MODULATORY EFFECT OF EXECUTIVE CONTROL THROUGH THE PRESENCE OF PRIORITY-CUE AND RETRO-CUE ON EXTERNAL-TO-INTERNAL ATTENTION AND MAINTENANCE OF INTERNAL REPRESENTATION: A BEHAVIOURAL AND ELECTROPHYSIOLOGICAL STUDY

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Modulatory Effect of Executive Control Through the Presence of Priority-cue and Retro-cue on External-to-internal Attention and Maintenance of Internal Representation: A Behavioural and Electrophysiological Study

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ABSTRACT

Background

Emerging evidence has shown that the presence of visual cues under executive control could influence the attentional orientation to stimuli and representation. However, this modulatory effect of top-down visual cues has not been investigated in external, internal, or external-to-internal orientation in motor context. Concurrent motor imagery and action observation (AOMI) has been shown to heighten the cortical activations in the Action Observation Network (AON) and imagery-related network. AOMI involves attentional orientation from external images of action to internally generated kinesthetic images. It is speculated that the rapid shifting between external visual image and internal kinesthetic representation and the transition from visual to kinesthetic representation demand a higher level of top-down executive control, and it is suggested that the involvement of top-down visual cues might enhance the effect of AOMI, which in turn improves the motor performance in terms of precision. While visual cues may aid in the selection of relevant information and the suppression of irrelevant representations, their presence may also consume executive function resources. However, the related processes have not been well addressed.

Objectives

There were one pilot study and two main studies in the study. In the pilot study, it was aimed to examine if providing external-to-internal attention orientation training before AOMI would affect executive control on attention shifting. Study One aimed (1) to examine if the modulatory effect of executive

control on external-to-internal attention orientation through the presence of priority-cue in visual imagery and subsequent maintenance of visual representation in terms of behavioral measures and cortical oscillations; (2) to examine if the modulatory effect of executive control on internal maintenance through the presence of retro-cue and subsequent inspection of visuomotor representation in terms of measures and cortical oscillations. Study Two aimed to examine if the modulatory effect of executive control through the presence of priority-cue and retro-cue on inspection and maintenance of kinesthetic representation in AOMI in terms of motor precision and cortical oscillations.

Methods

Twelve healthy volunteers (mean age = 25±3.4) were recruited to participate in AOMI training in the pilot study. All the volunteers were allocated to either of the two training groups: (1) action observation and passive movement (AOPM) training (experimental group) or (2) action observation (AO) training. Each participant was required to complete 3 outcome tests, including the proprioceptive test, the Purdue Pegboard test, and the Stroop test, before and after the AOMI training.

Healthy adults (Study One: N = 20; mean age = 25.3±3.0; Study Two: N = 25; mean age = 26.1±4.4) were recruited to participate in delayed recognition tasks in Study One and cognitive-motor tasks in Study Two. The delayed recognition task in Study One consisted of 4 conditions, including (1) delayed recognition (control) task, (2) delayed recognition task with priority-cue, (3) delayed recognition task with retro-cue, and (4) delayed recognition task with priority-cue and retro-cue conditions. Reaction time, accuracy, and electroencephalogram data were recorded during the delayed recognition tasks in Study One. To accomplish the objectives, repeated measures ANOVA was used to examine: 1) the behavioural performance of the delayed recognition tasks; 2) the mean theta-band power in the presence of retro-cue; and 3) the mean alpha-band power during the maintenance phase. Study Two consisted of two conditions, i.e. (1) AOMI (control) condition, and (2) AOMI with priority-cue and retro-cue condition. Joint precision and electroencephalogram data were recorded during the cognitive-motor tasks in Study Two. To achieve the objectives, repeated measure ANOVA was used to examine 1) the joint precision of cognitive-motor tasks, 2) the mean theta-band power in the presence of retro-cue, and 3) the mean alpha-band power during the maintenance phase.

Results

In Study One, shorter reaction time and higher accuracy were found in the retro-cue condition and priority-cue and retro-cue condition. Higher frontal theta-band power was found in the retro-cue, priority-cue and retro-cue condition during retro-cue parietal alpha-band power was found in the retro-cue, priority-cue and retro-cue condition during maintenance.

In Study Two, enhancement in elbow joint precision was found in priority-cue and retro-cue condition. Higher theta-band power was found in priority-cue and retro-cue condition over left frontal cortical sites during retro-cue. Lower alpha-band power was found in priority-cue and retro-cue condition over right parietal cortical sites during maintenance.

Conclusion

The findings of this study shed light on how the higher centre of executive control on the attention and imagery-related systems and the presence of priority-cue and retro-cue on modulating attention Furthermore, the results of this study provided an insight on using priority-cue and retro-cue in cognitive training strategies to incorporate visual cues to enhance the attention orientation in individuals with attentional control deficits, e.g., elderly with mild cognitive impairments. The presence of both cues yielded the greatest beneficial effect on behavioural performance and showed a reduction in the alpha-band oscillations. It can pave the way to constructing an efficient programme to learn or relearn motor movement.

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OUTPUTS

Conference Presentation

1. **Tom C. W. Tsoi,** Sam C. C. Chan. The Aging Effect on Integrating Information with Different Levels of Familiarity: An ERP Study, *Pan-Pacific Conference on Rehabilitation 2018,* November 17 – 18, 2018 (Awarded with Gold Oral Presentation Award).
2. Sam C. C. Chan, **Tom, C. W. Tsoi**, & Tommy L.H. Lam. Effects of Imagery-based Chinese Calligraphy on Working Memory of Elderly. *The Organization for Human Brain Mapping – 23rd Annual Meeting OHBM 2018,* Singapore, June 17 – 21, 2018.
3. Sam C. C. Chan, & Tom, C. W. Tsoi. The effect of visual imagery on the N400 semantic congruity of Chinese stroke sequence in elderly. *The Organization for Human Brain Mapping – 22nd Annual Meeting OHBM 2017,* Vancouver, Canada, June 25 – 29, 2017.
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Manuscript

1. Chan, C. C., **Tsoi, C. W.**, Yip, C. T., Ho, L., Chen, W. P. W., Cheung, D. H. L., Ho, T. C. L., Ng, A. H. K., Ng, Z. K. H., & Wong, S. C. H. (Accepted/In press). Comparison of effects of prefabricated soft wrist orthosis and conventional wrist thermoplastic splint on symptoms of carpel tunnel syndrome. Journal of Prosthetics and Orthotics.

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   Chan, C. C., & **Tsoi, C. W.** (In preparation). The Aging Effect of Contextual Integration on visual imagery of Chinese stroke stimulus: Evidence from ERP Correlates.

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   Tsoi, C. W., & Chan, C. C. (In preparation). Modulatory effect of top-down visual cues on maintenance of internal motor representation: Behavioural and electrophysiological study.

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CHAPTER ONE

INTRODUCTION

Chapter One provides an overview of the current thesis on investigating the modulatory effect of executive control on the external-to-internal attention orientation, generation of internal representation, and maintenance of internal representation. This chapter includes a statement of purpose with the objectives of a pilot study and Studies One and Two, the background and justification of the study, the research hypotheses, and ends with the chapter organisation of the thesis.

1.1. Statement of Purpose

The study consisted of one pilot study and two main studies. The objectives of each study were:

The pilot study was (1) to examine if providing external-to-internal attention orientation training before AOMI would affect executive control on attention shifting; and (1) to examine if providing external-to-internal attention training before AOMI would affect executive control on attention shifting, which would then enhance their proprioception of precision in joint position in the pilot study.

Study One was (2) to examine the modulatory effect of executive control through the presence of priority-cue and retro-cue on external-to-internal attention orientation, and maintenance of visual representation, which induce facilitation on accuracy; (2) to examine the modulatory effect of executive control through the presence of priority-cue and retro-cue on external-to-internal attention orientation and internal generation of representation, indicated by frontal theta-band power; and (2c) to examine the modulatory effect of the presence of priority-cue and retro-cue on the subsequent maintenance of visual representation, indicated by parietal alpha-band power.

Study Two was (3) to examine the modulatory effect of executive control through the presence of priority-cue and retro-cue on maintenance and inspection of kinesthetic representation, which induce facilitation on motor precision; (3) to examine the modulatory effect of executive control through the presence of priority-cue and retro-cue on attention orientation from maintenance of visual representation to generation of kinesthetic representation, indicated by frontal theta-band power; and (3c) to examine the modulatory effect of the presence of priority-cue and retro-cue on the subsequent maintenance of kinesthetic representation, indicated by parietal alpha-band power.

1.2. Background and Justifications

A growing body of research has recently focused on the motor improvements induced by concurrent action observation and motor imagery (AOMI) and discovered improved function in motor precision (Romano-Smith et al., 2018; Smith et al., 2019) and muscle strength (Scott et al., 2018). Concurrent AOMI has been shown to activate neural substrates in the AON and imagery networks. However, researchers rarely consider the impact of limited executive control resources on the motor learning process. The literature has not addressed the fact that AOMI places a higher demand on executive control to orient attention between external information and internal representation, select relevant motor schema through externally oriented attention, and generate action kinematics through internally oriented attention. It has been speculated that the rapid shifting of attention between external and internal representations require a higher level of executive control. Furthermore, encoding an external visual image and creating an internal kinesthetic representation necessitate top-down executive control to select the most relevant information from the external and internal contexts. It is suggested that the involvement of top-down visual cues might reduce the demand on executive control, which in turn improves the subsequent maintenance of motor representation by facilitating the external-to-internal attention orientation and internal inspection, and subsequent motor performance in terms of precision. Visual cues are found to be effective at directing attention to relevant information. The visual cues can prioritise information from the external world as well as within internal representation (Griffin & Nobre, 2003; Poth, 2020). While visual cues may aid in the selection of relevant information and the suppression of irrelevant representations, their presence may also consume executive function resources. It is important to determine if the visual cues help or hinder executive control since they might have a significant impact on performance.

The current study used electroencephalography (EEG) as a neurophysiological measure and time-frequency analysis to investigate and evaluate the modulatory effect of executive control through the presence of priority-cue and retro-cue on external-to-internal attention orientation and the internal maintenance and inspection of visual and kinesthetic representation and subsequent execution of action. Theta-band power over the prefrontal cortex and alpha-band power over the parietal cortex were used to demonstrate the influence on executive control and the maintenance of internal representation. Furthermore, a proprioception test on precision was used to demonstrate the facilitation in executing the movement.

1.3. Hypotheses

For each of the objectives listed in the previous section, the hypotheses are described as follows:

For the objective of the pilot study, it was hypothesized that the precision of joint position of the non-dominant hand would be enhanced after external-to-internal training, as demonstrated by the proprioception test and the Purdue Pegboard test in the pilot study.

For the objectives of Study One, (1) it was hypothesized that the presence of top-down priority-cue and retro-cue would facilitate the internal maintenance and inspection of the visual representation and, therefore, they would be able to respond more accurately. (2) It was hypothesized that executive control through the presence of priority cues and retro-cue would facilitate the external-to-internal attention orientation and the internal maintenance of visual representation signified by lower theta-band power over frontal cortical areas. (3) It was hypothesized that the presence of priority-cue and retro-cue would facilitate the maintenance and inspection of visual representation signified by lower parietal alpha-band power in Study One.

For the objectives of Study Two, (1) it was hypothesized that top-down priority-cue and retro-cue would facilitate the maintenance and inspection of kinesthetic representation, therefore, allowing participants to respond more quickly in the priority-cue and retro-cue conditions. (2) It was hypothesized that top-down priority-cue and retro-cue would facilitate the attentional orientation from maintenance of visual representation to the generation of kinesthetic representation, as signified by lower theta-band power over frontal cortical areas. (3) It is hypothesized that the presence of priority-cue and retro-cue would facilitate the generation and maintenance of kinesthetic representation, as signified by lower parietal alpha-band power in Study Two.

1.4. Study Significance

The findings of this study will shed light on the influence of executive control through priority-cue and retro-cue on attention orientation and maintenance of internal representation and how the higher centre of executive control on the attention and imagery-related systems. Furthermore, the results of this study provide the insights on how the higher executive center cooperate with the lower attention and imagery networks and the role of the visual cues on attention orientation. This study provides better understanding on executive control on attention orientation for improving motor control. The findings may also give insights on the training approaches to enhance the executive control of individuals who requires to process continual flow of external and internal information.

1.5. Organisation of the Chapters

This thesis consists of six chapters. This chapter provides an overview of the current literature on AOMI and their recruitment on AON for action understanding and image generation. Chapter Two reviews studies of executive control, attention orientation, action observation and motor imagery, rationale, objectives and hypothesis of the study. Chapter Three describes the methodology, analysis methods, and discussion of the pilot study. Chapter Four describes EEG Study One which aimed to investigate the effect of visual cues on facilitating the attention orientation and generation of the visuomotor representation in the working memory. Chapter Five describes EEG Study Two which aimed to investigate the effect of visual cues on facilitating the attention orientation and generation of the kinesthetic representation in the working memory. The final chapter includes with the discussion of behavioral and neurophysiological results reported, limitations, and future investigations.

CHAPTER TWO

LITERATURE REVIEW

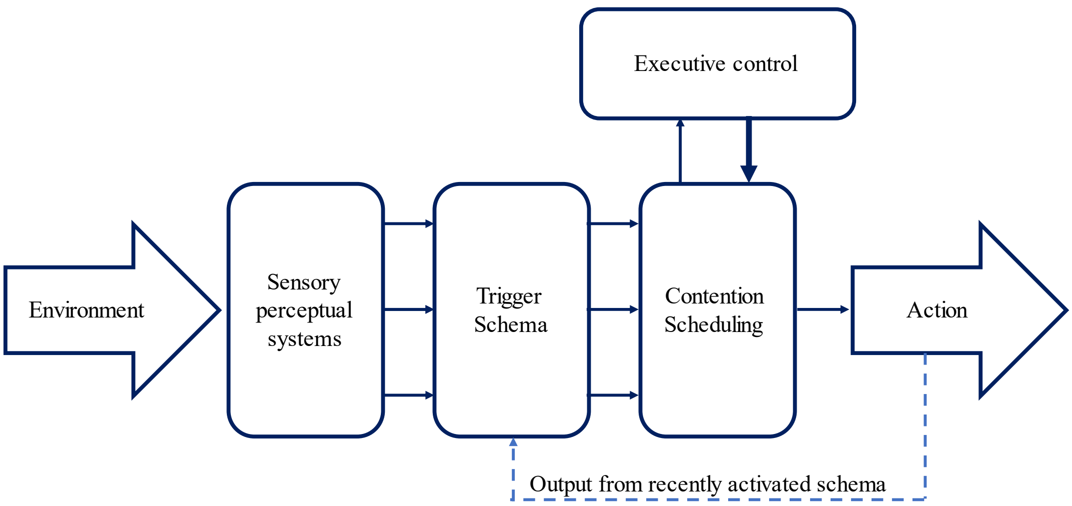
When we are learning new goal-directed movements through observation, our brain needs to process continual incoming visual information of the movement from the external context while generate the corresponding joint sensation in our mind. In order to achieve the action goal, the executive control may need to modulate attention to select relevant information and screen off irrelevant counterparts. Imagine a scenario in which you are watching a new YouTube video demonstrating muscle training on the posterior deltoid and you do not have the dumbbell in hand. You might try to imagine yourself performing the movement while simultaneously watching the video. In this example, the executive control needs to modulate attention to select relevant information, from the video, i.e., such as shoulder join angle and limb orientation, and imagine joint sensation when doing the movement in your mind at the same time. This attention would serve as an input filter because it enables the brain to prioritise the processing of sensory information according to the predetermined goal. As information comes from both external context and internal space, attention needs to operate externally and internally to select and filter relevant information. Externally oriented attention is drawn to environmental stimuli. External attention can be voluntarily controlled by task demands with top-down control, i.e., searching for some features in the scene. Internally oriented attention is focused on internal representations while being separated from external stimulation. So, how does the executive control monitor the situation when both external attention and internal attention are required at the same time? This is of specific concern if the executive control, which has limited resources, can master the attentional orientation between the external and internal information flow, as well as the transition from visual information to kinesthetic representation at the same time. A growing body of research has recently focused on the motor improvements induced by concurrent action observation and motor imagery (AOMI), which is similar to the aforementioned example, and was found to be able to improve motor control in terms of movement precision (Romano-Smith et al., 2018; Smith et al., 2019) and muscle strength (Scott et al., 2017). However, researchers rarely consider the impact of limited executive control resources on the motor learning process. Ongoing shifting of attention between external and internal representations may consume the resources in executive control and may impede both external and internal processes (Burgess et al., 2007; Verschooren et al., 2019). Indeed, attention can be directed to perceptual information and information in working memory. Visual cues are found to be effective "cognitive tools" to direct attention to relevant information while disregarding the goal-irrelevant counterpart. Visual cues can prioritise information from the external world as well as within internal representation (Griffin & Nobre, 2003; Poth, 2020). However, the executive control might be interfered by the presence of visual cue. Whether such cognitive strategies would give undermine the efficiency of executive control is not well addressed. Together, it becomes an intriguing question whether the presence of top-down visual cues which enhance the extraction of relevant sensory information and the generation and maintenance of internal representation would facilitate the executive control through prioritisation or the cognitive strategies actually reduce the available resources of executive control.

2.1. Executive Function and Attention

Various models developed referred to a central processor, a central executive system, or a supervisory system. This system is in a higher hierarchy in the cognitive architecture, which involves higher-order processes like interference control and attention orientation and leads to selection and control over lower-level subsystems (Gardelle & Kouider, 2009). Broadbent (1958) put forward another key element related to executive control; that is, attention filer the relevant information. Because of the continual influx of sensory information from the external context, a huge amount of information becomes available to our brain (Lachter et al., 2004). However, executive control is very limited in terms of computational resources. Therefore, a selection mechanism is required to prevent overloading. Attention operates by selecting the most relevant information and filtering out information that is irrelevant. The most relevant information becomes the target of executive control and benefits from more enriched processing (Kouider & Gardelle, 2009). Norman and Shallice (1986) developed a theoretical framework for the implementation of goal-directed behavior against competing sensory input. According to this model, automatic actions are based on the activation of a task schema by bottom-up sensory input. Schema can be activated by triggers, such as sensory input or the outcomes of another schema. Competition between schema is controlled by lateral inhibition mechanisms, termed "contention scheduling." However, the coordination of schema with higher-level goals requires the additional employment of a supervisory attentional system to exert top-down control by deactivating certain schema and activating relevant schema for higher-level goals (Alexander & Brown, 2010). This model depicts the basic architecture of the cognitive system: Sensory inputs are processed in parallel; attention performs selection on the sensory information, and the executive control acts as a supervisor to exert top-down control over attention according to the behavioural goals (Kouider & Gardelle, 2009). Therefore, the executive control would exert top-down control through deactivating irrelevant schema and activating relevant schema when there is more than one sources of information (Alexander & Brown, 2010). In daily life, sensory information from the external environment and internal information in the brain. However, not much is currently known about cognitive processes involved in attention shifting between external information and internal representation.

Figure 2.1

Schematic Presentation of Norman and Shallice' Theoretical Framework



Note. Sensory inputs are processed in parallel; schemas are activated by sensory inputs; attention performs selection on the sensory information; the executive control acts as a supervisor to exert top-down control over attention

2.2. External Oriented Attention and Internal Oriented Attention

Attention operates by selecting the most relevant information and filtering out information that is irrelevant. As information comes from both external and internal world, attention need to operate externally and internally to select and filter relevant information. Externally oriented attention is directed at external stimuli and refers to the processes of selecting and modulating sensory information. External attention can be voluntarily controlled by task demands with top-down control, i.e., when we search for some features in the scene, or involuntarily captured by an object in a bottom-up fashion. Internally, oriented attention is separated from external stimulation and focused on internal representations; it refers to the selection and modulation of internal information (Chun et al., 2011).

2.2.1. External-to-Internal Attention Orientation

Everyday life overloads us with sensory information from the external environment and internal information (e.g., memories, ideas) in the brain. Attentional orientation directs the selection of useful information from a large amount of irrelevant data and optimises our perception (Lepsien & Nobre, 2006), selecting one or more pieces of useful information for further processing (Perterson & Posner, 2012). Orienting attention allows a person to perceive information from the external environment as well as internal processing, such as imagery and working memory (Lepsien & Nobre, 2006).

According to Posner's attention orientation model developed by (Posner et al., 1984; Peterson & Posner, 2012), the act of orienting one's attention between two different external stimuli is comprised of three different sub-processes, including disengagement, shifting, and reengagement. This model states that the shift of attention involves disengaging from the fixation point, shifting attention to a new target, and then re-engaging on the new target. Many studies have investigated the attentional orientation between two external stimuli in the last few decades (Dowman, 2011; Dowman et al., 2007; Kuo & Astle, 2014). Posner's model illustrates the attentional orientation between two visual stimuli in the external environment but not the attentional orientation between an external stimulus and an internal representation. External-to-internal attention orientation is important as we are often required to have high-level internal cognitive processes while perceiving perceptual information in the external world, like discrimination or appraisal. The attention orientation between external stimulus and internal representation involves executive control (Chan et al., 2012; Legrain et al., 2013). However, how the top-down control modulates the external-to-internal attention orientation is still not clear. The external-to-internal attention orientation requires the executive control to modulate the shifting of attention between two sources of information, i.e., perceptual information and internal representations. It involves the disengagement from the external stimuli, shifting attention toward the internal representation, and re-engage on the internal representations. The relatively large amount of external sensory stimuli requires external attention to select the most relevant information to the current goal and the maintenance of the internal generated representation required internal oriented attention. As the executive control has a limited capacity to govern the attention system, it is not clear that how the top-down executive control modulates the attention orientation to select relevant information between two information without disrupting each information flow.

2.3. Executive Function and Attentional Control on Motor Control: AOMI

People frequently encounter situations in which they must maintain an attentional orientation between external stimuli and internal representations. The neural processes underpinning concurrent action observation and motor imagery not only require the executive control to modulate the attention orientation between the external information and internal representation, but they also include the visual processing, the retrieval of action associations, the selection of the actions that are most likely to occur, the encoding of action representation, and the prediction of action kinematics (Kilner, 2013).

Conventionally, action observation (AO) refers to the process of observing meaningful actions with the intention to imitate, followed by execution (Buccino et al., 2014). Through the frontoparietal mirror network, AO is able to enlist the brain areas in the observer that are responsible for the matching motor execution (ME). The results of neurophysiological investigations on monkeys' mirror neurons have contributed to the body of information that exists about AO intervention in the domain of neurorehabilitation (Bahr et al., 2018; Pellegrino et al., 1992). The transition of visual information into motor format by activating a replication of comparable action representations stored in the motor repertoire is the core of the mirror neuron process. This helps an observer to comprehend an action being performed by other people. Indeed, the internalisation of visual information can be related to the neural processes that generate and maintain a visual representation. The internalisation of visual information into internal representation involves the external-to-internal attention orientation. Attention needs to be directed internally when the visual representation of an action is generated and maintained. This process requires the executive control to orient attention disengaging from external information and re-engaging to the internal generated representation. Subsequent studies have provided evidence that mirror neurons exist in humans and are activated when observing and executing movements (Kilner & Lemon, 2013). Studies using functional magnetic resonance imaging (fMRI) have discovered that humans possess a network that is analogous to the one observed in monkeys. This network, known as the "action observation network" (AON), is comprised of the ventral premotor cortex, the IPL, and the STS (Ertelt & Ninkofski, 2012; Kilner & Lemon, 2013). This AON network contributes to the comprehension of actions and intentions, as well as speech production and imitation (Rizzolatti & Fabbri-Destro, 2008). Two meta-analyses found evidence of an overlapping network that includes regions of the inferior prefrontal gyrus (IFG) and the inferior parietal lobule (IPL) in the AO and ME of the same action (Caspers et al., 2010; Mukamel et al., 2010). These regions came together to form the premotor-parietal mirror system. Action understanding involves several neural processes, including visual processing, the retrieval of action associations, the selection of the actions that are most likely to occur, the encoding of action representation, and the prediction of action kinematics (Kilner, 2013). The ventral pathways of the middle temporal gyrus (MTG) and the inferior frontal gyrus (IFG), respectively, are responsible for encoding the retrieval of action associations and the selection of the most appropriate action. Executive control would take place to exert top-down control by deactivating certain schema and activating relevant schema during the selection of the most appropriate actions in the ventral pathway. The most relevant feature in AO becomes the target of executive control and benefits from more enriched processing (Norman & Shallice, 1986). The dorsal action-observation network (AON) is responsible for the generation of action representation as well as action kinematic prediction. Several studies have demonstrated a beneficial effect of AO on improving the learning of motor tasks, ranging from simple pointing tasks to complex sports movements. The

AO-induced neuroplastic reorganisations may provide an explanation for the motor learning achieved by AO. Both healthy individuals and clinical post-stroke patients have been shown to benefit from these positive effects on motor learning (Emerson et al., 2018).

