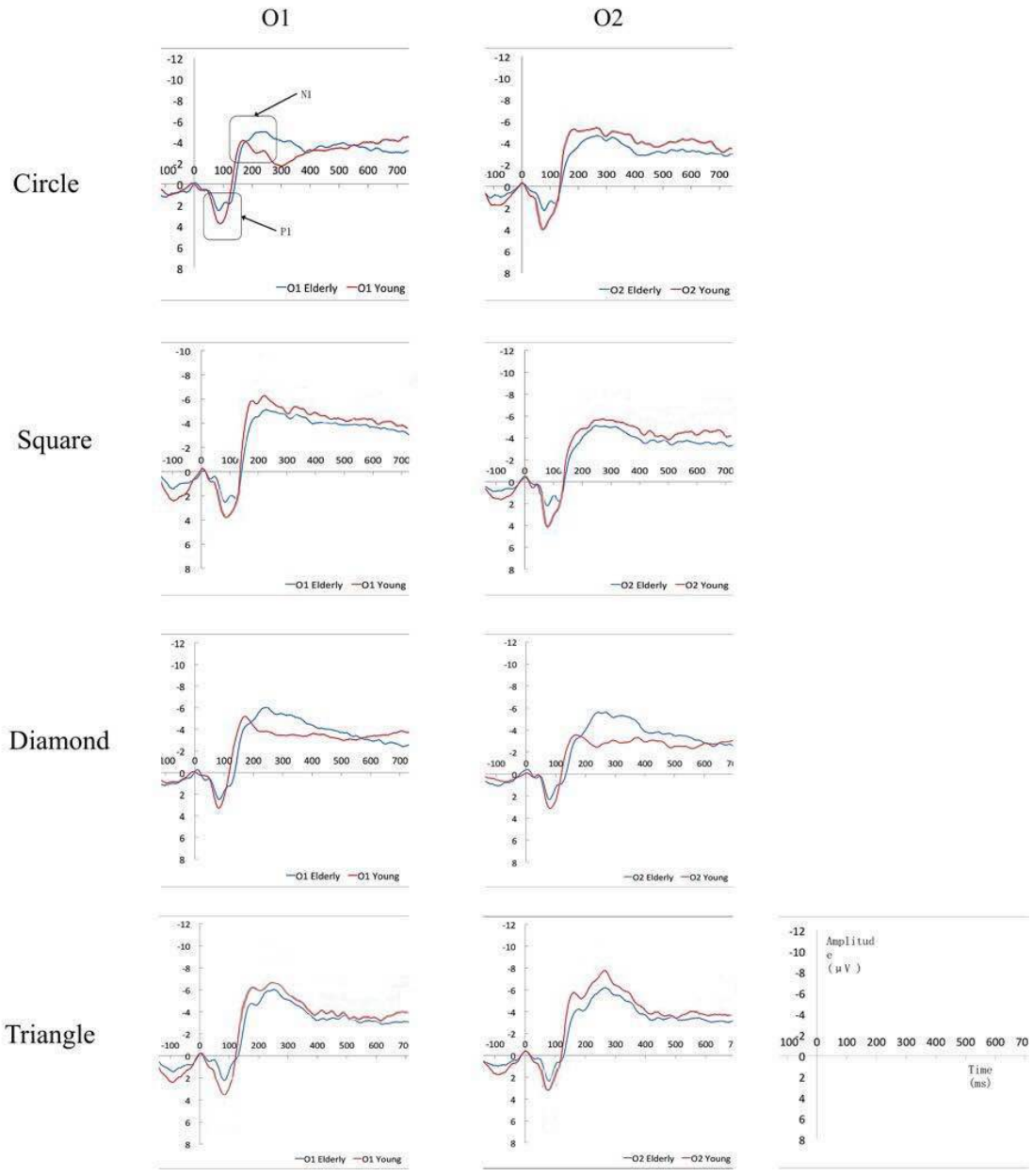
** Adjusted significant *p*-level at $p \leq 0.008$

Table A13.3 Details of the pair-wise post-hoc analysis of Configuration of response-locked LRP peak amplitude between left-hand-initiated sequences and right-hand-initiated sequences.