On the other hand, motor imagery (MI) is the imagery of a movement without its actual execution (Decety, 1996; Borst & Kosslyn, 2010; Monany et al., 2022). Imagery was defined as a multi-componential process, composed of generation, maintenance and inspection of mental images (Beni et al., 2007; Kosslyn, 1994). Among different forms of MI, kinesthetic imagery focuses on the kinesthetic sense and the muscle aspect of action whilst visuomotor imagery is related to the mental visualisation of a movement. In MI, kinesthetic information is retrieved from long-term memory, and representations of the kinesthetic senses are generated in the frontoparietal areas of the brain. As there are no sensory inputs in kinesthetic imagery, executive control is required to initiate a top-down control on the retrieval of the schemata from the long-term memory and the selection of the most relevant schema. After the selection of action schema, the next step is the encoding of the motor parameters to generate a prediction of the sensory consequences of the observed action, which is the generation of kinesthetic representation in the frontoparietal brain regions. During kinesthetic motor imaging of a specific finger sequence, Lebon et al. (2018) discovered that the frontal and parietal areas are functionally connected to each other, which might indicate the generation of kinesthetic representation. The neurofunctional equivalence between MI and ME may explain motor skill learning without actual execution. According to the simulation theory proposed by Jeannerod (2001), MI and ME have similar neuro-functional properties. Both MI and ME have neuronal substrates that overlap with one another (Gerardin et al., 2000). A meta-analysis reported an overlapping network that comprises premotor and parietal regions during MI and ME (Hardwick et al., 2018). In addition, investigations that used transcranial magnetic stimulation found an effector-specific increase in corticospinal excitability during a MI (Grospretre et al., 2016). Temporal characteristics linked with MI are comparable to those of ME, as are the biomechanical and environmental restrictions (Kilteni et al., 2018). It has been proposed, from a computational point of view, that the equivalent sensorimotor mechanisms that are involved in ME and MI would be the reason why these two events would have similar features. Numerous studies (e.g., Collet et al., 2011) have shown that MI has a positive impact on the learning, consolidation, and retention of motor skills, which includes improvements in muscular strength and speed (Grabherr et al., 2015).

The transition of visual information into internal representation in AO involves the external-to-internal attention orientation which requires the executive control to orient attention disengaging from external information and re-engaging to the internal generated representation. On the other hand, MI requires the executive control to orient attention on the selection of action schema to generate kinesthetic representation. Therefore, the executive control not only exerts top-down control on activating relevant schema and generates the kinesthetic representation, but it also requires additional effort to orient attention between two information. It is important to study AOMI from the limited resources of executive control.

2.4. Modulating Effect of Top-down Executive Control on AOMI

In recent studies, the effects of concurrent AO and MI has been investigated. It was hypothesized that this would improve the process of selecting an action representation from an action via AO and would initiate mental rehearsal and the generation of associated sensory components through MI. According to the findings of a meta-analysis research study that compared the networks of AO, MI, and ME, AO and MI recruited the same frontoparietal cortical networks for mental rehearsal of the action (Hardwick et al., 2018). Jeannerod (2006) proposed that AO develops a mental image of the activity being performed internally. Internally, visual rehearsed action can be regarded as the encoding of action representation and anticipating action kinematics from observing action in motion. The MI utilises top-down mental rehearsal of action movement, which requires the selection of the most relevant action representation from memory and the generation of associated sensory or kinesthetic representations. Both processes need higher top-down executive control in order to keep the mental rehearsal of the appropriate action going on in the inside. In addition, simultaneously encoding relevant action representation via AO and retrieving kinesthetic action representation via MI therefore elicits two flows of action information in the action organisation network (AON) and the motor imagery network, which would require ongoing attentional orientation between these two representations. According to Posner's attention orientation model, orienting one's attention between two different stimuli is comprised of three different sub-processes, including disengagement, shifting, and reengagement (Peterson & Posner, 2012; Posner et al., 1984). The attention orientation between external stimulus and internal representation involves executive control (Chan et al., 2012; Legrain et al., 2013). However, very little research has been done on whether the executive would be able to handle external-to-internal attention orientation of the action movement and the image generation of kinesthetic sensation. Concurrently, top-down executive control is required to orient attention between the external stimulus and internal representation, select the appropriate action schema induced from the visual AO, and select the relevant schema related to the instructed action to generate the kinesthetic representation in MI. Therefore, the effect of top-down executive control on concurrent AOMI requires further investigation. In such an overloaded situation, the processes to retrieve and select relevant schema are supposed to be interfered with.

2.5. The Interaction of Visual Cues and AOMI

Concurrently, top-down executive control is required to orient attention between the external stimulus and internal representation in AOMI, select the appropriate action schema induced from the visual AO and the subsequent relevant schema related to the instructed action to generate the kinesthetic senses in MI. In this respect, AOMI requires a high level of top-down executive control in order to modulate the selection of appropriate action kinematics and shift one's attention between the external visual motions and the internal kinesthetic representations. Utilising visual cues is one method that may be used in order to regulate the top-down executive control that is present in AOMI. Nobre et al. (2004) have used the visual priority-cue and retro-cue paradigms to study covert attention with visual stimuli. They discovered that externally oriented attention can be manipulated by using priority-cue and internally oriented attention can be manipulated by using retro-cue, and that doing so, results in greater accuracy and shorter response time (Griffin & Nobre, 2003; Li & Saiki, 2015; Nobre et al., 2004). Indeed, priority-cue and retro-cue manipulate the selection process of information externally and internally. Priority-cue manipulates the selection of external information into internal representation, whereas retro-cue helps to select the relevant information within an internal representation, which has been generated and maintained on the working memory buffer under the executive control.

AO requires the participants to process visual inputs, encode action representations, and anticipate action kinematics from observing actions in motion (Kilner, 2013). The priority-cue integrates feature information from sensory stimuli and top-down representations of behavioural goals originating in the dorsolateral prefrontal and premotor cortex (Ptak, 2012). Indeed, the priority-cue provide information to the executive control to modulate the selection of relevant and irrelevant information. It is possible for the existence of the priority-cue to modulate attention that is focused externally on the selection of relevant and irrelevant information, which then, facilitates the prioritisation of the maintenance of relevant information (Robison & Unsworth, 2017). As a result, the existence of the priority-cue may make it easier to retrieve the action association and identify the appropriate action representation in AOMI.

On the other hand, in order to participate in MI, a person needs to mentally practice the actions and keep a kinesthetic image in their head. According to the findings of a few pieces of research, retro-cue acts as a catalyst for improved behavioural performance (Fan et al., 2021; Gazzaley et al., 2012; Rerko et al., 2014; Ye et al., 2016). Retro-cue during the maintenance period can manipulate knowledge or representation retroactively about which internally maintained items will be relevant for subsequent behavior (Gazzaley & Nobre, 2012). Retro-cue provide information to executive control to modulate the selection of relevant internal representation. Internal inspection via retro-cue elicits executive control and operate on working memory representations. It has been hypothesized that providing a retro-cue to participants helps them perform better because it makes it easier for them to select relevant schema (Rerko et al., 2014). The selection of relevant information should directly contribute to the quality of the representation of the information. Compared to focusing on all items, it would provide more resources to be concentrated on the storage of the relevant information and reduce the interference of irrelevant information (Göddertz et al., 2018). The maintenance of the relevant information become more precise which in turn enhances their accuracy rate (Rerko et al., 2014). The presence of retro-cue actually may put a higher burden on the executive control. In fact, MI requires the selection of relevant action schema and the retrieval of kinesthetic information from long-term memory, as well as the generation of representations of the kinesthetic senses in the frontoparietal regions. Giving a retro-cue to AOMI may help keep irrelevant action representations and kinematics from being stored in long-term memory so that relevant kinesthetic representations can be formed more quickly and more accurately.

Priority-cue and retro-cue are suggested to lower the demand on top-down executive control to alternate between external visual information and internal kinesthetic representation. However, how these cognitive strategies could modulate the efficiency of executive control over attention orientation to movements or mental imagery of the kinesthetic sensation. The dual-entity strategy of AOMI requires a high level of top-down executive control in order to orient attention between external representation and internal representation, encode action representation, anticipate action kinematics from observing action in motion, and select appropriate schema to generate kinesthetic representation. However, the presence of visual cues may hinder the concurrent processing of motor representation by adding additional burden on the executive control for selecting relevant and irrelevant information. This might cause the executive function to become overloaded. Studies on priority-cue and retro-cue have shown activity over the prefrontal cortex, which demonstrates the involvement of top-down executive control on the prioritizing of representations (Myers et al., 2015; Ptak, 2012; Riddle et al., 2020).

There is a limited number of studies that address the effect of the top-down priority-cue and the top-down retro-cue on the attention orientation to maintain alignment between the information received from the external environment and internal representation. Additionally, despite the fact that both the priority-cue and the retro-cue engage the same frontoparietal control network, it is probable that the two types of cues have some distinct processing distinctions. In the same way that a priority-cue makes it easier to pick up forthcoming visual information, a retro cue helps an individual to prioritise and select information internally (Myers et al., 2015). Therefore, it is worth investigating whether the incorporation of top-down visual cues will result in a net facilitation or impediment of AOMI processing. This question may be answered by comparing the effects of both scenarios.

2.6. Electrophysiological Measures on Concurrent AOMI

In order to measure the neural activities that are related to the effect of executive control on attention orientation and generation of imagery, Event-related desynchronisation would be one of the pertinent methods. Event-related desynchronisation, or ERD, is a relative power decrease of ongoing EEG activity in a specific frequency band (Neuper et al., 2006). ERD occurs when a specific area of the brain becomes more active for a specific neuronal activity. Event-related synchronisation, or ERS, refers to a rise in power in certain frequency bands when a particular area is less engaged and in synchrony with the majority of the neuronal population. ERD/ERS reflect changes in the activity of local interactions between main neurons and interneurons that control the frequency components of the ongoing EEG (Pfurtscheller & Lopes da Silva, 1999). The concept that the prefrontal cortex (PFC) is associated with executive control over attention shifting between internal and external information is supported by research on perceptual information and internal representation. It has been hypothesized that a control system located in the rostral prefrontal cortex controls two forms of attention (Gilbert et al., 2005; Henseler et al., 2011). An fNIRS study has demonstrated a neural signature for concurrent AOMI compared to AO-only and MI-only strategies over the left prefrontal cortical areas, and the corresponding cortical area is responsible for attentional switching between concurrent representations of bottom-up AO and top-down MI (Emerson et al., 2022). Indeed, enhanced theta-band ERS have been shown in response to stimuli with high levels of conflict (Clayton et al., 2015; Cohen & Donner, 2013; Cooper et al., 2017). Recent research has revealed that frontal theta-band oscillations and fronto-parietal network connections have a role in executive control when working memory tasks are being performed (Kawasaki et al., 2010). These findings imply that the frontal cortex regulates the initiation of various representational states within sensory working memory, as well as the switching between those states, and that it does so via low-frequency oscillations. Theta-band power changes are associated with the updating of task sets when attention needs to shift to incoming information (Braver, 2012; Clements et al., 2021). It has been discovered that the frontal midline theta-band power is unique to the performance of mental tasks and that it is more prominent during competition as compared to the performance of internal attention alone. According to Magosso and colleagues (2021), the frontal midline theta-band power may be a marker of greater executive control; the underlying brain substrate anterior cingulate cortex appears to be primarily implicated and causally related to distant posterior areas (occipital). Therefore, it is believed that frontal theta-band oscillations reflect executive control.

The role of alpha-band power over the parietal cortex in disengaging task-irrelevant cortical regions has been proposed (Brinkman et al., 2014). The alpha-band power decrease in the MI is associated with the process of retrieving and generating kinesthetic action representations (Wriessnegger et al., 2018). Indeed, changes in alpha-band power are frequently associated with the maintenance of currently active representations (Braver, 2012; Clements et al., 2021). For example, posterior alpha-band ERS (higher alpha-band power) has been linked to the inhibition of the processing of visual stimuli, whereas alpha-band ERD (lower alpha-band power) can be interpreted as release from inhibition (Klimesch et al., 2007; Lrincz et al., 2009; Mathewson et al., 2011). Therefore, the power of the alpha-band might be related to the mechanism by which, the brain filters out perceptual information so as to prevent it from interfering with the representations that are now being used. Time-frequency analysis can be used to investigate fluctuations in alpha power that occur during ongoing cognitive tasks. During working memory retention, increased alpha-band power has often been recorded (Blacker et al., 2016; Wianda & Ross, 2019). These changes in power within the alpha-band have been regarded as a process connected with the maintenance of task-related memories in the brain.

An electroencephalogram (EEG) study that was looking at the relationship between the medial prefrontal regions and memory schema modified the settings using the priority-cue. They discovered a decreased theta-band power over medial prefrontal regions when a priority-cue was present, and they hypothesized that this structure is accountable for the context-relevant activation of schemas (Gilboa & Moscovitch, 2017). It has been hypothesized that using a priority-cue may facilitate the encoding and retrieval of relevant action representations, thereby minimising the amount of effort required by executive control.

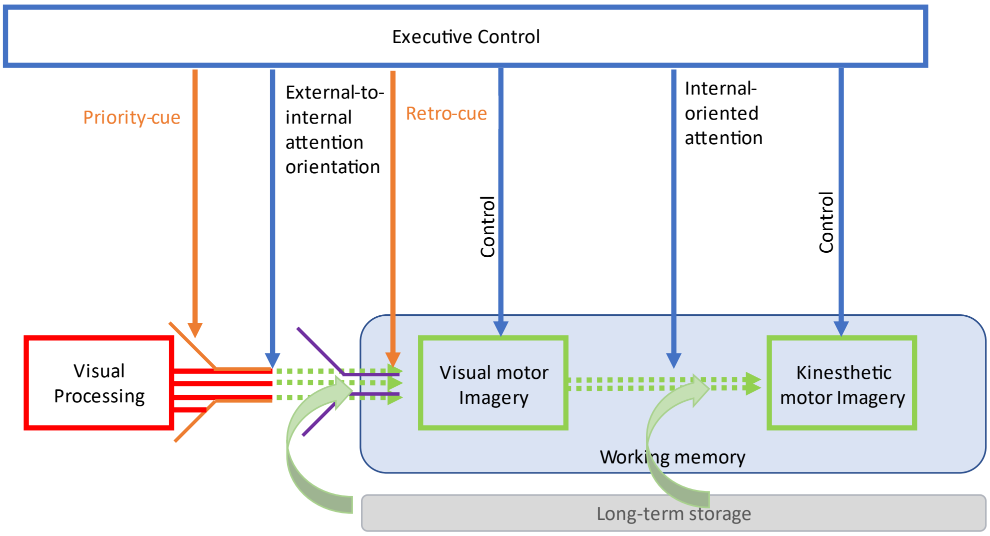
On the other hand, it has been shown that retro-cue is linked to decreased alpha-band power over parietal cortex as well as higher accuracy (Riddle et al., 2020). Furthermore, a study on working memory has investigated on the EEG dynamics with retro-cue. The participants were asked to remember the three orientations shown on the screen in the study. A retro-cue was presented pointing to the location of the target after the orientations was shown. A test display was presented which participants were asked to rotate a randomly oriented bar to match the orientation of the tested target. Alpha-band power suppression was found during the intention interval (Günseli et al., 2019). Sauseng et al. (2005) found a link between alpha-band oscillations in the parietal cortex and the suppression of representations that have already been encoded but are no longer important to the current task. It has been suggested that the use of a retro-cue in AOMI would make it easier to inhibit task-irrelevant schema and select task-relevant schema, minimising the amount of effort required by executive control. In order to facilitate the prioritisation of relevant features and the suppression of irrelevant representation in AOMI, the priority-cue and the retro-cue have been proposed as possible solutions.

2.7. Study Rationale

Although concurrent AOMI has been shown to heighten the cortical activations in the AON and imagery network, the literature has not addressed the fact that AOMI may place a higher demand on executive control to orient attention between external action-related information and internal action-related representations, to select relevant motor schema through externally oriented attention, and generate action kinematics through internally oriented attention. It has been speculated that the rapid shifting of attention between external representation and internal representation requires a higher level of executive control. Furthermore, encoding an external visual image and creating an internal kinesthetic representation necessitate top-down executive control to select the most relevant information from the external and internal contexts. It is suggested that the involvement of top-down visual cues might reduce the demand on executive control, which, in turn, improves the subsequent maintenance of motor representation, and motor performance in terms of precision. While visual cues may aid in the selection of relevant information and the suppression of irrelevant representations, their presence may also consume executive function resources. It is important to determine if the visual cues help or hinder executive control since they might have a significant impact on performance. A schematic diagram in Figure 2.2 was proposed to illustrate the hypothesized neural processes of executive control on external-to-internal attention and generation of visuomotor and kinesthetic images. A pilot behavioural study was conducted to investigate the effect of external-to-internal attention shifting training on executive control and the subsequent regeneration of movement. The Study One used a delayed recognition task with visual stimuli along with the measurement of cortical oscillations and the subsequent Time-Frequency Analysis to evaluate the modulatory effect of executive control through the presence of priority-cue and retro-cue on external-to-internal attention orientation and, the internal maintenance and inspection of visual representation, and subsequent behavioural performance in terms of accuracy. Another EEG study with Time-Frequency Analysis has been carried out in Study Two to investigate the modulatory effect of executive control through the presence of priority-cue and retro-cue on external-to-internal attention orientation and, the internal maintenance and inspection of kinesthetic representation in AOMI, and subsequent motor performance in terms of motor precision. In the EEG studies, healthy participants' mental processes of executive control and maintenance of representation under the influence of visual cues in terms of cortical oscillations and motor performance were investigated.

Figure 2.2

Schematic Diagram of the Facilitating Effect on Attention Orientation



Note. The Priority-cue and Retro-cue was hypothesized to facilitate the external and internal selection of information.

Theta-band power over the frontal region is related to top-down executive control. It is suggested that visual cues could facilitate the selection of relevant information, which, in turn, would reduce the load on the executive control system, as indicated by reduced theta-band power over the prefrontal cortex. Alpha-band power over the parietal cortex is related to maintaining and inspecting action representation in kinesthetic form. It is suggested that the presence of visual cues could facilitate executive control and modulate attention toward the suppression of irrelevant representation, which, in turn, would reduce the alpha-band power over the parietal cortex.

2.8. Objectives

In order to address the rationales discussed above, there were three stages of the study. For the pilot study, the objectives were: (1) to examine if providing external-to-internal attention orientation training before AOMI would affect executive control on attention shifting; and (2) to examine if providing external-to-internal attention training before AOMI would affect executive control on attention shifting, which would then enhance their proprioception of precision in joint position.

For Study One, the objectives were as follows: (1a) the modulatory effect of executive control through the presence of priority-cue on external-to-internal attention orientation, and maintenance of visuomoter imagery, which induce facilitation on reaction time; (1b) the modulatory effect of executive control through the presence of retro-cue on internal maintenance and inspection of visuomotor imagery, which induce facilitation on accuracy; (2a) the modulatory effect of executive control through the presence of priority-cue on external-to-internal attention orientation in visual imagery, indicated by frontal theta-band power; (2b) the modulatory effect of executive control through the presence of retro-cue on internal maintenance of visual representation, indicated by frontal theta-band power; (3a) the modulatory effect of the presence of priority-cue on the subsequent maintenance of visual representation, indicated by parietal alpha-band power; and (3b) the modulatory effect of retro-cue on the subsequent inspection of visual representation, indicated by parietal alpha-band power.

For Study Two, the objectives were as follows: (1) the modulatory effect of executive control through the presence of priority-cue and retro-cue on maintenance and inspection of kinesthetic representation in AOMI, which induce facilitation on behavioural performance; (2) the modulatory effect of executive control through the presence of priority-cue and retro-cue on internal attention orientation from the maintenance of visual representation to the generation of kinesthetic representation in AOMI, indicated by frontal theta-band power; and (3) the modulatory effect of the presence of priority-cue and retro-cue on the subsequent maintenance of kinesthetic representation in AOMI, indicated by parietal alpha-band power.

2.9. Hypotheses

In the pilot behavioural study, it was hypothesized that the precision of joint position of the non-dominant hand would be enhanced after external-to-internal training, as demonstrated by the proprioception test and the Purdue Pegboard test.

In Study One, it was hypothesized that a top-down priority-cue would facilitate the external-to-internal attention orientation and maintenance of visual representation, therefore, allowing the participants to respond more quickly in priority-cue conditions. It was hypothesized that a top-down retro-cue would facilitate the internal maintenance and inspection of the visual representation and, therefore, they would be able to respond more accurately. On a neurophysiological level, it was hypothesized that executive control through the presence of a priority-cue would facilitate the external-to-internal attention orientation signified by lower theta-band power over frontal cortical areas, indicating a lower demand on executive control. It was also hypothesized that the executive control through the presence of a retro-cue would facilitate the internal maintenance and inspection of the visual representation signified by lower theta-band power over frontal cortical areas, indicating a lower demand on executive control. It was hypothesized that the presence of a priority-cue would facilitate the maintenance of visual representation signified by lower parietal alpha-band power, indicating the relevant representation is released from inhibition. It was hypothesized that the presence of a retro-cue would facilitate the inspection of the visual representation signified by lower parietal alpha-band power, indicating the relevant representation is released from inhibition.

In Study Two, it was hypothesized that top-down priority-cue and retro-cue would facilitate the maintenance and inspection of kinesthetic representation, therefore, allowing participants to execute the movement more accurately in the combined priority-cue and retro-cue condition. It was hypothesized that top-down priority-cue and retro-cue would facilitate the attentional orientation from the maintenance of visual representation to the generation of kinesthetic representation, as signified by lower theta-band power over left lateral frontal cortical areas. It is hypothesized that the presence of the combined priority-cue and retro-cue condition would facilitate the generation and maintenance of kinesthetic representation, as signified by lower parietal alpha-band power.

CHAPTER THREE

PILOT STUDY

Enhancement of the External-to-internal Attention Training on the AOMI Effect on Motor Precision

3.1. Overview of the Study

In this pilot study, the effect of external-to-internal attention training on attention shifting function was investigated. The results of this pilot study would set a good foundation to conduct the two main studies which aimed to investigate the modulatory effect of executive control on generation and maintenance of internal representation and subsequent facilitation on motor precision. It is suggested that AOPM group would enhance attention disengagement and shifting, which, in turn, would mediate improvement in motor precision through the AOMI training. Participants were allocated to either of the two training groups: (1) action observation and passive movement (AOPM) training (the experimental group) or (2) action observation (AO) training. The whole training lasted for six sessions within a period of two weeks, and participants were required to complete the three outcome tests before and after the training.

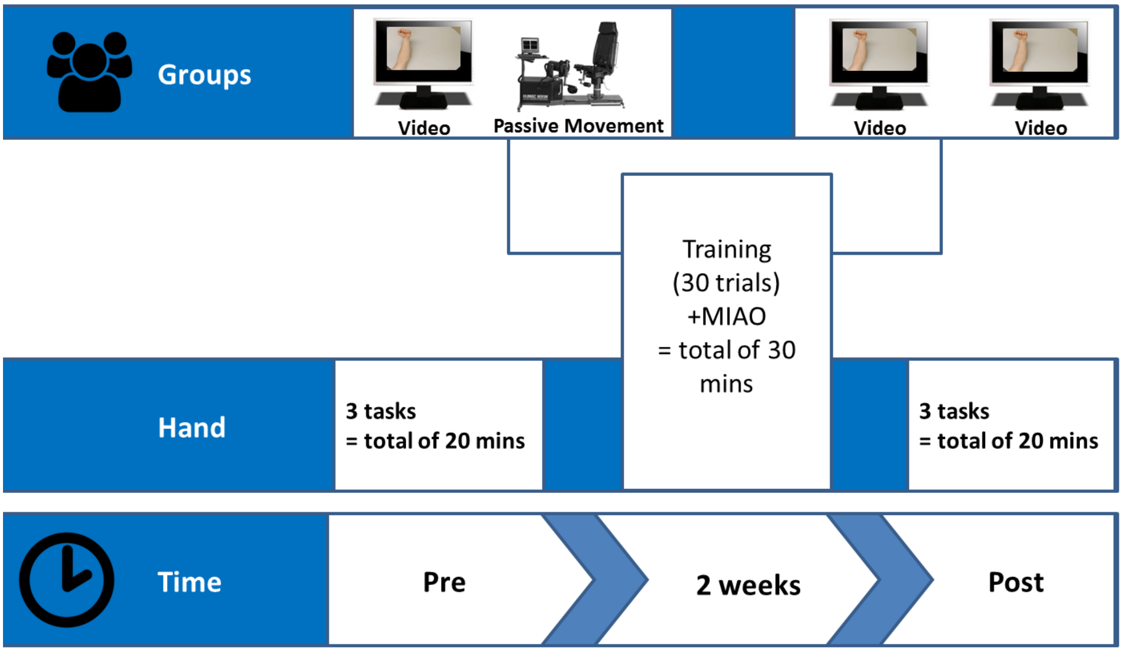
3.2. Methods

3.2.1. Experimental Design

A pre-and-post longitudinal design with two groups was adopted in this pilot study. Each participant was required to complete 3 outcome tests, including the proprioceptive test, the Purdue Pegboard test, and the Stroop test, before and after the AOMI training. All the volunteers were allocated to either of the two training groups: (1) action observation and passive movement (AOPM) training (experimental group) or (2) action observation (AO) training. Each training group had to complete discrimination training in each training session. The whole training lasted for six sessions within two weeks (Figure 3.1). After the training sessions had been completed, participants were required to complete the three outcome tests.

Figure 3.1

Schedule of the Study. Bottom: Timeframe from the Pre (Baseline) to Post; Top: Groups' Conditions.



3.2.2. Participants

The pilot study included twelve healthy volunteers (eight men). The mean age of adults was obtained to be 25 years (SD = 3.4). The inclusion criteria were: (1) being right-handed as assessed by the Edinburgh Handedness Inventory (Oldfield, 1971); and (2) not having an injury in their elbow joint. No one had a history of brain trauma or other disease that alters the brain.

3.2.3. Stimulations for Training

There were two types of stimulation given to the participants: video clips of elbow movements to be used during the AOMI training for both the action observation and passive movement (AOPM) and action observation (AO) groups, and kinesthetic sensations provided by the Cybex Humac Norm System.

Video clips with a non-dominant (left) upper extremity (from the hand to the mid-length of the upper arm) moving from full elbow extension to elbow flexion at 5 pre-set angles, i.e., 30°, 50°, 70°, 90°, and 110°, with a speed of 20°/s, were presented to each participant in the experiment. The video was provided on a computer screen (dimensions: 35cm in length by 20cm in width) with an eye-to-screen distance of 80cm.

The Cybex Humac Norm System was used to provide kinesthetic sensation by passively moving the elbow in between extension and flexion (Figure 3.2). With the participants seated on a seat with back and foot support, passive movement moving from full elbow extension (0°) to elbow flexion at 5 pre-set angles (i.e., 30°, 50°, 70°, 90°, and 110° with a speed of 20°/s) were used in the experiment. The Cybex Humac Norm System has specific settings for elbow extension/flexion testing, including a chair rotation scale of 35° and a dynamometer rotation scale of 55°. The operator needs to raise the dynamometer and adjust the length of the elbow adaptor to properly align the participants' axis of rotation with the dynamometer's axis. The chair location is also adjusted at an appropriate distance from the dynamometer to properly align the axes.

Figure 3.2

Cybex Humac Norm

3.2.4. Experimental Procedure

Each participant, who fulfilled the inclusion and exclusion criteria, gave their written consent to join the study and was allocated randomly to either the AOPM (experimental) or AO (control) groups. The Edinburgh Handedness Inventory was used to distinguish his or her dominant hand (Oldfield, 1971). Each participant was required to go through a number of outcome measures tests at the baseline, including the Purdue Pegboard Test, proprioception testing on the elbow joint, and the Stroop Test. Following the initial outcome tests, each participant then received attention and imagery training depending on the AOPM or AO protocol before they went through the AOMI training, in which, each of them was required to observe the elbow in motion and to generate kinesthetic imagery. All participants in either group went through all the outcome measure tests again after the completion of the training.

3.2.5. Training Protocol for AOPM, AO, and AOMI Training

Each participant was assigned to either the AOPM or the AO group and instructed to attend a six-session training programme three times per week for two weeks. In each session, each of the participants in both groups was also required to attend AOMI training.

3.2.5.1. AO (Control) Group

Prior to the beginning of the AO training, each participant was explained the purpose of the AO training and how he or she was to be positioned in relation to the computer screen on which the video clips of movements were played. For familiarisation purposes, he or she was first shown video clips of the non-dominant elbow joint moving from full extension to flexion at one of the five pre-set angles to be used in the training, i.e., 30°, 50°, 70°, 90°, and 110° at a speed of 20°/s. In each trial of the AO training, the participants were required to view a video clip with a non-dominant arm moving from full elbow extension to elbow flexion at one of the five pre-set angles (30°, 50°, 70°, 90°, and 110° for 20°/s in speed). He or she needed to remember the angle being shown visually. After 2 seconds, the participants were asked to view a video clip of the same arm moving from full elbow extension to another randomised pre-set angles (30°, 50°, 70°, 90°, 110° for 20°/s in speed) of elbow flexion. Within 2 seconds, the participants were required to discriminate if the joint angle just shown was the same as the one shown. There were a total of 15 trials in each block with all five pre-set angles pseudorandomised, and there were 2 blocks (a total of 30 trials) with a 2-minute break in between.

3.2.5.2. AOPM Group

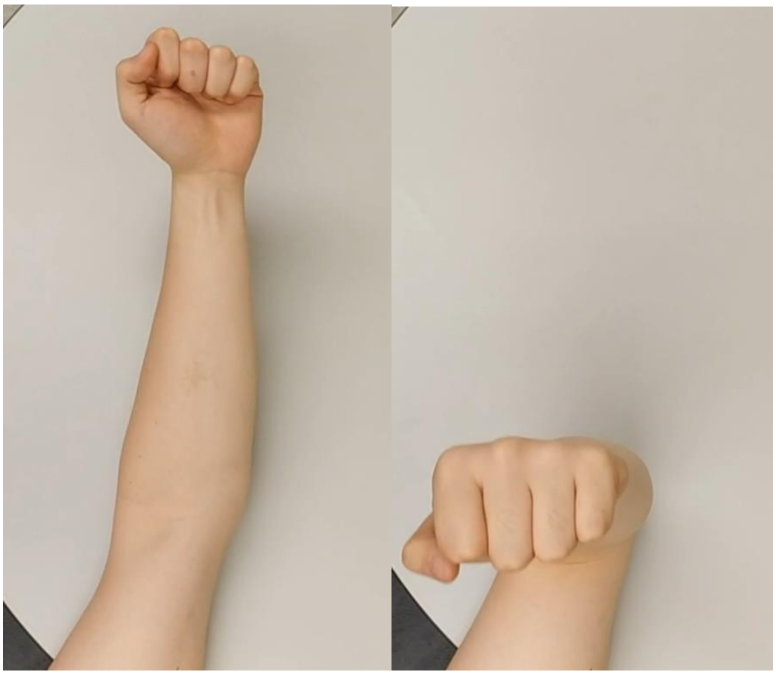
Prior to the start of the AOPM training, each participant was explained the purpose of the AO training and how he or she should position himself or herself in relation to the computer screen on which, the video clips of movements and the Cybex Humac Norm System were displayed. For familiarisation purposes, he or she was shown video clips of the non-dominant elbow joint moving from full extension to flexion at one of the five pre-set angles to be used in the training, i.e., 30°, 50°, 70°, 90°, 110° at a speed of 20°/s. Besides, his or her non-dominant elbow was moved from full extension to the maximum elbow at an angle of 110°. In each trial of AOPM training, the participants were required to view a video clip with a non-dominant hand moving from full elbow extension to elbow flexion at one of the five pre-set angles, i.e., 30°, 50°, 70°, 90°, and 110°, at a speed of 20°/s. He or she needed to remember the angle being shown visually. After 2 seconds, the participants were asked to have their eyes closed and to feel a movement of the non-dominant elbow, which was passively moved by the Cybex Humac Norm System, from full extension to flexion at one of the 5 pre-set angles (i.e., 30°, 50°, 70°, 90°, 110° for 20°/s in speed). Within 2 seconds, the participants were required to discriminate if the joint angle just shown visually on the computer screen was the same as the joint angle of the non-dominant elbow positioned by the Cybex Humac Norm System. There were a total of 15 trials in each block with all five pre-set angles pseudorandomised. There were 2 blocks (a total of 30 trials) with a 2-minute break in between.

3.2.6. AOMI Training

After the AOPM or AO training session, each participant in both the experimental and control groups was then required to participate in the AOMI training. In each AOMI session, each participant was seated on a chair with back support in a sound-proof chamber with a computer screen placed 80 cm away from their eyes. He or she was asked to view a video clip showing a non-dominant elbow continually moving between full extension to 110° in flexion (Figure 3.3). A video of an elbow joint moving across a range of 30 and 110 degrees from extension to flexion from a first-person perspective at a speed of 20/s was presented. The participants were required to concurrently view the video (action observation) and generate and rehearse the kinesthetic image at the elbow that they had been trained to remember previously (kinesthetic imagery). Each participant was required to engage in concurrent action observation and kinesthetic motor imagery for 15 minutes. A 2-minute break was provided to participants every 5 minutes

Figure 3.3

Elbow Extension at 0 Degree and Flexion at 90 Degrees



3.2.7. Outcome Measures

Before and after the six sessions of AO/AOPM training followed by AOMI training, the motor performance of each participant was assessed by three motor-related tests: Purdue Pegboard Test (PPT), Stroop Test and Proprioception Test.

3.2.7.1 Purdue Pegboard Test (PPT) (Ashford et al., 2008; Buddenberg & Davis, 1999)

The PPT consists of a test board, pins, collars, and washers. Participants were instructed to insert one pin at a time, starting with the top hole, in a vertical column as quickly as possible in a fixed time. The final score was the number of pins inserted. The test consists of four separate scores from test procedures, including 1) right hand (30s), 2) left hand (30s), 3) both hands (30s), and 4) assembly (60s). The experimenter required each participant to use their left hand, right hand, or both hands to insert the pins in 30s; a digital timer was used. In the assembly test, the experimenter asked each participant to use both hands to insert pins, washers, or collars in a specific order of the set (pins, washers, collars, washers). The number of sets was recorded.

3.2.7.2 Stroop Test

Each participant had to name the ink color of congruent or incongruent color words. After 2 weeks of training, all participants performed the same standardized tests. The Stroop Test involves three subtasks: Word reading requires participants to read the color word (red, blue yellow, green) printed in black ink; Color naming displayed solid color patches in one of these four colors; Incongruent color naming contains color words printed in an incongruent color. The experimenter recorded the number of mistakes made by each participant and the number of self-corrected mistakes in each part of the test. The experimenter recorded the time the participants took to read the words with a digital timer. An interference measure was calculated by subtracting the average time needed to complete the first two subtasks from the two subtasks from the time needed to complete the third subtask (Scarpina & Tagini, 2017; Van der Elst et al., 2006).

3.2.7.3. Proprioception Test

The design of the Proprioception Test was based on ipsilateral joint position reproduction (IJPR) approach used in the study by Han et al. (2016). Each participant's non-dominant arm was placed on the Chair of the Cybex Humac Norm System with axis of rotation aligned with the dynamometer close to his or her eyes to reproduce the position. The elbow was passively moved from full extension to flexion at one of the predetermined target joint positions, 30°, 50°, 70°, 90°, and 110° at a speed of 20°/s lasting for 2 seconds, and the participants were required to remember that target position. Then, the elbow joint was moved passively by the Cybex Humac Norm System to the initial starting position at full elbow extension with the same speed of 20°/s. The participants were then required to reproduce the elbow joint position previously experienced by actively flexing the elbow joint to the target position. There were a total of 50 trials with 10 trials of each predetermined joint angles presented to the participants in a pseudorandomised manner.

3.3. Results

3.3.1. Purdue Pegboard Test

The purpose to use the Purdue Pegboard Test was to examine the effect of the six sessions of AOMI training on motor coordination and precision as compared with the AO training with the same duration. The means and the standard deviations (SDs) of the scores in the all four subtests of the AOPM (experimental) and AO (control) groups are summarised in Table 1. Repeated measures ANOVA were conducted to look at the effect of the AOPM training on motor function in terms of the four subtests of the Purdue Pegboard Test across the two measurements points as compared with the AO counterpart. Repeated measures ANOVA did not reveal any significant Group × Time interaction effect for the Right Hand [$F_{1,11} = 0.027$, $p > 0.05$], Left Hand [$F_{1,11} = 1.47$, $p > 0.05$], or Assembly [$F_{1,11} = 0.202$, $p > 0.05$] subtests. On the other hand, repeated measures ANOVA statistics showed a marginal significant Group (AOPM vs AO) × Time (pre vs post) interaction effect of Both Hands Subtest [$F_{1,11} = 3.07$, $p > 0.05$ (= 0.110)]. A post-hoc contrast test was then conducted separately for each group. It was shown that the AOPM group had a marginal significant improvement after the six sessions of training (mean = 12.33 (2.23) and mean = 14.33 (1.4) for the pre- and post-measurements, respectively) [$t_5 = -2.481$, $p = 0.056$] while no significant finding were revealed in the post-hoc test for the AO group [$t_5 = -0.25$, $p > 0.05$ (p = 0.813)].

Table 1

Purdue Pegboard Test Mean and SD (Right Hand, Left Hand, Both Hand, and Assembly)

		Pre		Post	
		Mean	SD	Mean	SD
Right	Experimental	16.83	2.3	17.83	1.1
	Control	16.92	1.2	18.17	1.5
Left	Experimental	14.83	2.1	16.58	1.1
	Control	16.33	0.68	16.5	1.5
Both	Experimental	12.33	2.2	14.33	1.4
	Control	14.17	0.68	14.33	1.2
Assembly	Experimental	10.25	1.13	11.27	0.89
	Control	11.48	1.4	12.02	1.5

3.3.2. Stroop Test

As it was speculated that the MIAO training would enhance the executive functions on the attention orienting between the visual representation of the action in motion from the external context and the internally generated kinesthetic imagery at the elbow joint, the Stroop Test for measure executive functions on conflict resolution, was chosen as an outcome measure. The Chinese characters Stroop test was selected as an outcome measure in these studies because it provides a useful assessment of executive functions, particularly in the domain of attention orienting and conflict resolution. The reaction time and accuracy rate for the three subtests of the Stroop Tests along with the composite score are summarised in Tables 2-5. Repeated measures ANOVA showed a marginally significant Group (AOPM vs AO) × Time (pre vs post) interaction effect in [name of the composite score] of the Stroop Test

[$F_{1,11}$ = 2.23 p = 0.16]. Despite the marginally significant interaction effect, post-hoc analysis was attempted separately for each group. The contrast test revealed significantly shorter reaction time in the AOPM group in terms of Interference between pre- and post-measurements [t_5 = 4.15, p = 0.01)]. In contrast, no significant findings were revealed in [the name of the composite score] of the AO group across time [t_5 = 1.45, p > 0.05)].

Table 2

Stroop Subtest I Means and SDs of the Two Groups

		Stroop I			
		Pre		Post	
		Mean	SD	Mean	SD
Time	Experimental	44.17	9.08	39.61	8.74
	Control	42.93	3.69	40.45	4.59
Accuracy	Experimental	0.99	0.012	0.99	0.012
	Control	1	0.01	1	0.004

Table 3

Stroop Subtest II Means and SDs of the Two Groups

		Stroop II			
		Pre		Post	
		Mean	SD	Mean	SD
Time	Experimental	61.16	13.76	54.87	7.80
	Control	56.97	9.35	49.13	7.21
Accuracy	Experimental	2.33	1.63	1.67	2.25

Control	0.99	0.015	1	0.008

Table 4

Stroop Subtest III Means and SDs of the Two Groups

		Stroop III			
		Pre		Post	
		Mean	SD	Mean	SD
Time	Experimental	101.39	15.86	88.15	15.26
	Control	91.73	14.18	79.71	11.60
Accuracy	Experimental	0.97	0.02	0.97	0.03
	Control	0.97	0.01	0.97	0.01

Table 5

Stroop Interference (Composite Score) Means and SDs of the Two Groups

		Interference			
		Mean	SD	Mean	SD
Time	Experimental	40.91	9.09	48.73	7.50
	Control	34.92	8.77	41.78	9.33

3.3.3. Proprioception Test

The Proprioceptive Test was considered to test of precision motor control in a same context. The overall performance of the AOPM and AO groups in the five joint angles in terms of precision (calculated by subtracting the actual joint angle from the ideal joint angle) are shown in Table 6.

Table 6

Proprioception Testing for the Five Target Elbow Angle Joints, i.e., 30°, 50°, 70°, 90°, 110° (Mean and SD) of the Two Groups

		Pre		Post	
		Mean	SD	Mean	SD
30°	Experiment	7.65	3.64	4.78	0.65
	Control	7.17	2.94	4.05	1.54
50°	Experiment	8.12	1.23	5.12	1.72
	Control	6.53	2.74	6.22	1.94
70°	Experiment	8.93	4.11	5.18	1.95
	Control	7.50	1.89	5.68	1.61
90°	Experiment	6.58	3.33	3.97	1.61
	Control	6.43	2.09	4.22	2.19
110°	Experiment	6.85	2.25	3.47	0.97
	Control	4.97	1.38	4.43	2.22

Repeated measures ANOVA with a model of Group (AOPM vs AO) × Time (pre vs post) were computed for all five target elbow angle joints, i.e., 30°, 50°, 70°, 90°, and 110°, to investigate the effect of the AOPM training on motor precision across time as compared with the AO training.

Repeated measures ANOVA showed significant Group × Time interaction effect in the target joint position at 50° [$F_{1,11} = 8.22$, $p = 0.017$]. Post-hoc contrast tests revealed a significant improvement in motor precision of the AOPM group [$t_5 = 6.18$, $p < 0.005$ (= 0.002)] only but not in the AO group [$t_5 = 0.39$, $p > 0.05$]. Due to the relatively small sample size, other marginally significant results found repeated measures ANOVA with a model of Group × Time were also examined for the other target joint angles.

There was a trend of significant interaction effect found at the target joint angle 70° [$F_{1,11}$ = 1.27, p = 0.286] and 110° [$F_{1,11}$ = 2.65, p = 0.135]. For the target angle position at 70°, the post-hoc contrast tests revealed a significant improvement in motor precision in the AOPM group across two measurement points [t_5 = 2.71, p < 0.05 (= 0.04)] but not in the AO group [t_5=1.80, p > 0.05 (= 0.132)]. For the target angle position at 110°, the post-hoc contrast tests revealed improvement in terms of motor precision in the AOPM group [t_5 = 2.8, p < 0.05 (= 0.038)] while no significant finding in the same outcome was obtained for the AO group [t_5 = 0.42, p > 0.05 (= 0.691)] across the two measurement points.

Finally, no significant results were obtained in repeated measures ANOVA with a Group × Time model for 30° and 90° [$F_{1,11}$ = 0.017, p > 0.05 (= 0.897)]; $F_{1,11}$ = 0.076, p > 0.05, respectively].

3.4. Discussion

In this pilot study on the effect of the prior AOPM training, we examined if external-to-internal attention training in the AOPM group would enhance attention disengagement and shifting and, in turn, would mediate improvement in motor precision through the MIAO training. Despite the relatively small sample size leading to some marginally significant results, the preliminary results suggested that the AOPM training was able to enhance the executive function for attention orienting (as indicated in the results of the Stroop Test) and motor precision (as indicated in the results of the Purdue Pegboard Tests and the Proprioceptive Test). The AOPM group was shown to have a significant improvement in composite reaction time in the Stroop Test. It is suggested that the Stroop Test provides information on selective attention and control over conflict resolution between lexicon and colour stimuli, which are considered to be mediated by the higher level of executive functions (Wang et al., 2018). The improvement in the Stroop Test after the AOPM training found in this pilot implies that AOPM may facilitate one's attention orienting between the external image of the action in motion and the internally generated image of kinesthetic senses at the elbow joint.

Furthermore, the preliminary results intriguingly revealed significant improvement in the Both Hands subtest of the Purdue Pegboard Test, which is supposed to measure hand dexterity and eye-hand coordination (McLellen, 2011), while no significant findings were found in the other subtests (Right Hand, Left Hand, and Assembly). Though no definite conclusion could be made, the improvement in the Both Hands subtest suggests that, among all the different subtests, the Both Hands subtest may be the one that requires one's attention to perform peg placement tasks bilaterally and concurrently. This implies that AOPM training may have the potential to enhance one's attention's ability to orient between two stimuli or representations, as required in the MIAO training for motor precision improvement.

In spite of a relatively small sample size, the results of the proprioception test, which was a contextual test to indicate the joint movement precision after the AOPM training followed by MIAO training, also provided some insight about the future study. The preliminary results suggested that the motor precision was enhanced differentially across the range of the elbow joints from 30° and 110°. A significant improvement in movement precision was found in the target joint angle of 50° in the AOPM group compared with the AO group. In addition, the statistical results also revealed some trends of improvement in movement precision at the target joint angles of 70° and 110°, and there was no significant improvement found at the target angles of 30° and 90°. One possible explanation for the phenomenon is that the kinesthetic sense at the elbow joint angle was relatively familiar to the participants. In a motor-related study, Frey-Law et al. (2012) found that a peak torque-angle-velocity appeared in the mid-range, especially at 90°, which may give participants a stronger kinesthetic sense to experience and store as a long-term representation at the higher cortical level. In contrast, elbow joint angles at 50°, 70°, and 110° was less familiar to the participants. Based on this related study (Frey-Law et al., 2012), it could help explain the improvement in movement precision at other intermediate angles, i.e., 50°, 70°, and 110°. This could be due to the fact that the kinesthetic senses at the intermediate angle appeared to be less familiar to the participants, and supposedly, the saliency of the kinesthetic images generated internally would be weaker. This may, in turn, hinder the process of attentional disengagement from the external image of the action in motion and the subsequent attention shifting and reengagement to the internal kinesthetic images. The improvement in these intermediate angles suggests that the AOPM training does facilitate the participants' ability to disengage from the external images of the action in motion and shift their attention to internally generated and rehearsed kinesthetic images. The effect was then indirectly shown through the improvement in movement precision. As for the joint angle at 90°, the internal attention shifting training in the AOPM group would be as beneficial as the kinesthetic image at the angle at 90°, which would be more salient for either group of participants to retrieve and generate.

As for the joint angle at 30°, the statistical analyses also did not reveal any significant between-group results. This would be due to the fact that the 30° may be at the outer end range of the elbow in the experiment, and both the corresponding video clip and the kinesthetic sense at the end range would serve as cues for them to discriminate between the visual image of the joint angle in the video clip and the kinesthetic senses positioned by the Cybex Humac Norm System regardless of the types of attention training.

3.4.1 Implication of the Pilot Study

The results of this pilot study set a good foundation for the two main studies which aimed to investigate the modulatory effect of executive control on generation and maintenance of internal representation and subsequent facilitation on motor precision under the modulatory effect of visual cues. While using Cybex Humac Norm System is an instrument to precisely measure joint movements, this equipment may only allow one-joint measurement only, a simple movement with elbow extension and flexion. In order to study the effect of executive control on attention and imager generation on more complex movement learning in the main studies, an alternative method will be used to measure more complex movement of elbow and wrist joints. This would allow to study the effect the visual cueing on relatively complex motor movement and the results could be more generalized to real-life settings. On the other hand, the passive movement training provided in pilot study enabled the participants to disengage from the visual stimuli and re-engage in the generation of kinesthetic senses. Therefore, later experiments would try to involve the passive movement pre-experiment training to enhance the participants' attention orientation and generation of kinesthetic senses.

CHAPTER FOUR

STUDY ONE

The Modulatory Effect of Top-down Visual Cues on the Maintenance of Internal Motor Representation: A Behavioural and Electrophysiological Study

4.1. Overview of the Study

In Chapter 3, it was demonstrated the attention-orientation training could improve executive control and facilitate joint position regeneration. It serves as the foundation for investigating the underlying neural mechanisms. Using priority-cue and retro-cue, the EEG study sought to investigate how executive control modulated attention orientation influences subsequent maintenance of internal visual representation. Previous studies suggested that there is a close relationship between theta-band power in the prefrontal cortex and executive control. However, there are some issues that have remained unclear. First, theta-band power modulations in frontal midline regions have been extensively studied with internally oriented attention, while theta-band power oscillations induced by executive control on external-to-internal attention have been less explored. The external-to-internal attention is important to select relevant information from external environment. Second, the alternating processing of internal representation and external visual image demands a higher level of top-down executive control. However, only a few studies have investigated the facilitation effect of priority-cue and retro-cue on inhibiting irrelevant and focusing on relevant representation, which is a subfunction of attention and may differentially influence executive control in dealing with two representations.

4.2. Methods

4.2.1. Participants

Twenty healthy volunteers (10 females; age: M = 25.3, SD = 3.0, range = 20-33) were recruited to participate in the study via convenient and snowball sampling. The inclusion criteria were: (1) age between 20 – 35 years old; right-handed as assessed by the Edinburgh Handedness Inventory (Oldfield, 1971); (2) no history of upper limb injuries; (3) obtaining at least 29 (out of 30) points in the Hong Kong version of the Montreal Cognitive Assessment (MoCA) points (Wong et al., 2009); and (4) normal or corrected-to-normal vision. Those with psychiatric disorders (e.g., psychosis) or neurological conditions (e.g., stroke and traumatic brain injury) were excluded from the study.