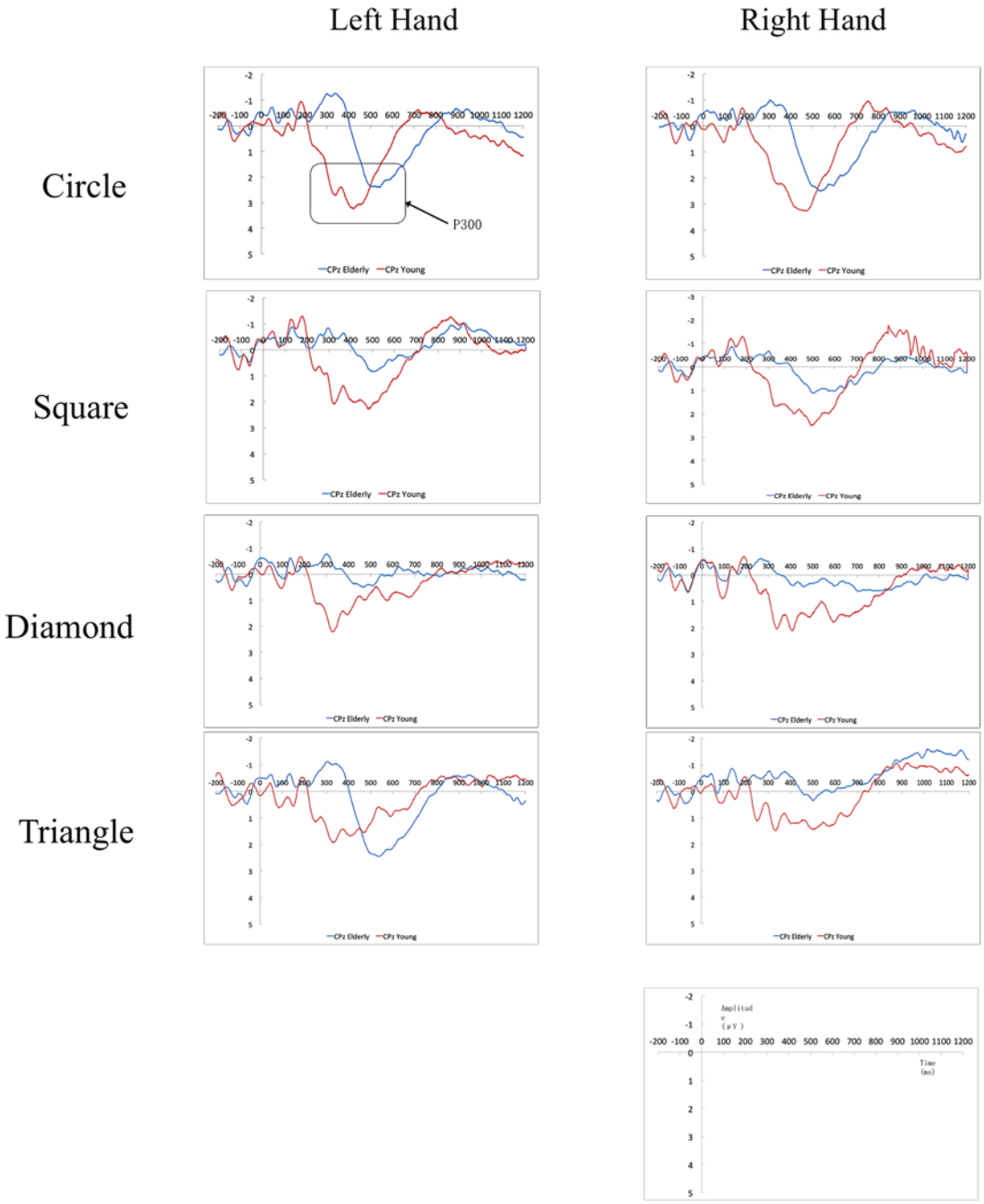
Effect			df	F-value	*p*-value
Left-hand-initiated sequences					
Circle	N/A	Square	1,39	2.15	0.151
Circle	N/A	Diamond	1,39	0.22	0.641
Circle	N/A	Triangle	1,39	0.01	0.940
Square	N/A	Diamond	1,39	1.26	0.277
Square	N/A	Triangle	1,39	2.45	0.125
Diamond	N/A	Triangle	1,39	0.42	0.520
Right-hand-initiated sequences					
Circle	>	Square	1,39	15.13	<0.001**
Circle	>	Diamond	1,39	11.68	0.001**
Circle	N/A	Triangle	1,39	2.64	0.112
Square	N/A	Diamond	1,39	0.06	0.804
Square	<	Triangle	1,39	5.41	0.025*
Diamond	<	Triangle	1,39	4.27	0.045*