4.2.2. Experiment Procedure

Each participant who fulfilled inclusion criteria was asked to sign an informed consent form after the experimenter explained the purpose and procedure of the study. The participant was required to complete a questionnaire on demographic information after signing the consent form (covering name, age, education level, and medical record). To confirm the individual's intact cognitive functions, the person was examined using the Hong Kong version of MoCA (Wong et al., 2009). Each participant received training in the cognitive tasks using priority-cue and retro-cue before the experiment. Training blocks of 15 trials for each type of cognitive task were provided. Each participant was required to reach a minimum accuracy of 70% before beginning the cognitive experiment with concurrent electroencephalogram recordings.

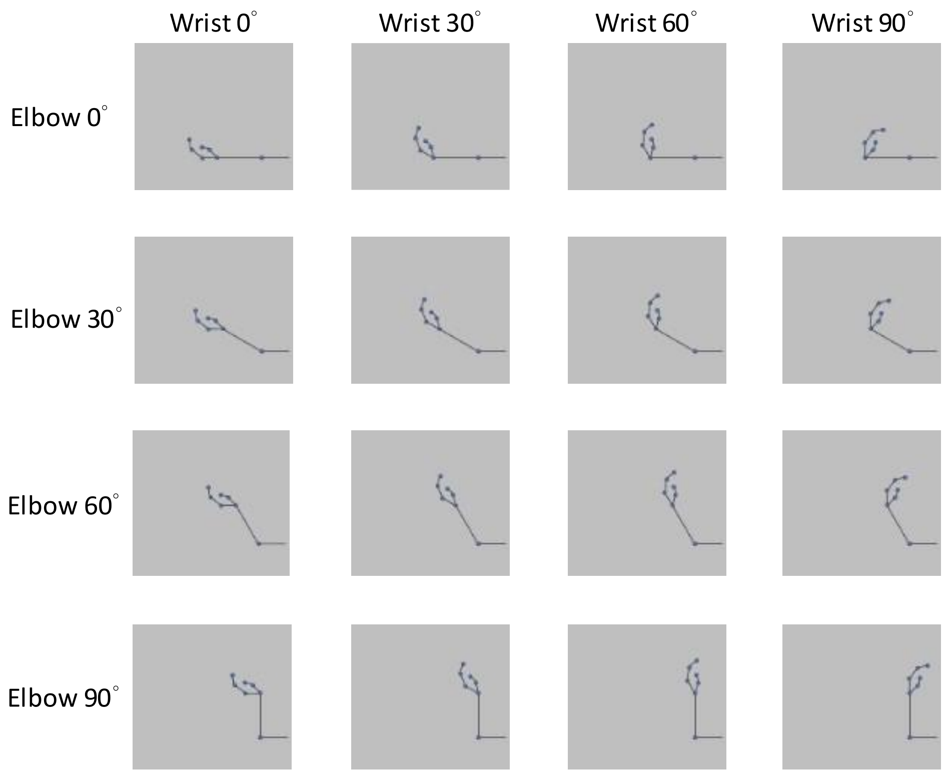
Each participant was comfortably seated in an electrically protected and soundproof chamber during the experiment with data acquisition. He or she was seated in front of a computer-synchronized display panel, 60 to 65 cm away from the screen. STIM2 was used to display stimuli (NeuroScan Labs, Sterlimg, VA). A 5-degree viewing angle was chosen. His or her arm was comfortably held in place, allowing both index fingers to rest on the designated button on a keyboard that is connected to a computer for making responses as required by the cognitive experiment.

4.2.3. Experiment Stimuli

As adopted from Rerko's retro-cue paradigm (Rerko et al., 2014; Ye et al., 2021), stimuli of human forearms in a simplified dot-and-line representation were displayed on a computer screen with a gray background during the experiment. The dots and lines were arranged to simulate the form of the human elbow, forearm, wrist, metacarpal, and interphalangeal joints of the thumb and index finger. The angles of the elbow joint and wrist joint varied at pre-set 0°, 30°, 60°, and 90° from the neutral position (refer to Figure 4.1 for details).

Figure 4.1

Illustration of the Visual Stimuli Presented in the Experiment



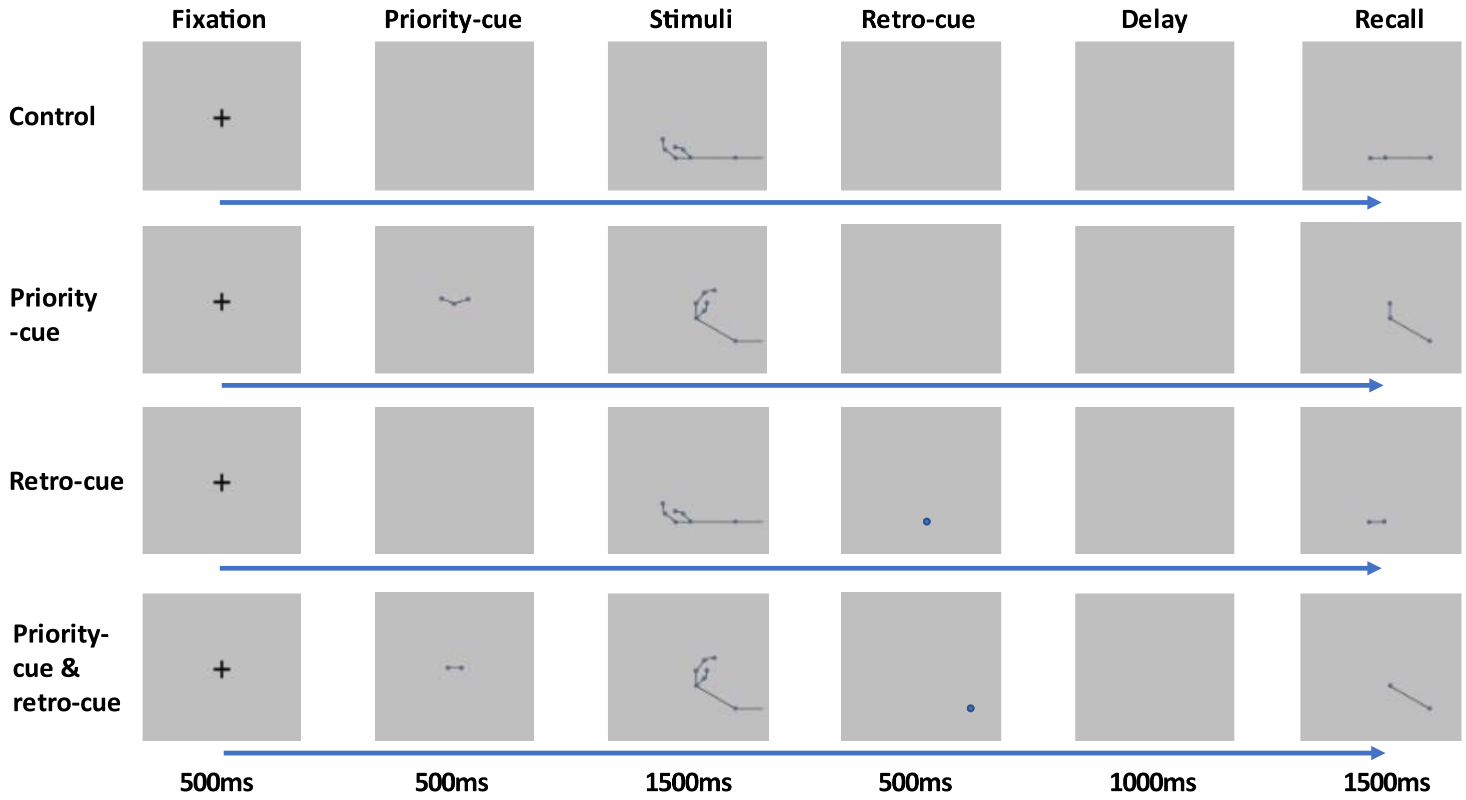
Note. Figure 4.1 illustrates the visual stimuli presented in the experiment. The form of the human elbow, forearm, wrist, metacarpal and interphalangeal joints of the thumb and index finger are simulated by dots and lines. The angles of the elbow joint and wrist joint varied at pre-set 0°, 30°, 60°, and 90° from the neutral position.

4.2.4. Experimental Paradigms

Each participant was required to participate in four cognitive tasks in a pseudo-randomized order: (1) a delayed recognition task (control), (2) a recognition task with a priority-cue, (3) a recognition task with a retro-cue, and (4) a recognition task with a priority- and retro-cue (Figure 4.2). (1) In each trial of the visual recognition (control) task, the participant was presented with a white central fixation cross on a gray background for 500 milliseconds, then a 500-millisecond grey blank screen. A forearm in a dot-and-line format was shown on a gray background with the elbow joint and wrist joint at one of the pre-set angles of 0°, 30°, 60°, or 90° for 1,500 ms. A recall probe, consisting of either one segment (formed by two dots and one line) or one joint (formed by three dots and two lines) of the upper limb (i.e., the forearm and the hand), was shown to the participant after a 1,000 ms delay. He or she was required to indicate whether the probing stimulus was identical to the orientation or angle of the dot-and-line upper limb that had just been presented by pressing the Z key using left hand or M key using right hand on the keyboard. The recall probe was shown on the screen for 1500ms. The participant was required to press the M key in an identical trial. In non-identical trials, the user must press the Z key. (2) In the trial of the recognition task with a priority-cue, the stimulus presentation timing was the same as in the control task, but a priority-cue appeared after the central fixation and lasted for 500 ms. The priority-cue was to let the participant know which feature, either joint angle or segment orientation, they should pay attention to before the dot-and-line forearm stimulus was about to be presented. (3) In the trial of the recognition task with a retro-cue, the stimulus presentation timing was the same as in the control task, but a retro-cue appeared after the dot-and-line upper limb and lasted for 500ms. The retro-cue was to indicate the specific joint location the participant was required to rehearse mentally. After a 500-ms retro-cue, there is a subsequent 1000-ms delay. (4) In the trial of the recognition task with priority-cue and retro-cue, the stimulus presentation timing was the same as that in the control task, except a priority-cue appeared after the central fixation and retro-cue appeared after the display of the dot-and-line forearm for 500ms. For each type of cognitive task, there were a total of two blocks with 64 trials. There was a total of eight blocks, each with 64 trials, and where necessary, breaks were given between blocks. The schematic representation of the experimental paradigm is shown in Figure 4.2.

Figure 4.2

Illustration of the Experimental Paradigm



Note. Figure 4.2 illustrates the experimental paradigm (the delayed recognition task required participants to respond by clicking the right or wrong button when the recall probe appeared; participants were required to participate in four conditions: the control recognition task, the recognition task with priority-cue, the recognition task with retro-cue, and the recognition task with priority-cue and retro-cue). A forearm in a dot-and-line format with different angles was displayed in each condition. Recall probes were stimuli with angle or orientation characteristics; only one testing probe appeared in each trial.

4.2.5. Neurophysiological Data Acquisition

The electroencephalogram (EEG) was recorded concurrently with the behavioral data using 64 electrodes (90mm Ag/AgCl sintered) mounted on a Quikcap via CURRY **Scan 7 Neuroimaging Suite** (NeuroScan Labs, Sterling, VA). A head-box of the SynAmps2 Digital DC EEG Amplifier was used to amplify the EEG signals. The vertical and horizontal electrooculograms (EOGs) due to blinks and eye saccades were recorded by two separate pairs of electrodes at 2cm above and below the left eye and at the outer canthus of each eye, respectively. Each electrode received an injection of conductance gel to keep all electrode impedances at or below 5 kΩ and the signal was sampled at 1000Hz. The head-box of the SynAmps2 Digital DC EEG Amplifier was used to amplify the EEG signals. The ground electrode was located on the forehead in front of the vertex electrode, and the montage was referenced to the left and right bony mastoids (Cz). Using the EEGLAB toolbox, the EEG data was down-sampled to 200 Hz and filtered between 1 and 50 Hz.

4.2.6. EEG Offline Processing - Preprocessing

Signals captured were processed offline using EEGLab (Delorme and Makeig, 2004) and offline Matlab scripts. Raw EEG data were band-pass filtered between 1 and 80 Hz and then down-sampled to 250 Hz. Then, a 50 Hz notch filter was used. Electrodes on both sides of the mastoid were used as a reference for the data. The signals with significant movement artifacts and prolonged eye closure were removed from the visual inspection. Then EEG was segmented into 2,000 ms epochs (pre-stimulus −1,000 ms sand post-stimulus 1,000 ms). In order to remove eye movement artifacts, an independent component analysis strategy was applied (Delorme and Makeig, 2004). Blinking and horizontal eye movement-reflecting typical components were disregarded.

4.2.7. EEG Offline Processing - Event-related Spectral Perturbation (ERSP)

The event-related spectral perturbation (ERSP) method was adopted to calculate the spectral power change of the EEG relative to the delay event in the paradigm from the perspective of the time-frequency domain. As the pre-stimulus baseline was recorded with a mean power level, event-related spectral perturbations in power in each frequency were computed by normalizing the power spectral estimate at each frequency with the pre-stimulus baseline mean power. Decreases in spectral power from baseline were regarded as an increase in event-related desynchronization (ERD) in cortical activity, while an increase in spectral power from baseline indicates a resting state of cortical neural activity. The topographical distribution of brain activation was used to figure out which regions of the brain are involved when ERD occurs. Based on the ERSP values from 60 electrodes, the averaged ERSP value in the fixed frequency band and time interval within the theta and alpha bands were calculated. The mean spectral power for theta (4-8 Hz) and alpha (8-12 Hz) across four conditions were calculated.

4.2.8. EEG Offline Processing - Time-frequency Analysis

In a time-frequency domain, clean trials were examined. The event-related spectral perturbation (ERSP) technique was used to determine ERD power (Delorme and Makeig, 2004). ERSP are increasingly used in the EEG literature to visualize the change in spectral power in specific event in a broad frequency range. For the ERSP calculation, the power spectra of each epoch were calculated and each one was normalized by its own mean baseline spectrum. The power was then converted to log power by averaging it over all included trials (see the following formula).

$$ERSP(f,t) = \frac{1}{n}\sum_{k=1}^{n}(F_k(f,t)^2)$$

Fk (f, t) is a spectral estimation of the kth trial at frequency f and time t, where n is the number of trials. The formula shown below was used to further calculate ERD (Makeig, 1993):

$$ERD\ power = \frac{1}{N}\sum_{f\in F}\sum_{t\in T}\big(ERSP(f,t)\big)$$

where F stands for the targeted frequency range. Theta (4–8 Hz) and alpha were the two frequency ranges we chose as our focus areas (8–12 Hz). T refers to the time interval of interest, and a window from 0 to 1,000 ms was selected to represent the retro-cue and maintenance stage. N is the number of rectangular, two-dimensional, time-frequency bins in a specific matrix. Time-frequency figure visualization was completed by using specialized Matlab programs.

4.3. Statistical Analysis

4.3.1. Behavioural and Neurophysiological Measures

The normalized power was used as the dependent variable in independent analyses of variance (ANOVA) for each frequency band. For objective one, a two-way repeated measures analysis of variance (ANOVA) with priority-cue conditions (cue-present vs. cue-absent) and retro-cue conditions (cue-present vs. cue-absent) as two within-subject factors was used to investigate the accuracy and reaction time. For objective two, a three-way repeated measures ANOVA with midline electrode sites (Fz, Cz, and Pz) was used as the within-subject factors, the power of theta-bands during retro-cue was investigated. For objective three, a three-way repeated measures ANOVA with midline electrode sites (Fz, Cz, and Pz) was used as the within-subject factors, the power of alpha-band during maintenance was investigated. Priority-cue conditions (cue-present vs. cue-absent) and retro-cue conditions (cue-present vs. cue-absent) were also considered. Greenhouse-Geisser correction adjustment was applied when the sphericity assumption was violated. Post-hoc contrast tests were conducted for any significant interaction effects at a p-value of 0.01.

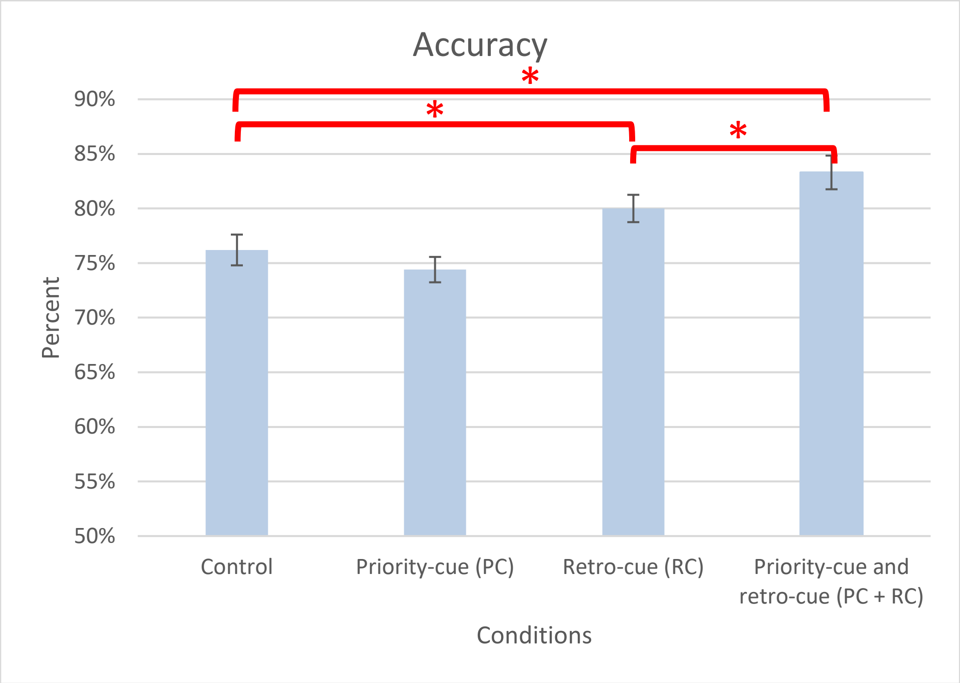
4.3.2. Results

4.3.2.1. Behavioural Measurements

Repeated measures ANOVA showed a significant retro-cue main effect [$F_{1,19}$ = 47.0, $p < 0.001$] and a significant interaction effect of priority-cue and retro-cue [$F_{1,19}$ = 16.7, $p = 0.001$] in terms of accuracy rate. A post-hoc contrast test revealed that the retro-cue condition had higher accuracy than the control condition [t_{19} = -3.76, p = 0.001; retro-cue task (M = 0.80, SD = 0.056), control task (M = -0.76, SD = 0.063)] and the priority-cue and retro-cue condition had higher accuracy than the control condition [t_{19} = -3.76, p = 0.001; priority-cue and retro-cue task (M = 0.83, SD = 0.069), control task (M = -0.76, SD = 0.063)]. A post-hoc contrast test also revealed that the priority-cue and retro-cue task had higher accuracy than the retro-cue task [t_{19} = -2.94, p = 0.009; priority-cue and retro-cue task (M = 0.83, SD = 0.069), retro-cue task (M = 0.80, SD = 0.056)]. Figure 4.3 shows the accuracy rate across the four experimental conditions.

Figure 4.3

Bar Graph Showing the Mean of Accuracy Rate Among the 20 Participants in the Four Experimental Tasks

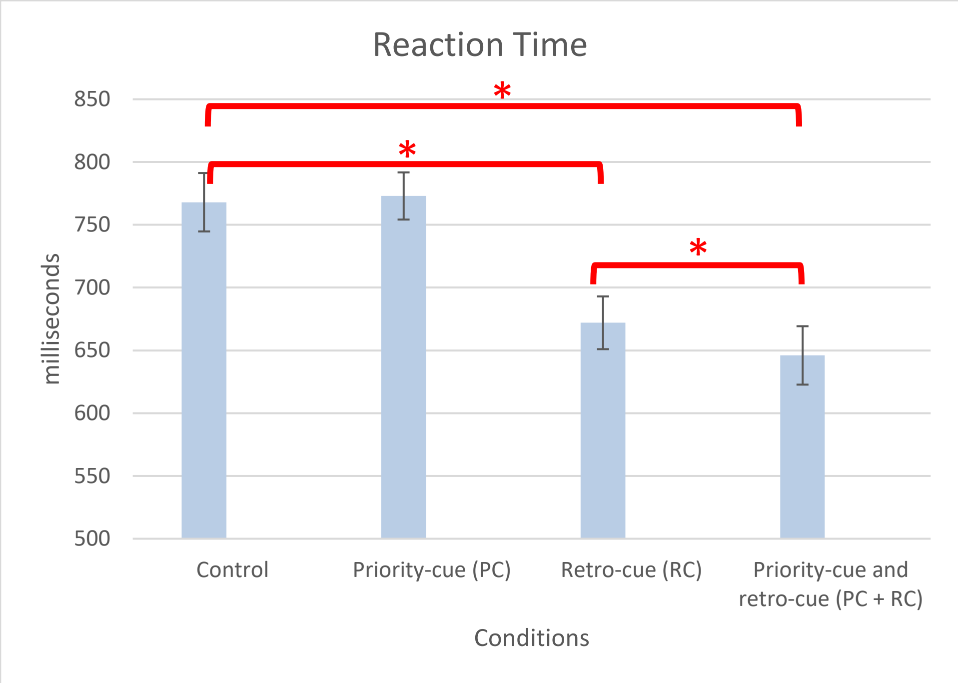


Note. * < 0.01, total number $N = 18$, the error bars represent the standard error of the mean.

A significant priority-cue effect [$F_{1,19} = 5.08$, $p = 0.036$] and a significant retro-cue effect [$F_{1,19} = 146.9$, $p < 0.001$] were found in reaction time. A post-hoc contrast test showed a shorter reaction time in the retro-cue condition compared with that of the control condition [$t_{19} = 6.57$, $p < 0.001$; retro-cue task ($M = 672$, $SD = 94$), control task ($M = 768$, $SD = 104$)]. Another post hoc contrast test showed a shorter reaction time in the priority-cue and retro-cue condition compared with control condition [$t_{19} = 11.4$, $p < 0.001$; priority-cue and retro-cue task ($M = 646$, $SD = 104$), control task ($M = 768$, $SD = 104$)]. Figure 4.4 shows the reaction time across the four conditions.

Figure 4.4

Bar Graph Showing the Mean Reaction Time Among the 20 Participants in the Four Experimental Tasks



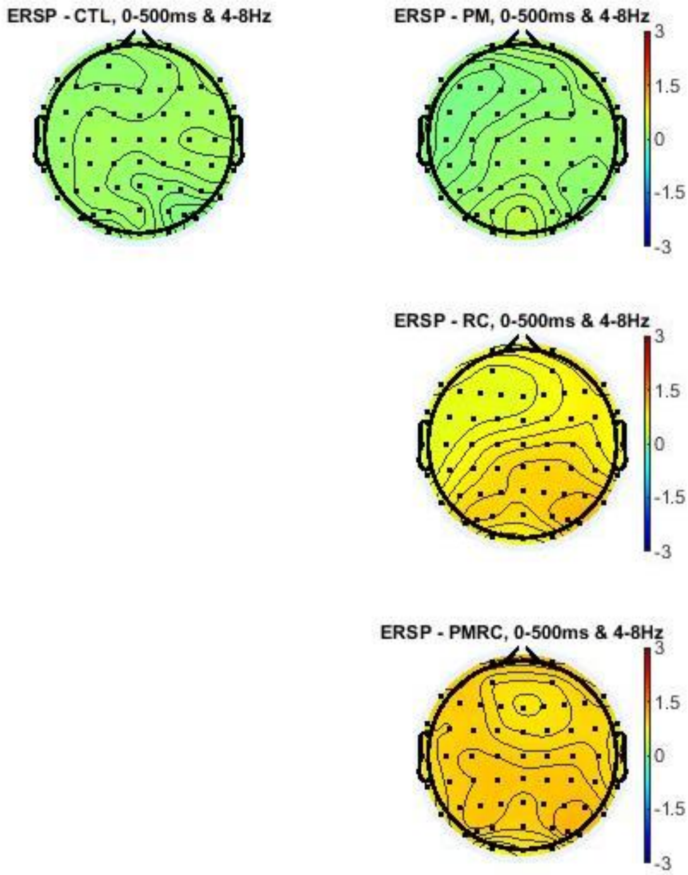
Note. * < 0.01, total number $N = 18$, the error bars represent the standard error of the mean.

4.3.2.2. Neurophysiological Measurement - Theta-band Power During Retro-cue

A significant retro-cue main effect [$F_{1,19} = 43.6$, $p < 0.001$] was found in the theta-band power. A significant cortical sites main effect [$F_{1,29} = 3.93$, $p = 0.04$, $\varepsilon = 0.78$] was found in the theta-band power. A significant priority-cue x retro-cue x cortical sites interaction effect [$F_{1,21} = 4.75$, $p = 0.038$, $\varepsilon = 0.55$] was found in the theta-band power. Figure 4.5 shows the topographical distribution of theta-band power in each condition and the statistical difference between conditions in different electrodes.