* Significant *p*-level at $p \leq 0.050$
** Adjusted significant *p*-level at $p \leq 0.008$

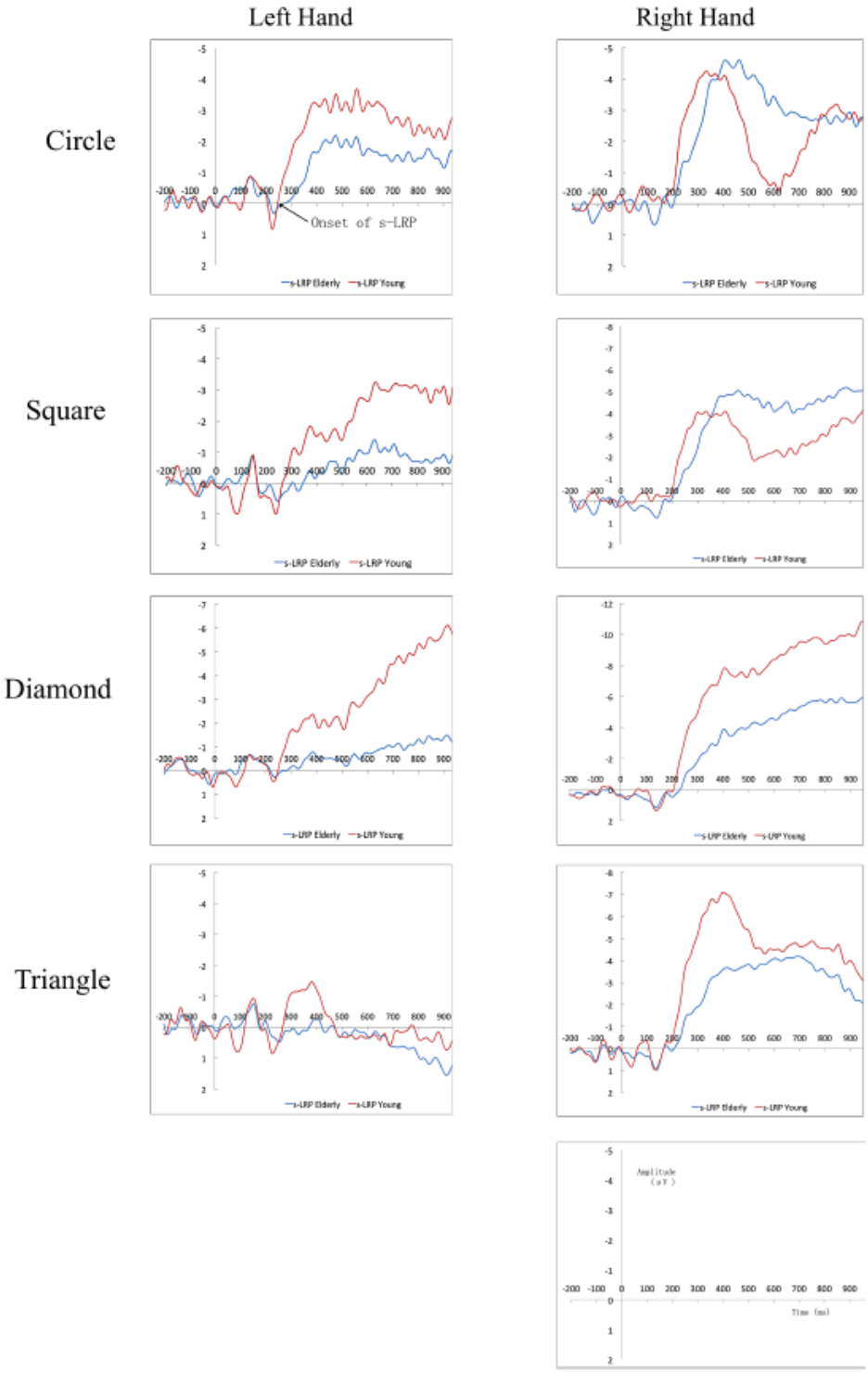
Appendix IX P1-N1 waveform elicited from electrode site O1 and O2 for four different configurations between younger and older groups.