Figure 4.5

The Topographical Distribution of Theta-band Power in Each Condition and the Statistical Difference Between Conditions in the Different Electrodes



Note. Topographical distribution of theta-band power across the four conditions; comparisons of each condition with the control condition have been shown. (ERSP: event-related spectral perturbation; CTL: control, PM: priority-cue, RC: retro-cue, PMRC: priority-cue and retro-cue).

A post-hoc contrast test revealed that theta-band power was higher in the priority-cue and retro-cue condition compared to the control conditions [t_{19} = -2.69, p = 0.015; priority-cue and retro-cue task (M = 0.88, SD = 1.11), control task (M = 0.12, SD = 0.87)] at the Fz site. A significant difference was also found in comparisons between the control with retro-cue condition [t_{19} = -2.57, p = 0.019; retro-cue task (M = 0.60, *SD* = 0.48), control task (*M* = 0.12, *SD* = 0.87)] at the Fz site. A significant difference was also found in comparisons between the priority-cue condition with priority-cue and retro-cue condition [t_{19} = -3.15, p = 0.005; priority-cue and retro-cue task (*M* = 0.88, *SD* = 1.11), priority-cue task (*M* = 0.05, *SD* = 0.63)] at the Fz site.

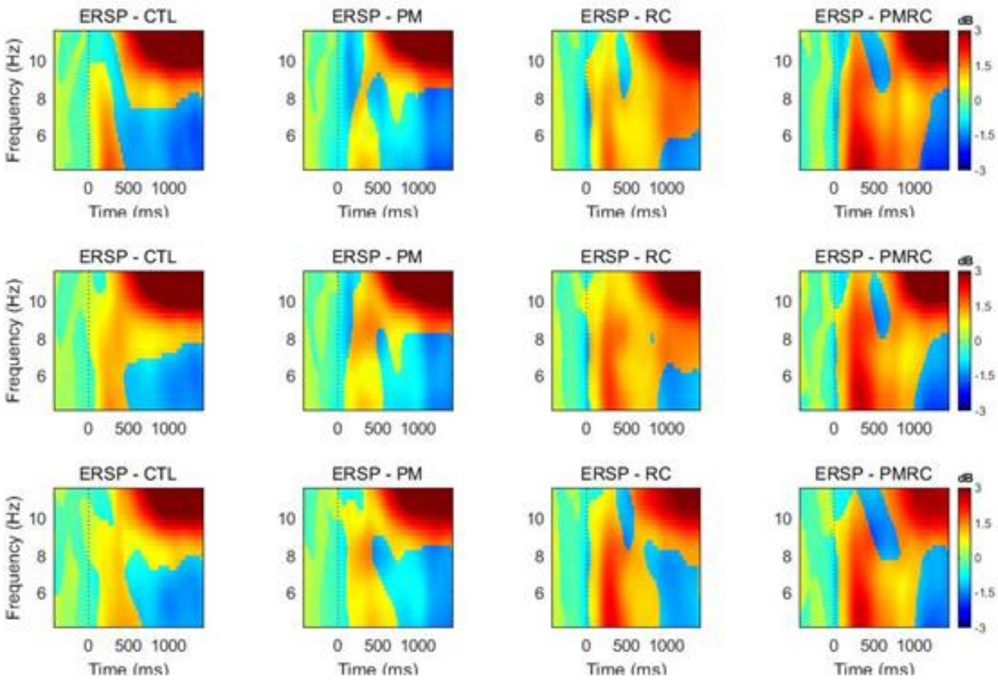
A post-hoc contrast test revealed that theta-band power was higher in the priority-cue and retro-cue condition compared to the control condition [t_{19} = -3.74, p = 0.001; priority-cue & retro-cue task (*M* = 1.00, *SD* = 1.00), control task (*M* = 0.19, *SD* = 0.80)] at the Cz site. A significant difference was also found in the contrast test of theta-band power comparing between the control with retro-cue condition [t_{19} = -3.80, p = 0.001; retro-cue task (*M* = 0.86, *SD* = 0.64), control task (*M* = 0.19, *SD* = 0.80)] at the Cz site. A significant difference was also found in contrast test of theta-band power comparing between the priority-cue condition with priority-cue and retro-cue condition [t_{19} = -4.06, p = 0.001; priority-cue and retro-cue task (*M* = 1.00, *SD* = 1.00), priority-cue task (*M* = 0.14, *SD* = 0.67)] at the Cz site.

A post-hoc contrast test revealed that theta-band power was lower in the priority-cue and retro-cue condition compared to the control condition [t_{19} = -5.57, $p < 0.001$; priority-cue and retro-cue task (*M* = 1.03, *SD* = 0.79), control task (*M* = 0.10, *SD* = 0.67)] at the Pz site. A significant difference was also found in comparisons between the control with retro-cue condition [t_{19} = -4.80, $p < 0.001$; retro-cue task (*M* = 1.01, *SD* = 0.68), control task (*M* = 0.10, *SD* = 0.67)] at the Pz site. A significant difference was also found in comparisons between the priority-cue condition with priority-cue and retro-cue condition [t_{19} = -4.94, $p < 0.001$; priority-cue and retro-cue task (*M* = 1.03, *SD* = 0.78), priority-cue task (*M* = 0.20, *SD* = 0.61)] at the Pz site. Figure 4.6 shows the time-frequency analysis in theta-band power across Fz, Cz, and Pz sites during retro-cue. The time-frequency analysis provides the distribution of theta-band

and alpha-band power during the presentation of retro-cue.

Figure 4.6

Time-Frequency Analysis of the Four Conditions



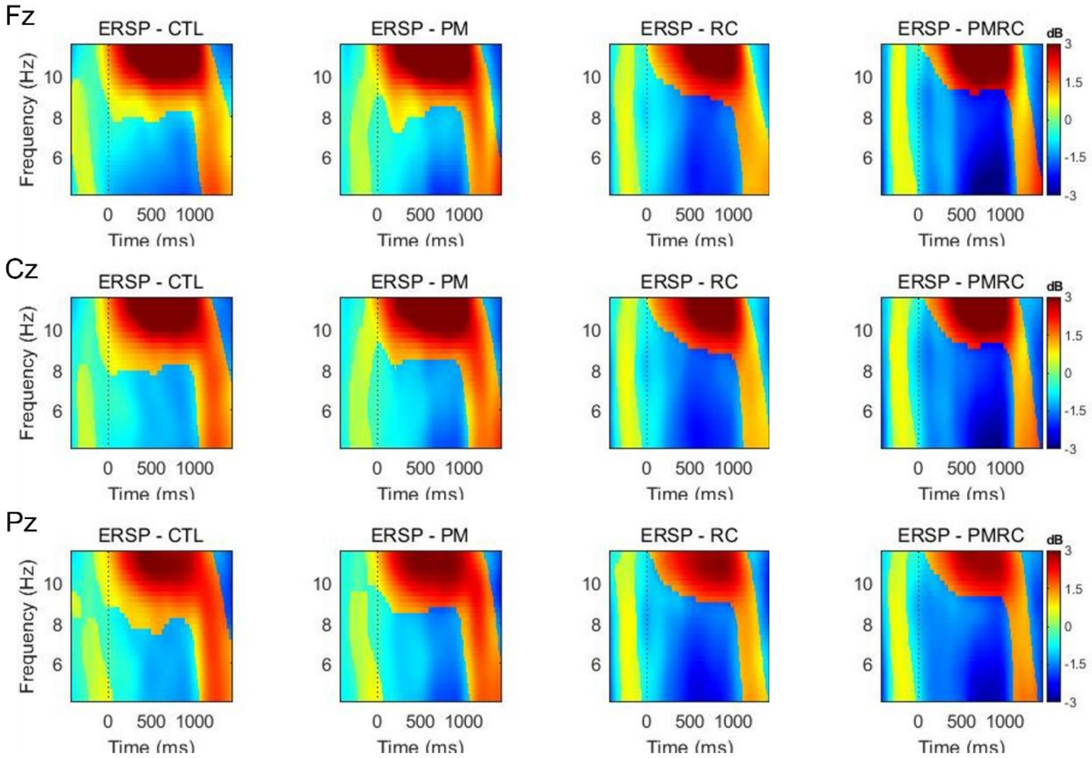
Note. Time-Frequency Analysis of the four conditions (CTL: control; PM: priority-cue; RC: retro-cue; PMRC: priority-cue and retro-cue) from 4Hz to 12Hz (theta: 4-8Hz; alpha: 8-12Hz) at the Fz, Cz, and Pz sites. Retro-cue onset at 0ms and offset at 500ms.

4.3.2.3. Neurophysiological Measurement - Theta-band Power during Maintenance

A significant main retro-cue effect [$F_{1,19} = 8.13$, $p = 0.01$] and cortical sites effect [$F_{2,38} = 3.71$, $p = 0.034$] were found in the theta-band power. A significant interaction effect of retro-cue and cortical sites was found in the theta-band power as well [$F_{1.25,23.9} = 6.10$, $p = 0.016$, $\varepsilon = 0.628$]. A marginal interaction effect of priority-cue, retro-cue, and cortical sites was found in the three-way repeated measures ANOVA [$F_{1.27,24.1} = 3.75$, $p = 0.056$, $\varepsilon = 0.634$]. Figure 4.7 shows the time-frequency analysis in theta-band spectral power across Fz, Cz, and Pz sites in different experimental conditions.

Figure 4.7

Time-Frequency Analysis of the Four Conditions



Note. Time-Frequency Analysis of the four conditions (CTL: control; PM: priority-cue; RC: retro-cue; PMRC: priority-cue and retro-cue) from 4Hz to 12Hz (theta: 4-8Hz; alpha: 8-12Hz) at the Fz, Cz, and Pz sites.

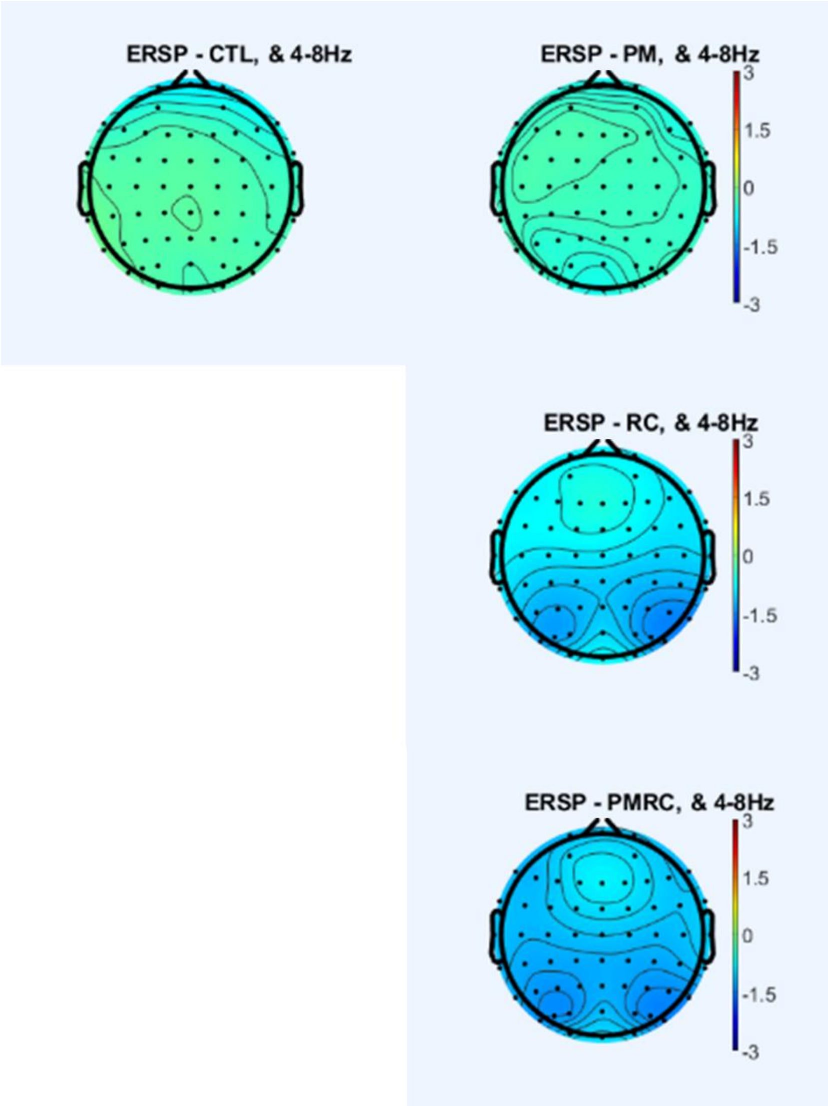
A significant main retro-cue effect was found in the theta-band power at the Cz site [$F_{1,19} = 9.23$, $p = 0.007$] and the Pz site [$F_{1,19} = 17.1$, $p = 0.001$]. A marginally significant priority-cue main effect was also found in the theta-band power at the Cz site [$F_{1,19} = 3.78$, $p = 0.067$]. A significant priority-cue main effect was also found at the Pz site [$F_{1,19} = 5.98$, $p = 0.024$].

A post-hoc contrast test revealed that theta-band power was lower in the priority-cue and retro-cue conditions compared to the control condition [$t_{19} = 3.24$, $p = 0.004$;

priority-cue and retro-cue task (*M* = -1.11, *SD* = 1.19), control task (*M* = -0.29, *SD* = 0.75)] at the Cz site. Table 2 shows the mean and SD of the theta-band power at Fz, Cz, and Pz sites. A significant difference was also found in the post-hoc contrast test between the control condition with retro-cue condition [t_{19} = 3.76, p = 0.001; retro-cue task (*M* = -1.07, *SD* = 1.04), control task (*M* = -0.24, *SD* = 0.72)] and priority-cue and retro-cue condition with control condition [t_{19} = 4.51, $p < 0.001$; priority-cue and retro-cue task (*M* = -1.23, *SD* = 0.99), control task (*M* = -0.24, *SD* = 0.72)] at the Pz site. At Pz site, there was a marginally significant difference between the control and priority-cue conditions [t_{19} = 2.11, p = 0.048; priority-cue task (*M* = -0.48, *SD* = 0.77), control task (*M* = -0.24, *SD* = 0.72)]. Figure 4.8 shows the topographical distribution of theta-band power in each condition and the statistical difference between conditions in different electrodes.

Figure 4.8

Topographical Distribution of Theta-band Power Across the Four Conditions



Note. Topographical distribution of theta-band power across the four conditions; comparisons of each condition with the control condition are shown. (ERSP: event-related spectral perturbation; CTL: control, PM: priority-cue, RC: retro-cue, PMRC: priority-cue and retro-cue).

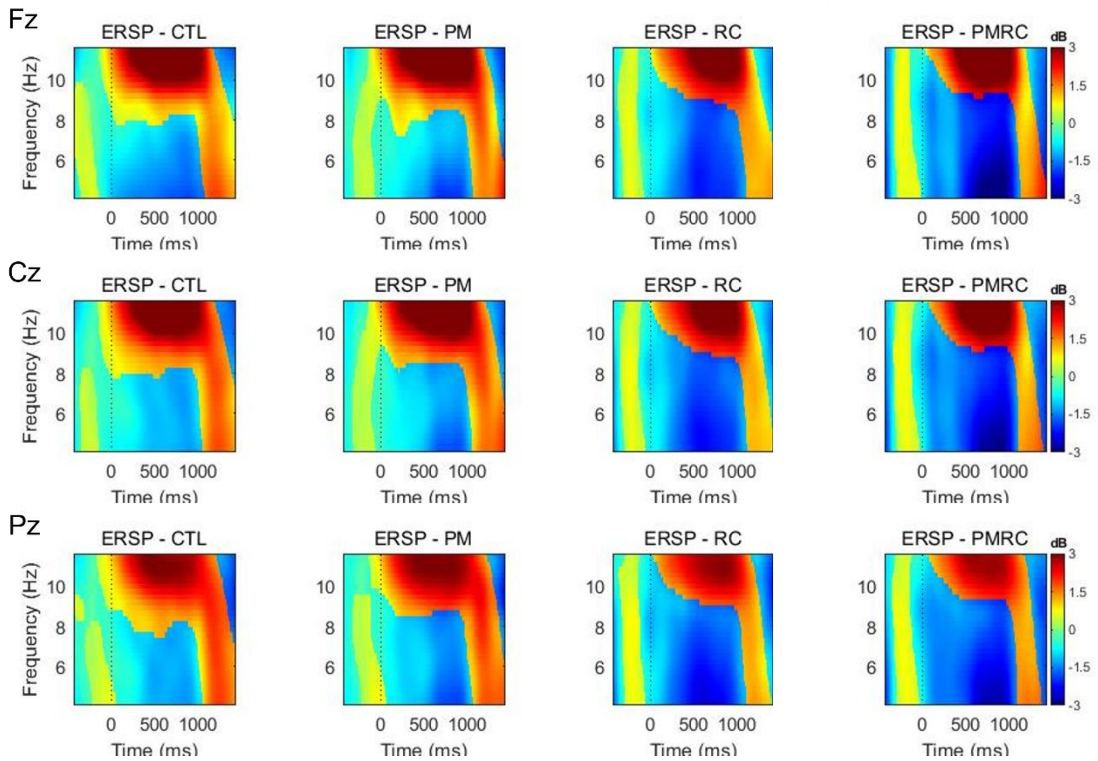
4.3.2.4. Neurophysiological Measurement - Alpha-band Power During Maintenance

A significant retro-cue effect [$F_{1,19} = 27.3$, $p < 0.001$] and cortical sites effect [$F_{1.5,28.9} = 6.36$, $p = 0.009$, $\varepsilon = 0.761$] were found in alpha-band power analysis. Figure

4.9 shows the time frequency analysis across Fz, Cz, and Pz sites involving alpha-band spectral power.

Figure 4.9

Time-Frequency Analysis of the Four Conditions



Note. Time-Frequency Analysis of the four conditions (CTL: control; PM: priority-cue; RC: retro-cue; PMRC: priority-cue and retro-cue) from 4Hz to 12Hz (theta: 4-8Hz; alpha: 8-12Hz) at the Fz, Cz, and Pz sites.

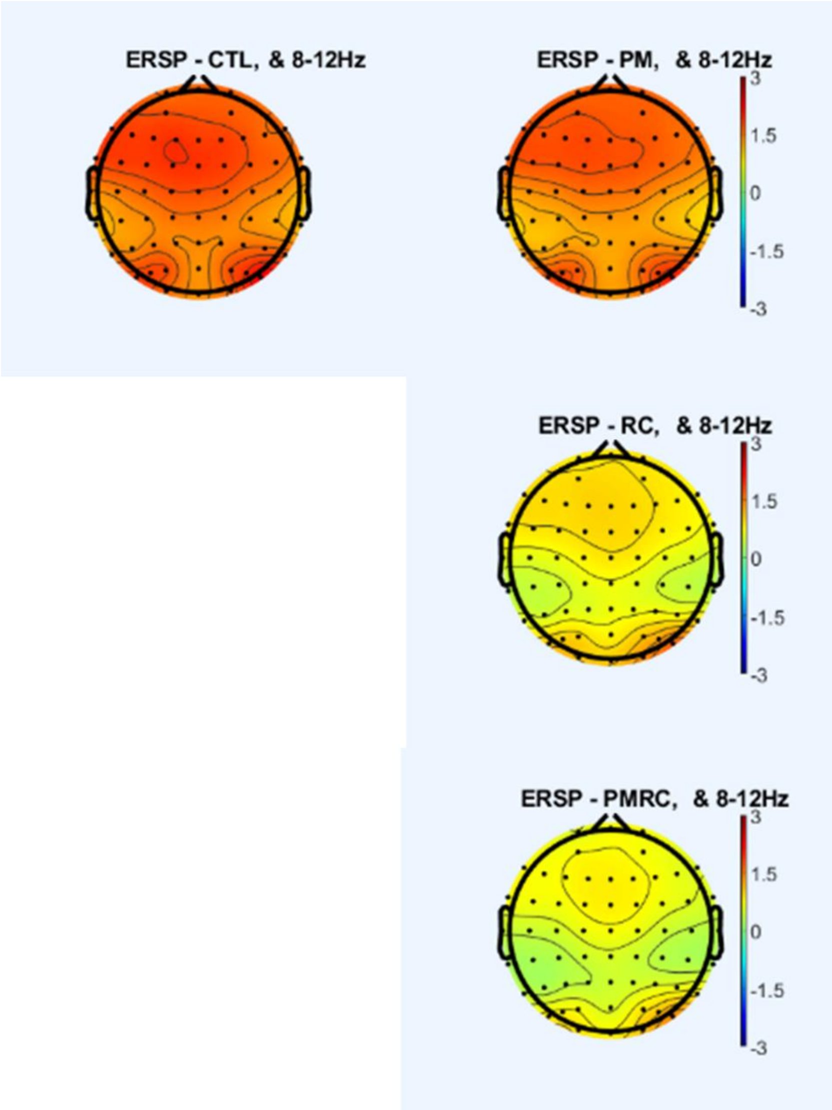
A significant retro-cue main effect was found in the alpha-band power at Fz [$F_{1,19} = 24.8$, $p < 0.001$], Cz [$F_{1,19} = 27.5$, $p < 0.001$] and Pz [$F_{1,19} = 19.1$, $p < 0.001$]. A marginally significant main priority-cue effect was found in the alpha-band power at Pz site [$F_{1,19} = 3.87$, $p = 0.064$]. In the alpha-band power, there was no significant interaction effect between the Fz, Cz, and Pz sites.

A post-hoc contrast test showed a decreased alpha-band power in the priority-cue and retro-cue condition compared with the control condition [$t_{19} = 4.17$, $p = 0.001$;

priority-cue and retro-cue task (*M* = 0.73, *SD* = 1.98), control task (*M* = 1.79, *SD* = 1.60)] at the Fz site. There was also a significant difference between the control with retro-cue condition [t_{19} = 4.30, $p < 0.001$; retro-cue task (*M* = 0.96, *SD* = 1.66), control task (*M* = 1.79, *SD* = 1.60)] at the Fz site. In the Cz site, a significant difference was found in comparisons between control with retro-cue condition [t_{19} = 4.76, $p < 0.001$; retro-cue task (*M* = 0.87, *SD* = 1.66), control task (*M* = 1.71, *SD* = 1.59)], and priority-cue & retro-cue condition [t_{19} = 4.69, $p < 0.001$; priority-cue and retro-cue tasks (*M* = 0.63, *SD* = 1.89), control task (*M* = 1.71, *SD* = 1.59)] respectively. In the Pz site, there was a significant difference between the control and retro-cue conditions [t_{19} = 3.82, $p = 0.001$; retro-cue task (*M* = 0.64, *SD* = 1.50), control task (*M* = 1.40, *SD* = 1.34)], and priority-cue & retro-cue condition [t_{19} = 4.93, $p < 0.001$; priority-cue and retro-cue tasks (*M* = 0.38, *SD* = 1.55), control task (*M* = 1.40, *SD* = 1.34)] respectively. Figure 4.10 shows the topographical distribution of alpha-band power in each condition and the statistical difference between conditions at different electrodes.

Figure 4.10

Topographical Distribution of Alpha Oscillations Across the Four Conditions



Note. Topographical distribution of alpha oscillations across the four conditions; comparisons of each condition with the control condition have been shown. (ERSP: event-related spectral perturbation; CTL: control, PM: priority-cue, RC: retro-cue, PMRC: priority-cue and retro-cue). (ERSP: event-related spectral perturbation; CTL: control, PM: priority-cue, RC: retro-cue, PMRC: priority-cue & retro-cue)

4.3.3. Summary of the Key Findings in Study One

To summarize, retro-cue condition and, priority-cue and retro-cue condition had a significant enhancement in accuracy and a significant reduction in reaction time compared with control condition. No significant difference was found between priority-cue condition with control condition. Furthermore, the contrast test between retro-cue condition and, priority-cue and retro-cue condition showed a significant difference in accuracy and a significant difference in reaction time. The results were consistent with objective 1b which hypothesized the retro-cue facilitates the behavioral performance. However, the objective 1a which hypothesized the priority-cue can facilitate the behavioral performance was not consistent with the results. An interaction effect of priority-cue and retro-cue effect was found in accuracy rate. The priority-cue and retro-cue task had a higher accuracy than retro-cue task. An additive effect was found with the presence of priority-cue and retro-cue.

There was a significant enhancement of frontal theta-band power in retro-cue condition compared with control condition. Also, there was a significant enhancement of frontal theta-band power in priority-cue and retro-cue condition compared with control condition. Objective two was to examine the effect of priority-cue or retro-cue in frontal theta-band power. Priority-cue did not induce a significant change in frontal theta-band power while retro-cue induced a significant enhancement in frontal theta-band power.

There was a significant reduction of parietal alpha-band power found comparing retro-cue condition with control condition and, priority-cue and retro-cue condition with control condition. Objective three was to examine effect of priority-cue or retro-cue in parietal alpha-band power. Priority-cue by itself did not induce a significant change in parietal alpha-band power while retro-cue induced a significant reduction in parietal alpha-band power. Moreover, there is significant reduction of alpha-band power found comparing retro-cue condition with control condition and, priority-cue and retro-cue condition with control condition over frontal, central and parietal regions.

4.4. Discussion

In this study, the delayed recognition task required the participant to perceive the visual forearm in a dot-and-line format externally and then generate and maintain the visual representation before the recall probe appeared. Before generating the internal visual representation, it requires the retrieval of visual schema from the long-term storage and the selection of the most related action schema. In different conditions, priority-cue and retro-cue were used to see if executive control could modulate the external-to-internal attention orientation and internal oriented attention to select relevant representation and generate the internal representation.

4.4.1. The Effect of a Top-down Priority-cue on External-to-internal Attention

The presence of a priority cue alone in the priority cue task did not improve accuracy or reaction time when compared to the control task. A pre-stimulus cue has been found to facilitate behavioral performance before the occurrence of the stimulus (Fazekas & Nanay, 2017), while this facilitating effect on behavioral performance was not shown in this task. In a working memory study (Ye et al., 2016; Niklaus et al., 2017), priority cues have been given to facilitate participants to focus on one of the features of the memory display, for example color or orientation. The stimuli in the memory display consists of generated bars with different color and orientation. Previous studies revealed that participants can flexibly allocate cognitive resources to a particular dimension of memory representation, which supported feature-based attention (Niklaus et al., 2017). The priority-cue integrates feature information from sensory stimuli and top-down representations of behavioral goals originating in the prefrontal cortex (Ptak, 2012). It is possible for the existence of the top-down priority-cue to modulate attention that is focused externally on the selection of relevant and irrelevant information, which then facilitates the prioritization of the maintenance of relevant information (Robison & Unsworth, 2017). However, in the present study, the EEG resulted in theta-band oscillation power comparing control task and priority task revealed no significant difference at the frontal sites, indicating that the presence of a priority cue had no effect on executive control. On the other hand, EEG result in alpha-band oscillation power comparing priority-cue task and control task showed no significant difference at the parietal sites. In Study one, the participants were required to participate in a delayed recognition task in which he or she was asked to encode the visual human forearms in a simplified dot-and-line representation after the presentation of the priority-cue and retrieve the visual motor representation before the recall probe. The presence of priority-cue was hypothesized to be prioritizing the external visual information and therefore facilitating the behavioral performance.

The absence of such a facilitating effect may be due to inefficient external prioritization by the priority-cue. It is speculated that the priority-cue may not be strong enough to enhance the external-to-internal attention and generation of visual internal representation, or that the priority-cue facilitate feature-based information that would require the participant to retain the entire image. In this study, priority-cue was presented in two formats, asking participant to focus on either a) joint angle or b) segment orientation. Focusing on joint angle or segment orientation may still require the participant to visually encode the entire forearm, making disengagement from visual more difficult and impeding the flow of external-to-internal attention. The absence of a priority cue effect in accuracy and reaction time in the experiment may be due to the feature relationship between orientation and angle. The feature relationship between orientation and angle features is unlike the discrete relationship between color and orientation in Ye's study (2016). Because the angle feature is part of the orientation feature, it became less important to prioritize the angle or orientation feature. Subjects might have encoded the entire image, no matter what orientation or angle feature was cued in the priority-cue. An additional analysis across trials with orientation and angle priority-cue did not show a significant difference.

4.4.2. The Effect of Top-down Retro-cue on Internal Maintenance and Inspection

The results showed the presence of retro-cue alone in the retro-cue task was able to facilitate accuracy and reaction time compared with the control task. Retro-cue was shown to enable us to manipulate the internally maintained and inspect representations on the working memory buffer (Rerko et al., 2014; Riddle et al., 2020). Internal prioritisations via retro-cue elicit executive control and operate on working memory representations. The use of a retro-cue would make it easier to inhibit task-irrelevant representation and select task-relevant representation, minimizing the amount of effort required by executive control (Souza & Oberauer, 2016). It is suggested that retro-cue improves participants' accuracy by facilitating the maintenance of specific internal representations and therefore enhancing behavioural performance (Rerko et al., 2014). The difference in theta-band oscillation power between the retro-cue task and control task was significant at the frontal sites, with higher theta-band power in the retro-cue task indicating higher executive control due to the presence of retro-cue. On the other hand, EEG resulted in alpha-band oscillation power comparing control task and retro-cue task showed significant difference at the parietal sites with lower alpha-power in retro-cue tasks. In Study One, a retro-cue was presented after the presentation of the visual human forearms in a simplified dot-and-line representation, and the participants were required to retrieve the visual presentation after the retro-cue and maintain the visual representation. Retro-cue had directed his or her attention to a specific joint location, i.e., the wrist or elbow of the forearm.

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4.4.3. The Interaction Effect of Top-down Priority-cue and Retro-cue on External-to-internal Attention, and Internal Maintenance and Inspection

In the priority-cue and retro-cue condition, the presence of priority-cue and retro-cue was able to facilitate the accuracy and reaction time compared with control task. The presence of priority-cue and retro-cue cues is suggested to lower the demand on top-down executive control and to alternate between external visual information and internal kinesthetic representation. Priority-cue are suggested to modulate the external-to-internal attention orientation on external sensory information and facilitate the selection of relevant information, while retro-cue are suggested to modulate the maintenance and inspection of internal representation and facilitate the suppression of irrelevant representation. In this study, an enhanced frontal theta-band power was observed in priority-cue and retro-cue task compared with control task, but a lower parietal alpha-band power and higher accuracy were observed. The theta-band oscillation power comparing control task and priority- and retro-cue task showed significant difference at the frontal sites with higher theta-band power in priority-cue and retro-cue task, which may indicate executive control require additional burden to handle the priority-cue and retro-cue. At frontal sites, the theta-band increase was mainly associated with internally oriented attention; specifically, frontal midline theta enhancement was previously observed during mental arithmetic tasks (Ishii et al., 2014; Mizuhara et al., 2004; Kitaura et al., 2017). Magosso and Ricci (2021) investigated the internal-external attention competition and found that frontal theta-band power was distinctive of mental task execution and more prominent during competition compared to internal attention alone. In this study, the participants were required to encode the visual human forearms in a simplified dot-and-line representation after the presentation of a priority-cue and a retro-cue presented after the presentation of the visual human forearms, for which the participants were required to generate the visual presentation after the retro-cue and maintain the visual representation. The priority-cue carried the feature-based information to the retro-cue phase. The wrist or elbow location cue was integrated with the feature-based information during the retro-cue phase, the priority-cue would reduce the amount of irrelevant information and the executive function could govern the internal attention more efficiently. Results showed that when cues accompanied the maintenance task, lower parietal alpha-band power was observed, which is statistically different from the control condition. A review on alpha-band oscillations and attention suggested that an increase in alpha-band power reflects inhibition while a decrease in power reflects release from inhibition (Klimesch, 2012). Internal maintenance induced a strong parietal alpha-band power increase, indicating the inhibition of the processing of visual stimuli in the control condition (Klimesch, Sauseng, & Hansilmayr, 2007; Lőrincz et al., 2009; Mathewson et al., 2009; Fell et al., 2011). This effect may result from two opposing directions: high internal processing demands increase alpha-band power while visual cues reduce alpha-band power. A possible interpretation of alpha-band power could be that internal processing operates in the opposite mechanism from external processing. An increase in alpha-band power to insulate internal processing and a decrease in alpha power induced by the maintenance of items can be manifested by the power of alpha, i.e., higher alpha power with more representations and lower alpha power with fewer representations. Therefore, participant could respond more accurately. According to our findings, prioritization could operate prospectively on perceptual external input using exogeneous selective attention to filter relevant information encoded into working memory and retrospectively on internal working memory maintenance using internal prioritization, resulting in an additive benefit in behavioral performance. Although the presence of visual cues increases the cognitive load on the executive control, there is still a facilitation in accuracy and reaction time. Priority cue, in particular, only manifested its facilitation with retro cue. The external prioritization of orientation or angle features integrated with the internal prioritization of directing attention to specific joint locations resulted in a summation of improvements in accuracy and reaction time. Furthermore, this study' results provide insight on using priority-cue and retro-cue in later experiments to facilitate executive control and the processes of action observation and motor imagery. The presence of both cues yielded the greatest beneficial effect on behavioral performance and showed the effect of visual cues in theta- and alpha-band oscillations.

CHAPTER FIVE

STUDY TWO

The Facilitating Effect of Visual Cues on Concurrent Action Observation and Motor Imagery: A Behavioral and Electrophysiological Study

5.1. Overview of the Study

In Chapter 4, It was demonstrated that the presence of visual cues could improve executive control and discovered an additive facilitating effect when two cues were presented in behavioral performance. The attention orientation was influenced by executive control under the modulatory effect of retro-cue, as signified by theta-band power enhancement The maintenance of visual representation was influenced by executive control through retro-cue, signified by alpha-band power reduction. It provides the basis for examination of the underlying neural mechanisms in motor context, that is during concurrent action observation and motor imagery.

Though Study One may have revealed information about executive control's modulatory effect on external-to-internal attention orientation and the generation of visual representation via priority-cue and retro-cue, it is unclear how external visual information and internal kinesthetic representation interact with visual cues. As there were no kinesthetic inputs, executive control would be required to initiate a top-down control on the retrieval of the action representation from the long-term memory based on the rehearsed visuomotor images and the selection of the most relevant representation to generate the kinesthetic images. As priority cue only manifested its facilitation with retro cue in Study One, Study Two used the condition with priority-cue and retro-cue to examine the additive effect on concurrent AOMI. Study Two aimed to investigate how the attention orientation modulated by the executive control influence the subsequent maintenance of internal kinesthetic representation by using priority-cue and retro-cue together.

5.2. Methods

5.2.1. Participants

Twenty-five healthy volunteers (12 females; ages: M = 26.1, SD = 4.4, range=20-34) were recruited to participate in the study via convenient and snowball sampling. The inclusion criteria were: (1) age between 20 – 35 years old; right-handed as assessed by the Edinburgh Handedness Inventory (Oldfield, 1971); (2) no history of upper limb injuries; (3) obtaining at least 29 (out of 30) points in Hong Kong version of Montreal Cognitive Assessment (MoCA) points (Wong et al., 2009); (4) normal or corrected-to-normal vision; (5) obtaining at most an average of 3 (out of 5) in the kinesthetic imagery subcategory of Vividness of Movement Imagery Questionnaire-2. Those with psychiatric disorders (e.g. psychosis) or neurological conditions (e.g. stroke and traumatic brain injury) were excluded from the study.

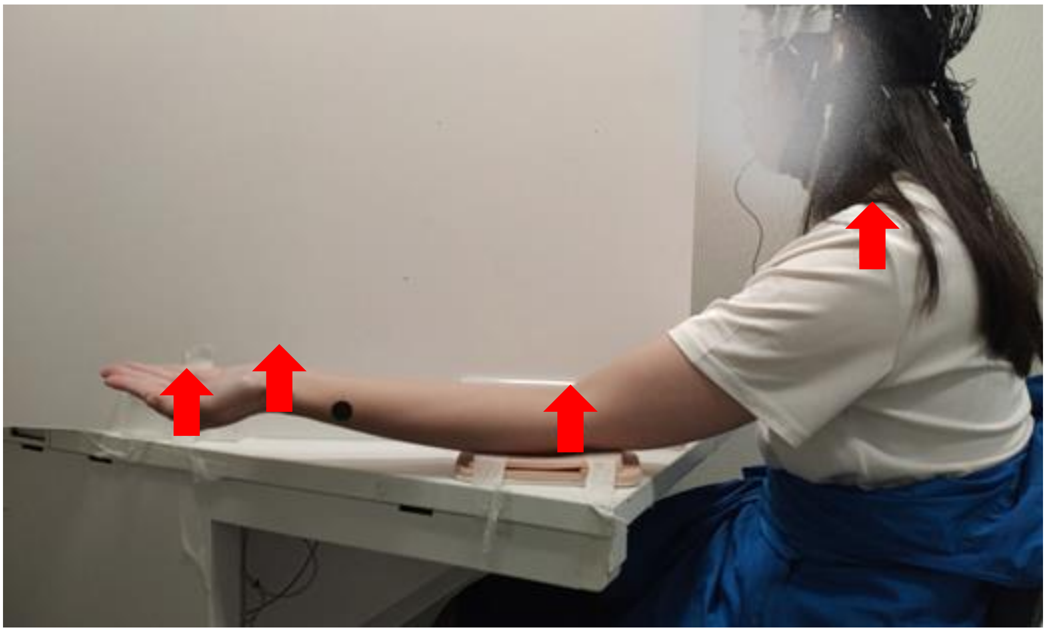
5.2.2. Experiment Procedure

Each participant was asked to sign an informed consent form after the experimenter explained the purpose and procedure of the study. The participant was required to complete a demographic questionnaire after completing the consent form (covering name, age, education level, and medical record), the Edinburgh Handedness Inventory (Oldfield, 1971) and the Vividness of Movement Imagery Questionnaire-2. To confirm the individual’s intact left hand physical function, the person was assessed with their range of motion in wrist and elbow actively and passively. To confirm the individual's intact cognitive functions, the person was examined using the Hong Kong version of MoCA (Wong et al., 2009). Each participant received training in the automatic imitation task with priority-cue and retro-cue before the experiment. The recall probe in the training session recorded the accuracy of the participant on identifying whether the wrist and elbow joint orientations in the probe was identical to the movements shown in the movie that had just been presented earlier. Before beginning the behavioral and electrophysiological data collection, a minimum accuracy of 70% was required.

The participant was comfortably seated in an electrically protected and soundproof chamber during the experiment with data acquisition. He or she was seated in front of a computer-synchronized display panel, 60 to 65 cm away from the screen. Stimuli were presented on a computer screen using the E-Prime 3.0 software (Psychology Software Tools, Pittsburgh, PA). A 5-degree viewing angle was chosen. The participant' left elbow was rest on a thermoplastic hand rest, 20 cm in front of them on the desk (Figure 5.1.).

Figure 5.1

Illustration of the Setup and the Start Location of the Participant's Left Hand

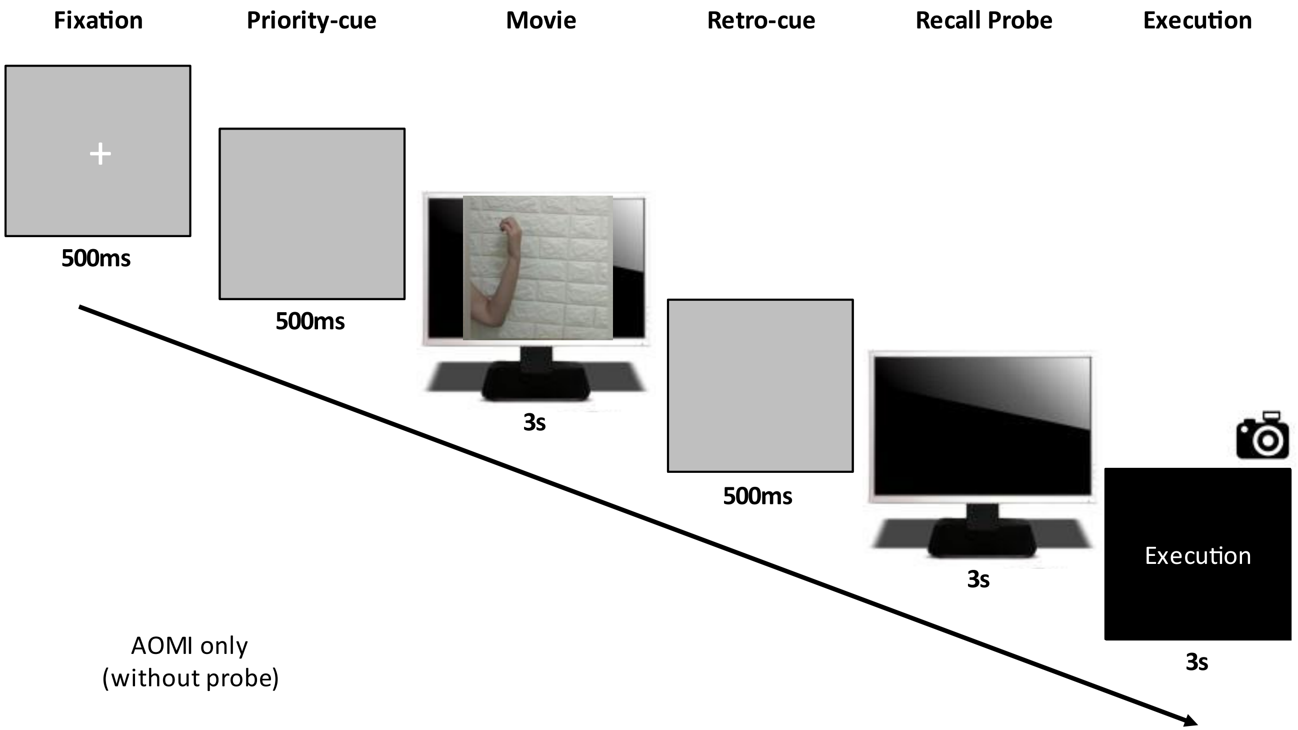


Note. This photograph illustrates the setup and the start location of the participant's left hand. Black dot markers were placed at the second metacarpophalangeal joint, radial styloid process, lateral epicondyle, and acromion of the participant' left upper arm to improve the precision of Kinovea.

A pre-experiment training session was given to each participant to get him or her familiar with the experimental procedure and the tasks they are required to be engaged. In step 1, participant learned to pantomime each action from a set of sixteen movies without visual feedback with elbow and wrist flexion offset angles at 0°, 30°, 60°, and 90°. In step 2, the participant was passively moved to the preset offset angles. The participant was required to perceive the joint kinesthetic sensation and linked with the movie. In step 3, the participant was instructed to rehearse mentally the kinesthetic sensation of the moving joint during the presentation of action movies. In step 4, the participant experienced the basic trial structure for the two AOMI conditions in the main experiment (Figures 5.2 and 5.3) and he or she was instructed to reproduce the action when he or she saw the word "Execution" on the screen. The participant was required to finish 5 trials of each condition in order to ensure he or she understand the instructions of the task before the start of the experiment.

Figure 5.2

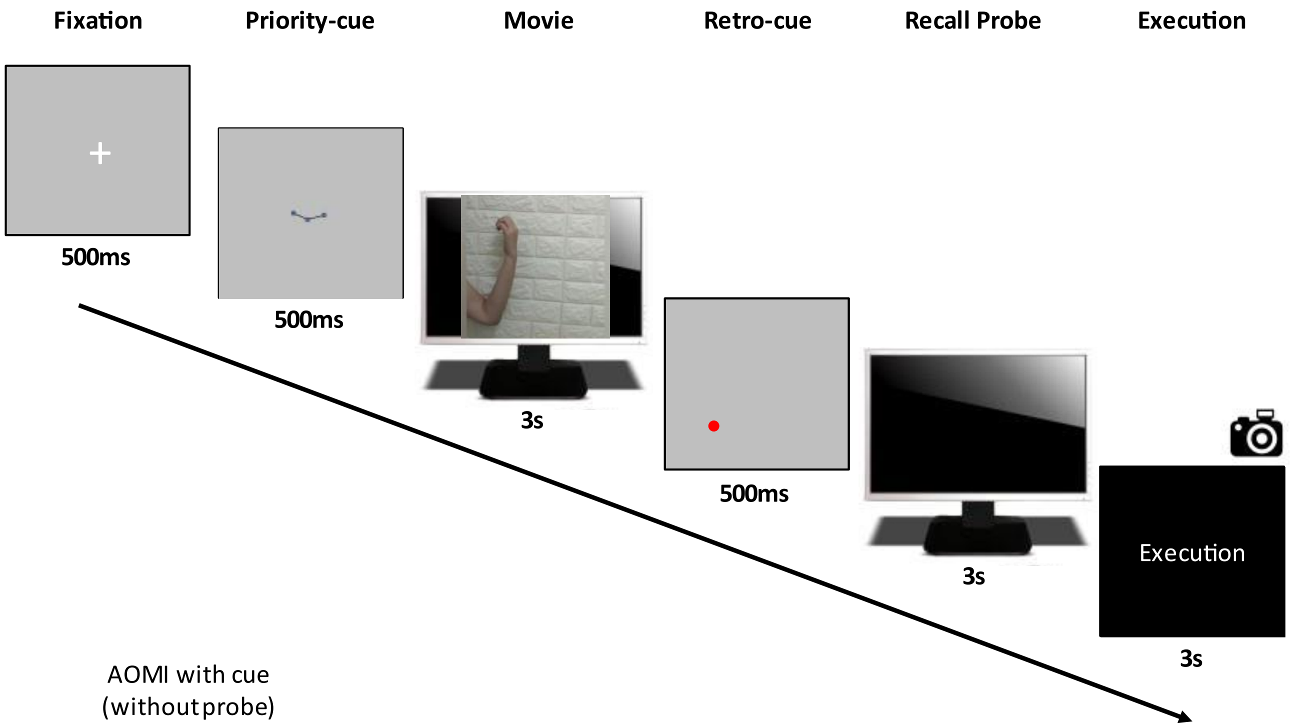
Illustration of One Basic Trial in the AOMI Condition during the Pre-experimental Training



Note. There was a 3.5-second delay after the movie and participants were required to reproduce the action when they saw the word "Execution" on the screen.

Figure 5.3

Illustration of One Basic Trial in the AOMI with Priority-cue and Retro-cue Condition During the Pre-experimental Training.



Note. There was a 3-second delay after the retro-cue, and participants were required to reproduce the action when they saw the word "Execution" on the screen

5.2.3. Experimental Setup

Each participant was comfortably seated in an electrically protected and soundproof chamber during the experiment with data acquisition in the University Research Facility in Behavioral and Systems Neuroscience, the Hong Kong Polytechnic University. He or she was seated in front of a computer-synchronized display panel, 60 to 65 cm away from the screen. Stimuli were presented electronically using the E-Prime 3.0 software (Psychology Software Tools, Pittsburgh, PA). A 5-degree viewing angle was chosen. The participant's left elbow was rest on a thermoplastic hand rest, 20 cm in front of them on the desk (Figure 5.1.).

A Smartphone was set up on a level tripod 1 m from the floor and 95cm to 100cm away from the participant's left forearm to capture clearly the image of the upper limb movement. This setting ensured that the calibration area covered the upper limb of the participant (Figure 5.4). The focus and aperture were adjusted until the phone display showed clear and sharp images, and the angle of the lens of the Smartphone was adjusted until it was parallel to the sagittal plane of the participant's upper limb. Black round markers with a 20 mm-diameter were placed at the second metacarpophalangeal joint, radial styloid process, lateral epicondyle, and acromion in order to improve the precision of locating geometric centers in the precision of Kinovea (Figure 5.1.).

Figure 5.4

Illustration of the Video-recording Covered the Upper Limb of the Participants

Note. The photograph illustrates that the video-recording covered the upper limb of the participants. The Smartphone was set up on a level tripod 1m from the floor and 95-100cm away from the participants to capture the upper limb movement clearly. This setting ensured that the calibration area covered the upper limb of the participants. Focus and aperture were adjusted until the system produced clear and sharp 2D images, and the lens of the Smartphone was adjusted until it was parallel to the sagittal plane of the upper limb.