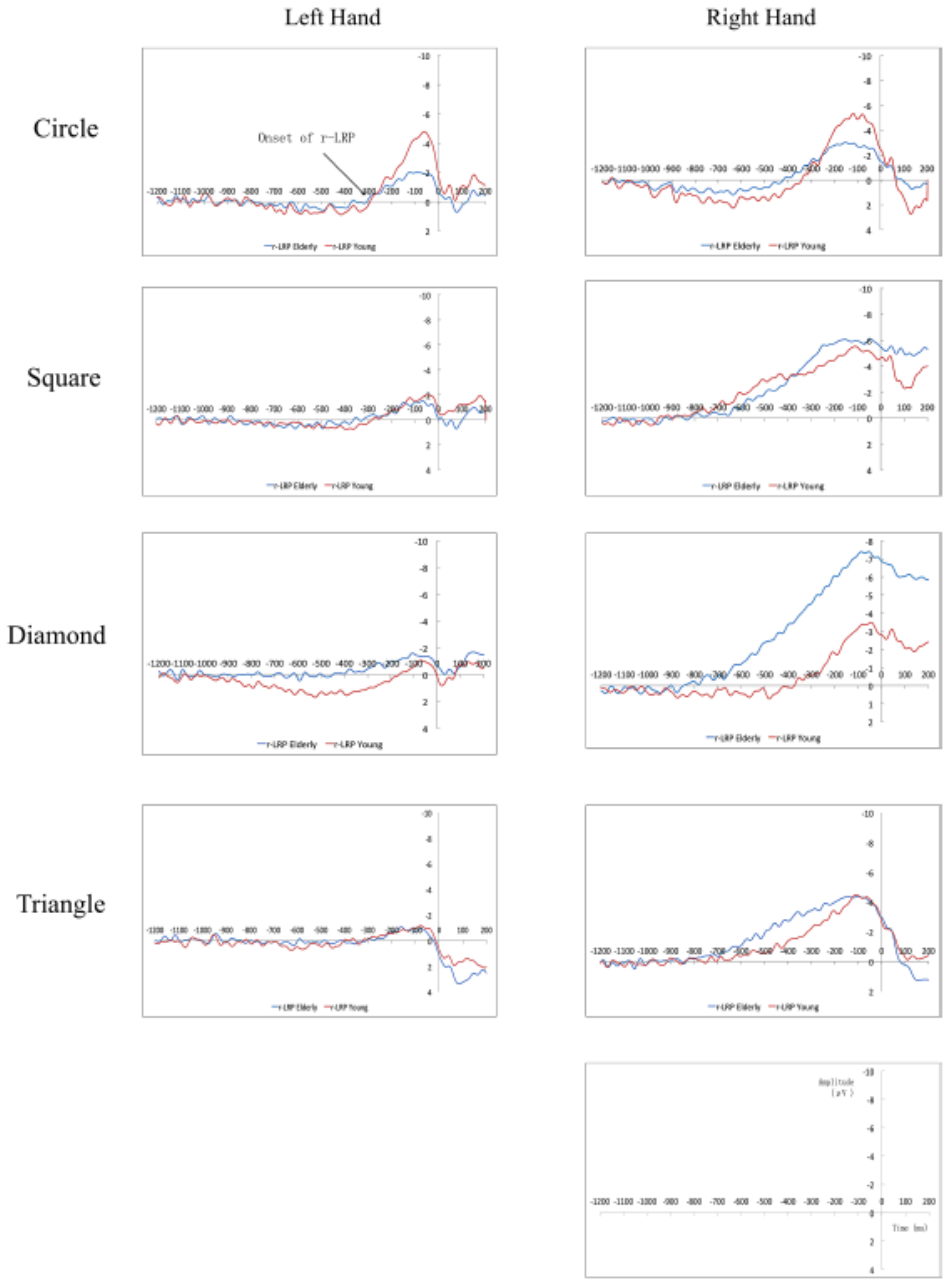
Appendix X P3 waveform for four different configurations between younger and older groups.



Appendix XI s-LRP waveform for four different configurations between younger and older groups.



Appendix XII r-LRP waveform for four different configurations between younger and older groups.



REFERENCES