5.2.4. Experimental Stimuli

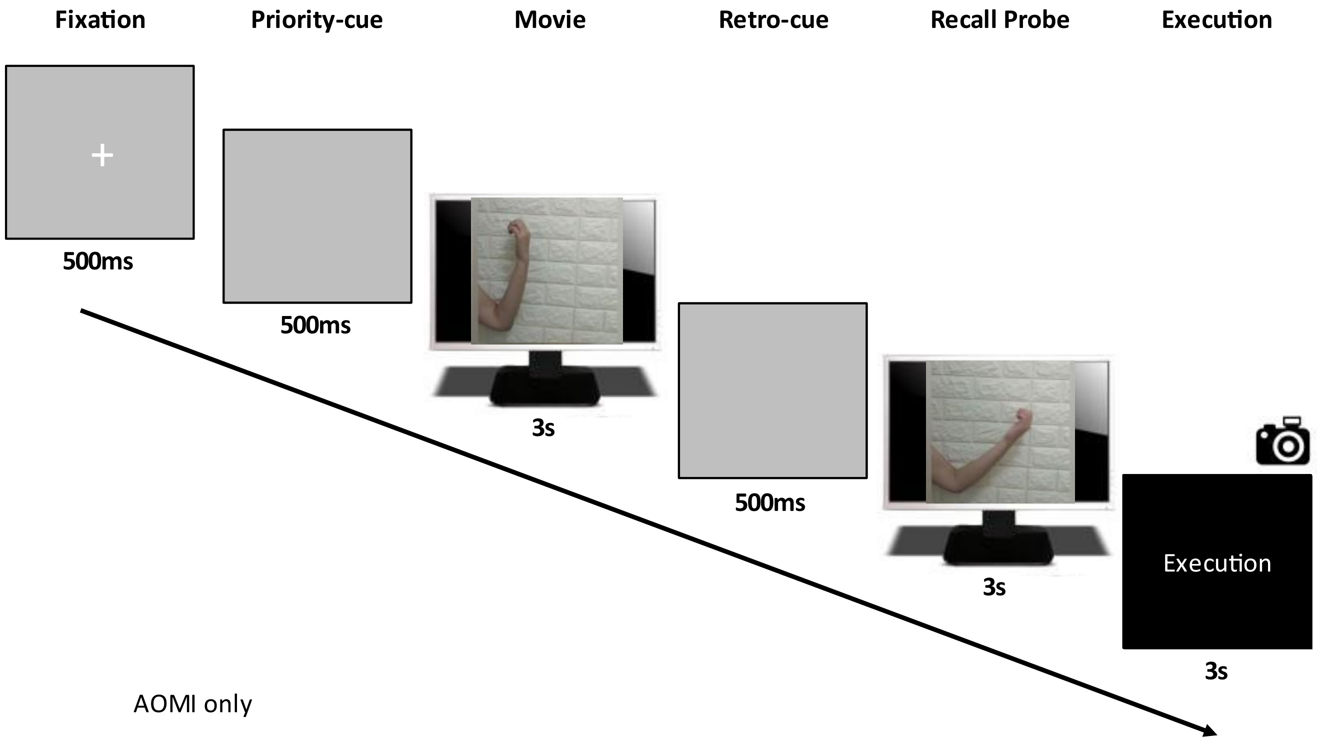
There were two types of visual stimuli being used in the cognitive experiment, one type of visual stimuli static pictures including visual cues and fixation just as in Study one. Another type of stimuli was movies of upper limb movement. The elbow joints and wrist joints were presented in the movies. The action movie was constructed with two variables: the elbow joint (elbow flexion and extension) and the wrist joint (wrist flexion and extension). The elbow joint and wrist joint were combined and pre-set at angles of 0°, 30°, 60°, and 90° from the neutral position. This provided sixteen instructed actions. The elbow, forearm, and wrist were all visible in the action movies. Each action was instructed to be in the vertical plane. The model performed all actions to provide images of the participants' actions, who always executed actions with their left hand. During the experiment, a computer screen with a gray background displayed the movies.

5.2.5. Experimental Paradigm

Each participant was required to participate in two cognitive-motor tasks (1)—an automatic imitation task (control) and (2) an automatic imitation task with a priority and retro cue—in a pseudo-randomized order. The paradigm was adopted from the one used in the study conducted by Eaves et al. (2016). The participant required to imagine the instructed action kinesthetically during the movies and then execute the action during the execution stage. The design and presentation of the visual cues followed Rerko's cue paradigm (Rerko et al., 2014; Ye et al., 2021). In each trial of the automatic imitation (control) task, the participant was presented with a white central fixation cross on a gray background for 500 ms, then a 500 ms grey blank screen. A movie was shown for 3 seconds with the elbow and wrist joint at onset angle 0° and offset angles at one of the pre-set angles of 0°, 30°, 60°, or 90° for 3s. A recall probe, consisting of a movie with the elbow and wrist joint was shown to the participant after a 500 ms delay. There were trials with the recall probe and trials without the recall probe. The recall probe only appeared pseudo-randomly in one quarter of trials in the experiment. He or she was required to indicate whether the wrist and elbow joint orientations in the probe was identical to the movements shown in the movie that had just been presented earlier by pressing the N key or M key using right hand index finger on the keyboard. The recall probe was shown on the screen for 3s. The participant was required to press the M key in an identical trial; otherwise, the participant was required to press the N key. In trials without the recall probe, each participant was required to execute the movement based on the action movie seen after 3s (Figure 5.5), the movement were recorded by a Smartphone video function.

Figure 5.5

Illustration the Presentation of Each Stimulus in the AOMI Condition



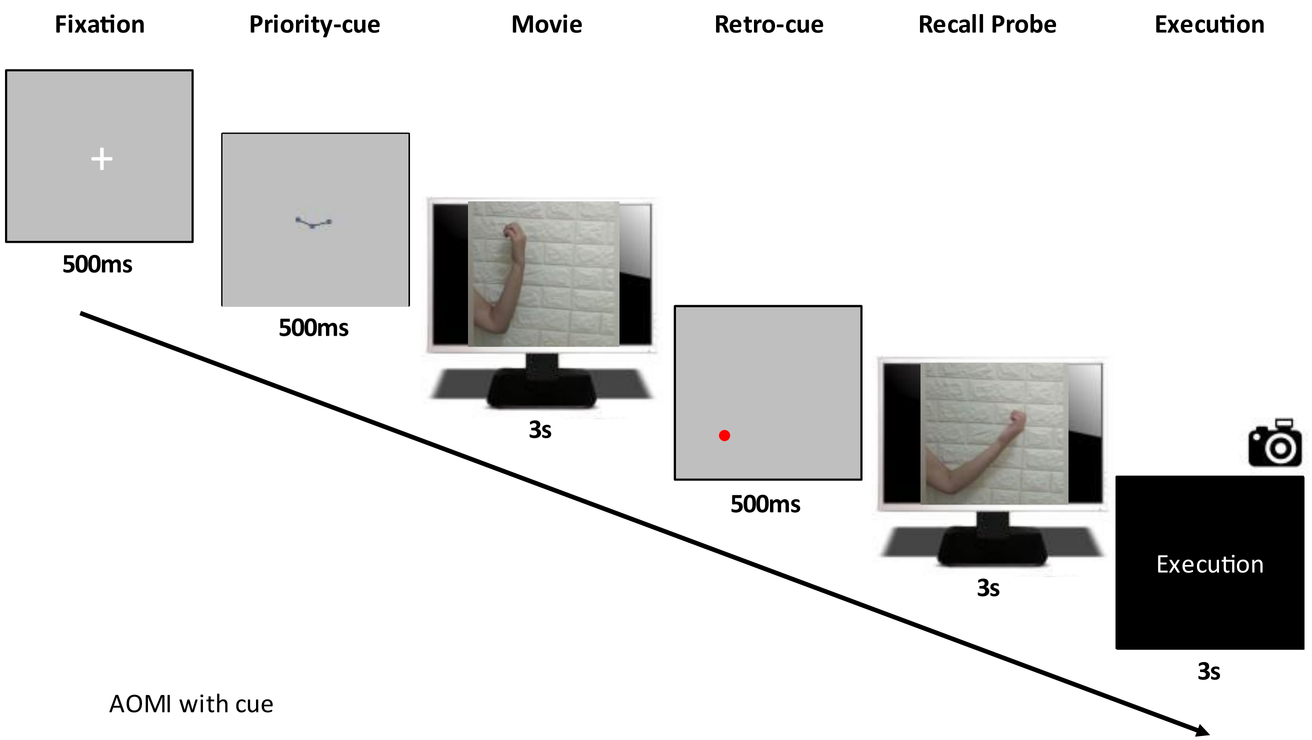
Note. The recall probe was shown to the participant after a 500 ms delay, which appeared in one quarter of trials in the experiment. There was a 3.5-second delay after the movie in the trial without discrimination probe, and participants were required to reproduce the action when they saw the word "Execution" on the screen.

(b) In the task of automatic imitation with priority-cue and retro-cue, the timing of the stimulus presentation was the same as that in the control task, except priority-cue appeared after the central fixation and retro-cue appeared after the display of the movie. A priority-cue that appeared after the central fixation and lasted for 500ms. The priority-cue was to inform the participant which feature, either joint angle or segment orientation, they should pay attention to before the movie was presented. A retro-cue that indicated the specific joint location to pay attention to appeared after the display of the movie. After a 500 ms retro-cue, there was a subsequent 3-second delay. A probe was shown to the participant after a 500 ms retro-cue, which appeared in one quarter of trials in the experiment. By pressing the M key or N key on the keyboard using right hand index finger, he or she was expected to indicate whether the probing movie was identical to the instructed action movie that was presented at the beginning of the trial. The participant was required to press the M key in an identical trial. In non-identical trials, the user should press the N key. In trials without the probe, each participant was required to execute the movement based on the action movie seen after 3s (Figure 5.6), the movement were recorded by a Smartphone video function.

For each type of cognitive task, there were a total of 2 blocks with 48 trials. There were a total of 4 blocks, with each having 48 trials. Breaks were given between blocks whenever needed. The schematic representation of the experimental paradigm is shown in Figure 5.7.

Figure 5.6

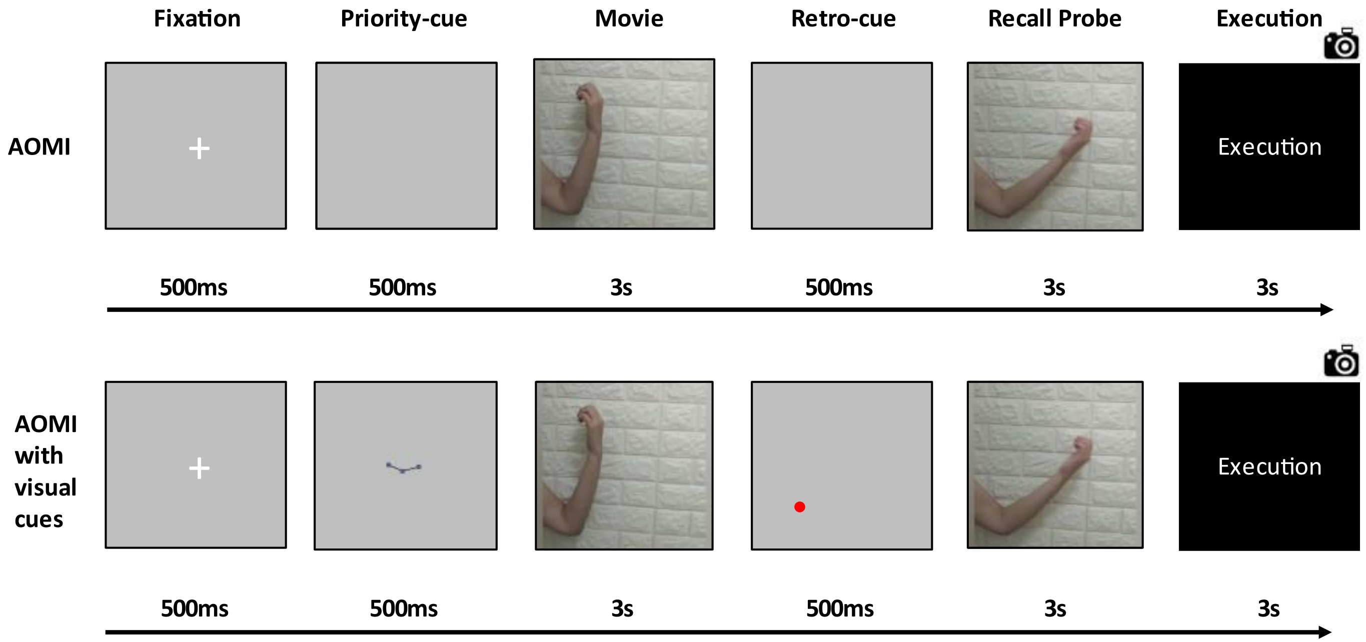
Illustration of the Presentation of Each Stimulus in AOMI with Priority-cue and Retro-cue Condition



Note. The recall probe was shown to the participant after a 500 ms delay, which appeared in one quarter of trials in the experiment. There was a 3-second delay in the trial without discrimination after the retro-cue, and participants were required to reproduce the action when they saw the word "Execution" on the screen.

Figure 5.7

Illustration of the Schematic Representation of an Experimental Paradigm



Note. The timing of the stimulus presentation was the same in two conditions. The stimuli displayed in priority cue and retro-cue event was different across two conditions, a priority-cue indicated which feature (angle joint or segment orientation) to attend, a retro-cue indicated location to attend. (On the top panel, AOMI condition; on the bottom panel, AOMI with priority-cue and retro-cue.)

5.2.6. Online Acquisition of Neurophysiological Data

The EEG data indicating cortical activities when each participant was performing the two cognitive tasks were recorded concurrently in a soundproof room along with the behavioral data using 64 electrodes (90mm Ag/AgCl sintered) mounted on a Quikcap and the CURRY Scan 7 Neuroimaging Suite (NeuroScan Labs, Sterling, VA). Blinks and eye saccades were detected using electrooculograms (EOGs) that were recorded both vertically and horizontally. Two electrodes were placed 2 cm above and below the left eye, as well as at the outer canthus of each eye. Each electrode received an injection of conductance gel to keep all electrode impedances at or below 5 kΩ and the signal was sampled at 1000Hz. The head-box of the SynAmps2 Digital DC EEG Amplifier was used to amplify the EEG signals. The ground electrode was located on the forehead in front of the vertex electrode, and the montage was referenced to the left and right bony mastoids (Cz). Using the EEGLAB toolbox, the EEG data was down-sampled to 200 Hz and filtered between 1 and 50 Hz.

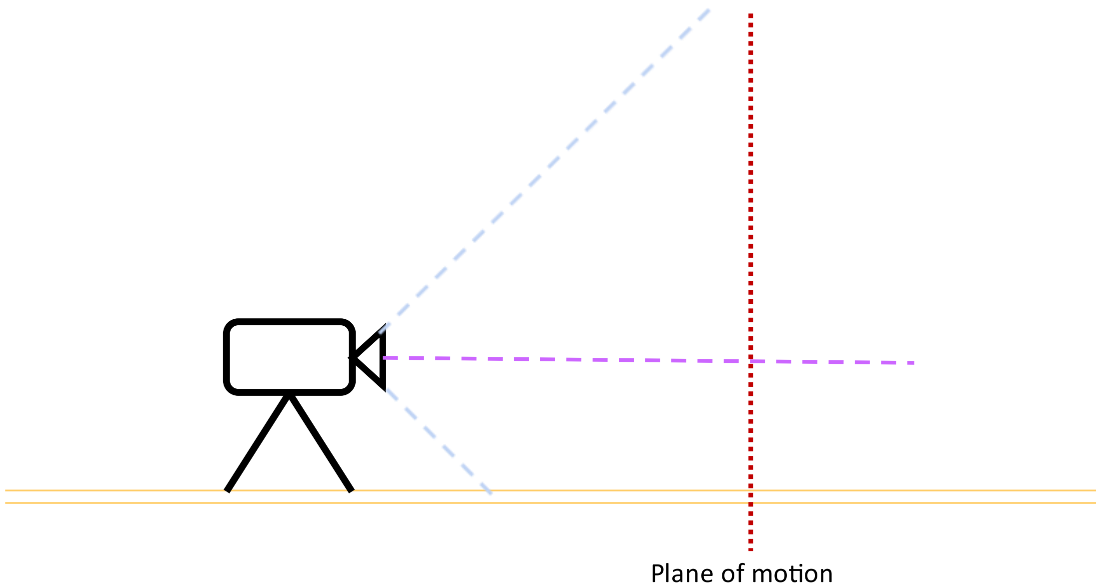
5.2.7 Offline Processing of Kinematic Data

The kinematic data of the participants was captured using a camera and then extracted and analyzed using motion analysis software, Kinovea 0.9.5, which is a motion analysis software that has been proven to be valid and reliable for measuring movement angle (Puig-Diví et al., 2019; Nor-Adnan et al., 2018). The video of action executed by the participant during the cognitive experiments was captured by the Smart phone video function. The movements were subsequently processed using Kinovea. The videos were first calibrated by line calibration to ensure the motion is sitting on a 2D plane parallel to the camera plane (Figure 5.8.). In Kinovea, the goniometer tool allows the measurement of the extension or a flexion of a body segment relative to a referenced anatomical angle or neutral position and allowed experimenter to check if any deviation of tracked angles throughout each video. The angular kinematics of elbow joint and wrist joint were then extracted according to the relative time scale of each movement in the experiment. Each measurement of flexion and extension of wrist and elbow were subtracted with the elbow and wrist joint offset angles in the movie to calculate the precision of each movement.

$$Precison\ (°) = preset\ angle\ in\ movie - extracted\ angle$$

Figure 5.8

Illustration of the Line Calibration by Kinovea



Note. The line calibration by Kinovea to ensure the motion is parallel to the camera plane. The videos were calibrated by line calibration to ensure the motion is sitting on a 2D plane parallel to the camera plane. The software provided a virtual grid line to align the plane of motion to be in parallel to the camera plane.

5.2.8. Offline Preprocessing of Neurophysiological Data

The EEG signals that were recorded during the cognitive experiments were processed using EEGLab (Delorme and Makeig, 2004) processing and offline Matlab scripts. Raw EEG data were band-pass filtered between 1 and 80 Hz and then down-sampled to 250 Hz. Then, a 50 Hz notch filter was used. Electrodes on both sides of the mastoid were used as a reference for the data. The signals with significant movement artifacts and prolonged eye closure were omitted from the visual inspection. Then EEG was segmented into 2,000 ms epochs (pre-stimulus −1,000 ms sand post-stimulus 1,000 ms). In order to remove eye movement artifacts, an independent component analysis strategy was applied (Delorme and Makeig, 2004). Blinking and horizontal eye movement-reflecting typical components were disregarded.

5.2.9. EEG Offline Processing - Event-related Spectral Perturbation (ERSP)

The event-related spectral perturbation (ERSP) method was adopted to calculate the spectral power change of the EEG relative to the retro-cue and recall probe period in the paradigm from the perspective of the time-frequency domain. As the pre-stimulus baseline was recorded with a mean power level, event-related spectral perturbations in power in each frequency were computed by normalizing the power spectral estimate at each frequency with the pre-stimulus baseline mean power. Decreases in spectral power from baseline were regarded as an increase in event-related desynchronization (ERD) in cortical activity, while an increase in spectral power from baseline indicates a resting state of cortical neural activity. The topographical distribution of brain activation was used to figure out which regions of the brain are involved when ERD occurs. Based on the ERSP values from 60 electrodes, the averaged ERSP value in the fixed frequency band and time interval within the theta and alpha bands were calculated. The mean spectral power for theta (4-8 Hz) and alpha (8-12 Hz) across two conditions were calculated.

5.2.10. EEG Offline Processing - Time-frequency Analysis

In a time-frequency domain, clean trials were examined. The event-related spectral perturbation (ERSP) technique was used to determine ERD power (Delorme and Makeig, 2004). For the ERSP calculation, the power spectra of each epoch were calculated and each one was normalized by its own mean baseline spectrum. The power was then converted to log power by averaging it over all included trials (see the following formula).

$$ERSP(f,t) = \frac{1}{n}\sum_{k=1}^{n}(F_k(f,t)^2)$$

Fk (f, t) is a spectral estimation of the kth trial at frequency f and time t, where n is the number of trials. The formula shown below was used to further calculate ERD (Makeig, 1993):

$$ERD\ power = \frac{1}{N}\sum_{f\in F}\sum_{t\in T}\left(ERSP(f,t)\right)$$

where F stands for the targeted frequency range. Theta (4–8 Hz) and alpha were the two frequency ranges we chose as our focus areas (8–12 Hz). T refers to the time interval of interest, and a window from 0 to 1,000 ms was selected to represent the maintenance stage. N is the number of rectangular, two-dimensional, time-frequency bins in a specific matrix. Time-Frequency figure visualization was completed by using specialized Matlab programs.

5.3. Statistical Analysis

5.3.1. Behavioural and Neurophysiological Measures

For behavioral results, the mean precision in the wrist and elbow joint angle of control and priority-cue and retro-cue conditions was calculated separately. For objective one, two-way repeated measures ANOVA model was conducted on angle precision with 2 cognitive conditions (control, and priority-cue and retro-cue condition) x 2 joint positions (elbow joint and wrist joint).

The normalized power was used as the dependent variable in independent analyses of variance (ANOVA) for theta-band and alpha-band frequency. For objective two, a three-way repeated measures ANOVA with 2 conditions (control and priority-cue and retro-cue condition) x 3 regions (frontal, central, parietal) x laterality (F5/6, C5/6, P5/6) was used as the within-subject factors during the presentation of retro-cue, the power of theta-band oscillations during maintenance was investigated. For objective three, a three-way repeated measures ANOVA with 2 conditions (control and priority-cue and retro-cue condition) x 3 regions (frontal, central, parietal) x laterality (F5/6, C5/6, P5/6) was used as the within-subject factors, the power of alpha-band oscillations during maintenance was investigated.

If any significant effects were found, contrast tests were carried out for the post hoc comparisons. The significant level of main and interaction effects of conditions and sites was set at 0.05. The Greenhouse-Geisser corrections were applied when the assumption of sphericity is violated. The Bonferroni correction was used in the post-hoc tests, with the p value adjusted to 0.01.

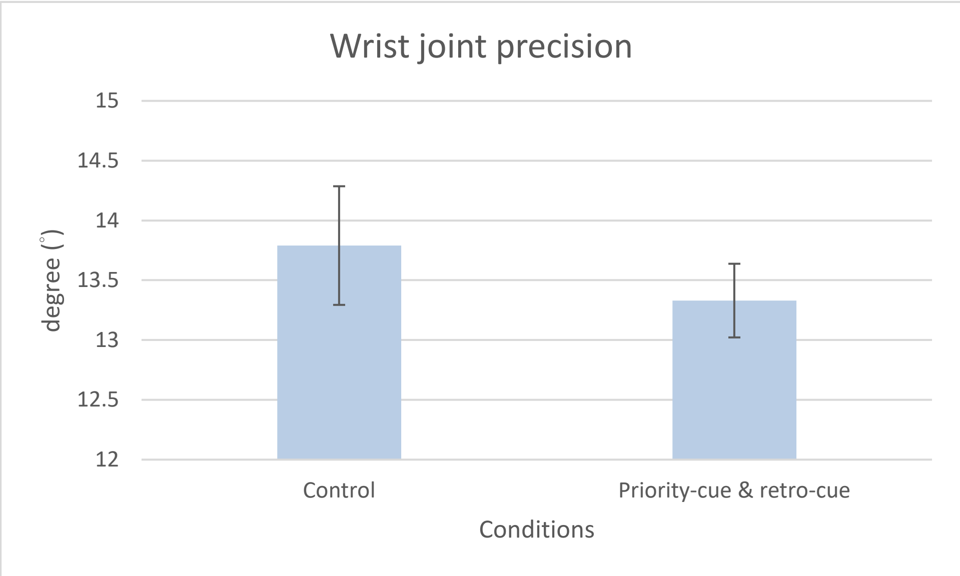
5.3.2. Results

5.3.2.1 Behavioural Measurements

Repeated measures ANOVA showed a significant condition main effect [$F_{1,19} = 47.0$, $p < 0.001$] and a significant joint position main effect [$F_{1,19} = 16.7$, $p = 0.001$]. A post-hoc contrast test revealed a significant improvement in precision [$t_{24} = 3.02$, $p = 0.006$] over the elbow joint between the priority-cue and retro-cue conditions ($M = 8.54$, $SD = 2.61$) and the control condition ($M = 9.47$, $SD = 2.92$). Table 1 displays the behavioral results of the ANOVA examining the experiment's elbow and wrist joint precision. Figures 5.9 and 5.10 show the precision difference in control and priority-cue and retro-cue conditions over the wrist and elbow joint, respectively.

Figure 5.9

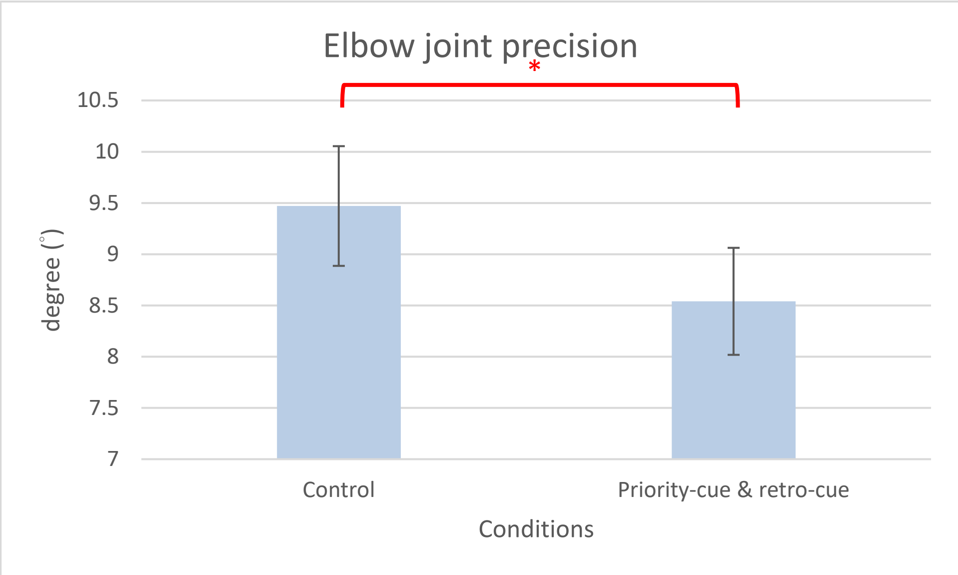
Bar Graph Showing the Mean Wrist Joint Precision Among the 25 Participants



Note. * < 0.01, total number *N* = 25, the error bars represent the standard error of the mean.

Figure 5.10

Bar Graph Showing the Mean Elbow Joint Precision Among the 25 Participants



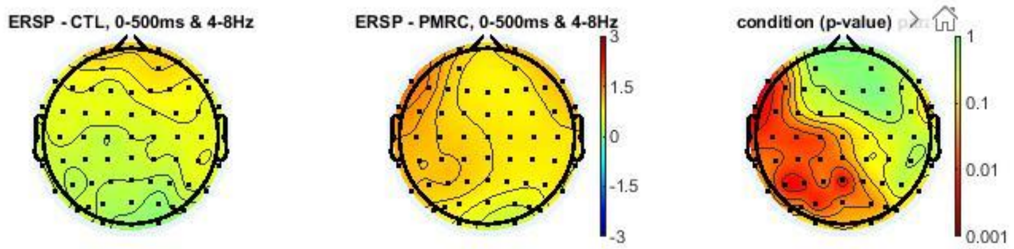
Note. * < 0.01, total number *N* = 25, the error bars represent the standard error of the mean.

5.3.2.2. Neurophysiological Measurement - Theta-band Power

A significant sites main effect was found in the theta-band power analysis during retro-cue [$F_{1,30} = 5.41$, $p = 0.02$, $\varepsilon = 0.638$]. A significant condition x laterality interaction effect [$F_{1,24} = 12.0$, $p = 0.002$] was found in the theta-band power analysis. Figure 5.11 shows the topographical distribution of theta-band power in each condition and the statistical difference between conditions in different electrodes.

Figure 5.11

Topographical Distribution of Theta-band Oscillations Power Across the Two Conditions

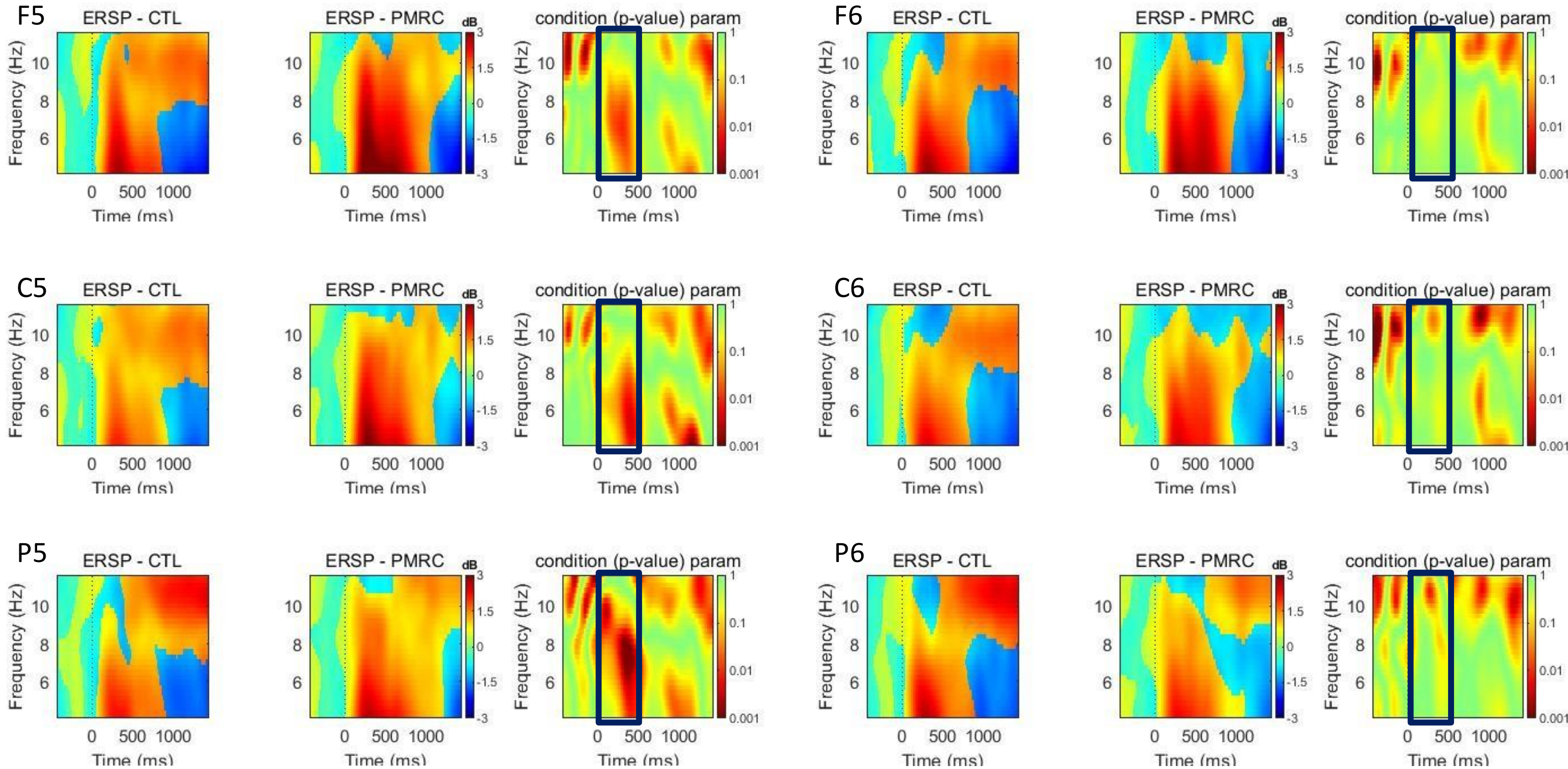


Note. Topographical distribution of theta-band oscillations power across the two conditions; comparisons of each condition with control condition are shown; red colour indicates that the specific electrodes yielded a significant difference between the two conditions. (CTL: control condition; PMRC: priority-cue and retro-cue conditions).

A post-hoc contrast test revealed that theta-band power was higher in the priority-cue and retro-cue condition compared to the control condition at the F5 site [t_{24} = -2.41, p = 0.024; priority-cue and retro-cue task (M = 1.38, SD = 1.23), control task (M = 0.67, SD = 1.16)]. A significant difference was found in contrast test comparing between the control with priority-cue and retro-cue condition at the C5 site [t_{24} = -2.66, p = 0.014; priority-cue and retro-cue task (M = 1.21, SD = 1.00), control task (M = 0.57, SD = 0.77)]. At P5 site, there was a significant difference in contrast test between the control and priority-cue and retro-cue conditions [t_{24} = -3.00, p = 0.006; priority-cue and retro-cue task (M = 1.06, SD = 0.82), control task (M = 0.28, SD = 1.12)]. Theta-band power was higher in the priority-cue and retro-cue condition compared to the control condition at F5, C5, and P5 sites. Figure 5.12 shows the time-frequency analysis across the F5/6, C5/6, and P5/6 sites involving theta-band spectral power.

Figure 5.12

Time-Frequency Analysis of the Two Conditions during Retro-cue



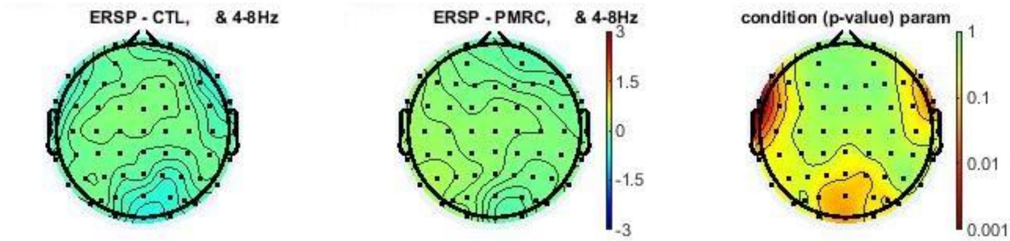
Note. Time-Frequency Analysis of the two conditions (CTL: control; PMRC: priority-cue and retro-cue) from 4Hz to 12Hz (theta: 4-8Hz; alpha: 8-12Hz) at the F5/6, C5/6, P5/6 sites. The dark blue boxes indicate the retro-cue event. Comparisons of control condition with priority-cue and retro-cue conditions are shown on the *p*-value plot, the red colour indicated a significant difference between conditions. (CTL: control condition; PMRC: priority-cue and retro-cue conditions).

5.3.2.3. Neurophysiological Measurement - Theta-band Power

A significant main laterality effect was found in theta-band power analysis during maintenance [$F_{1,24} = 6.73$, $p = 0.016$]. A post-hoc contrast test revealed P6 had lower theta-band power [$t_{24} = 2.53$, $p = 0.018$; P5 ($M = 0.29$, $SD = 0.71$) and P6 ($M = -0.030$, $SD = 0.68$)] than P5. Figure 5.13 shows the topographical distribution of alpha-band power in each condition and the statistical difference between conditions at different electrodes. Figure 5.15 shows the time-frequency analysis across F5/6, C5/6, and P5/6 sites involving the theta-band spectral power during maintenance.

Figure 5.13

Topographical Distribution of Theta-band Power across Two Conditions



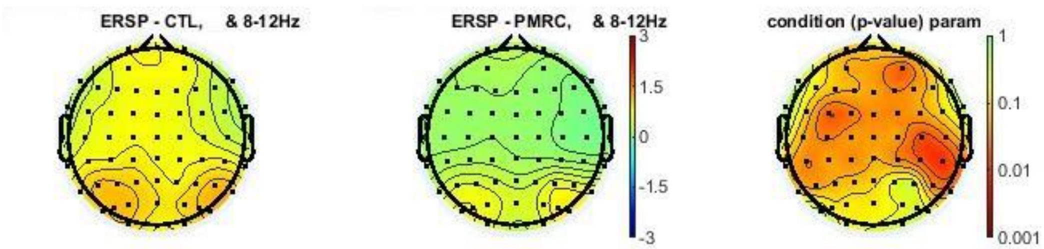
Note. The comparisons of each condition with control condition are shown, red color indicated the specific electrodes yield a significant difference between two conditions. (CTL: control condition; PMRC: priority-cue and retro-cue condition).

5.3.2.4. Neurophysiological Measurement - Alpha-band Power

A significant main condition effect [$F_{1,24} = 5.52$, $p = 0.027$] and a site main effect [$F_{1,29} = 12.7$, $p = 0.001$, $\varepsilon = 0.60$] were found in alpha-band power analysis during maintenance. A post-hoc contrast test revealed a decreased alpha-band power in priority-cue and retro-cue condition compared to the control condition, at P5 site [$t_{24} = 2.19$, $p = 0.038$; priority-cue and retro-cue tasks ($M = 0.41$, $SD = 0.67$), control task ($M = 0.97$, SD=1.25)] and at P6 site [$t_{24} = 2.40$, $p = 0.025$; priority-cue and retro-cue tasks (*M* = 0.45, *SD* = 0.67), control task (*M* = 0.97, *SD* = 1.31)]. A marginally significant difference was also found in comparisons of priority-cue & retro-cue with control condition at C5 site [t_{24} = 2.05, *p* = 0.05; priority-cue and retro-cue tasks (*M* = 0.10, *SD* = 0.70), control task (*M* = 0.56, *SD* = 0.98)] and at C6 site [t_{24} = 2.00, *p* = 0.058; priority-cue and retro-cue tasks (*M* = -0.08, *SD* = 0.61), control task (*M* = 0.36, *SD* = 1.10)]. Figure 5.14 shows the topographical distribution of alpha-band oscillations in each condition and the statistical difference between conditions in different electrodes. Figure 5.15 shows the time-frequency analysis across the F5/6, C5/6, and P5/6 sites involving alpha-band spectral power.

Figure 5.14

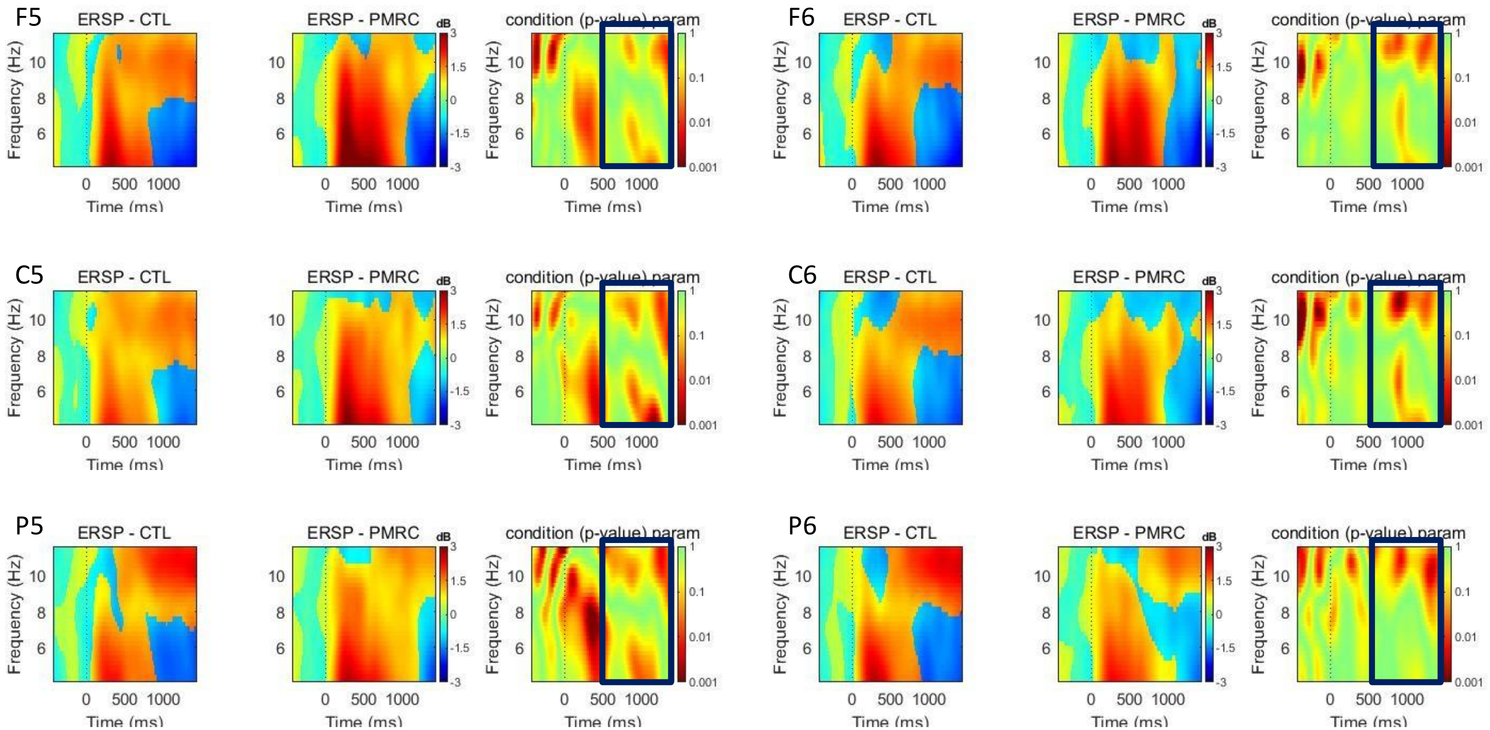
Topographical Distribution of Alpha-band Power across Two Conditions during Maintenance



Note. The comparisons of each condition with control condition are shown, red color indicated the specific electrodes yield a significant difference between two conditions. (CTL: control condition; PMRC: priority-cue and retro-cue condition).

Figure 5.15

Time-Frequency Analysis of Two Conditions during Maintenance



Note. Time-Frequency Analysis of two conditions (CTL: control; PMRC: priority-cue & retro-cue) from 4 Hz to 12 Hz (theta: 4-8Hz; alpha: 8-12Hz) at F5/6, C5/6, P5/6 sites. The dark blue boxes indicate the maintenance event. Comparisons of control condition with priority-cue and retro-cue condition was shown on the p-value plot, red color indicated a significant difference between two conditions. (CTL: control condition; PMRC: priority-cue and retro-cue condition

5.3.2.4. Summary of the Key Findings in Study Two

To summarize, the priority-cue and retro-cue condition had a significant enhancement in elbow joint precision compared with the control condition. The results were consistent with objective 1, which predicts the priority-cue and retro-cue facilitates the joint angle precision.

There was a significant difference found in frontal theta-band power across the two conditions during retro-cue. A laterality main effect was found in frontal theta-band power analysis. A contrast test has shown the theta-band power was lower in the control condition compared to the priority-cue and retro-cue condition at F5, C5, and P5 sites. Objective two was to examine the effect of priority-cue or retro-cue on attention orientation, which was measured in frontal theta-band power.

There was no significant difference found in frontal theta-band power during maintenance. There was a significant reduction of parietal alpha-band power found when comparing the priority-cue and retro-cue condition with the control condition during maintenance. Objective three was to examine the effect of priority-cue and retro-cue on maintenance, which was measured in parietal alpha-band power. From the topographical distribution of alpha-band power, the right parietal area has a significant reduction in power.

5.4. Discussion

In this study, the automatic imitation task required the participant to perceive a movie externally and then generate and maintain the kinesthetic representation before the recall probe appeared. Before generating the internal kinesthetic representation, it requires the retrieval of schema and the selection of the most related action schema. Priority-cue and retro-cue were used to see if executive control modulated the external-to-internal attention orientation to select relevant representation and facilitate subsequent maintenance. The finding would provide insights on how the higher executive center cooperate with the lower attention and imagery networks and the role of the visual cues on attention orientation.

5.4.1. The Effect of Top-down Priority-cue and Retro-cue on External-to-internal Attention, Maintenance, and Inspection of Kinesthetic Representation

The presence of priority-cue and retro-cue was able to facilitate greater precision in the elbow joint angle in the priority-cue and retro-cue conditions, compared to the control task. In this study, an enhanced frontal theta-band power was observed in the priority-cue and retro-cue task compared with the control task during retro-cue, but a lower parietal alpha-band power during maintenance and better behavioral performance were observed. The difference in theta-band power between the control task and the priority- and retro-cue task was significant at the frontal sites, with higher theta-band power in the priority- and retro-cue task, indicating higher executive control induced by the presence of priority- and retro-cue. The coming paragraphs would explain the neural processes underlying AOMI.

During AOMI, the executive control not only requires modulating attention orientation between external information and internal representation but also includes the generation and maintenance of internal representation. According to Kilner (2013), a ventral pathway linking the inferior frontal gyrus and middle temporal gyrus is responsible for the encoding of abstract representation. This ventral pathway retrieves and the select the most probable action schema to achieve the goal. The priority-cue is suggested to modulate the external-to-internal attention orientation on external sensory information in a way that facilitates the process of retrieval and selection of action schema. The frontal theta-band enhancement in the priority-cue and retro-cue condition may be induced by the facilitation of the retrieval and selection of the most probable action representation. Our initial hypothesis was that the presence of visual cues might reduce the demand for executive control and result in a reduction of frontal theta-band power. However, the frontal theta-band power increased with visual cues. The frontal theta-band power enhancement during retro-cue might represent the onset of visual cues and the enhanced involvement of the prefrontal cortex to control the selection of relevant schema. Taken together, the presence of priority-cue facilitated the prioritization of relevant information from the external visual stimuli and the retrieval and selection of relevant representation. The demand on executive control to manipulate the external-to-internal attention orientation became lower. Therefore, executive control could allocate more attentional resources to generate the kinesthetic senses. AO not only required the visual processing of the movies, but also triggered the activation of relevant representations (Kilner, 2013). The priority-cue was proposed to prioritize relevant action schema from the repertoire and facilitate the selection of specific schema.

On the other hand, the dorsal pathway AON was proposed to be responsible for the maintenance and inspection of internal representation (Kilner 2013). Encoding a concrete representation of the selected action schema and predicting the kinematics of the selected actions were required for efficient internal representation maintenance. The presence of retro-cue modulated our internal inspection, which prioritized relevant internal representations while suppressed irrelevant representations. The retro-cue further suppressed the associated action representation and direct the attention on the internal inspection of selected actions. Therefore, the alpha-band reduction in the right parietal might indicate the enhancement of the maintenance of kinesthetic representation. In addition, the external prioritization of orientation or angle features integrated with the internal prioritization of directing attention to specific joint locations resulted in a summation of improvements in joint precision.

5.4.2. Difference in Theta-band Power during Retro-cue and Maintenance

In this study, an enhanced frontal theta-band power was observed in the priority-cue and retro-cue task compared with the control task during retro-cue Enhanced theta-band power was hypothesized to relate with the higher demand on executive control. Magosso and Ricci (2021) investigated the internal-external attention competition and found that frontal theta-band power was distinctive of mental task execution and more prominent during competition compared to internal attention alone. Therefore, the enhanced theta-band power indicated the executive control was modulating several tasks, such as external-to-internal attention orientation and the internal inspection on kinesthetic representation, and also the presence of visual cues.

During the maintenance period, the frontal theta-band power difference between the two tasks was absent. The participant was required to maintain the kinesthetic representation before they execute the movements. Higher center executive control cooperated with lower imagery network to generate the kinesethetic senses. During the maintenance period, the kinesthetic senses were generated and maintained in the working memory buffer which need not the control from the higher executive. Therefore, it reflected maintenance of kinesthetic senses at the lower level, which appeared to be similar between two conditions. There was an absence of difference in theta-band power across two conditions. According to Norman and Shallice (1986), the coordination of schema with higher-level goals requires the additional employment of a supervisory attentional system to exert top-down control by deactivating certain schema and activating relevant schema for higher-level goals (Alexander & Brown, 2010). The executive control acts as a supervisor to exert top-down control over attention according to the behavioral goals. Attention performs selection on the corresponding task and sensory information (Kouider & Gardelle, 2009). During the maintenance period, executive control no longer required to exert top-down control over attention as the participant was already focusing on maintaining the internal representation.

CHAPTER SIX

GENERAL DISCUSSION

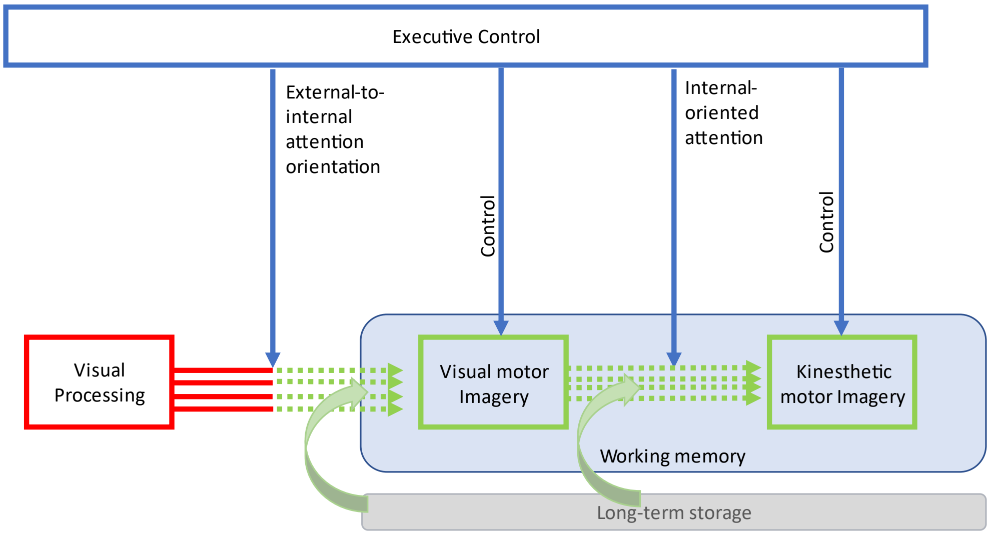
This study aimed to examine how executive control with the use of priority-cue and retro-cue facilitates the external-to-internal attention orientation and the generation and maintenance of the visuomotor and kinesthetic representations in the working memory. This chapter will discuss possible neural mechanisms behind executive control over the generation of visuomotor and kinesthetic images in the working memory buffer through the cognitive strategies of priority-cue and retro-cue. The chapter will conclude by discussing the limitations of the study and future directions of investigation.

6.1 Executive Control on External-to-Internal Attention Orientation and Internal-Oriented Attention

One of the main objectives was to examine how to optimize the efficiency of executive control to modulate attention orientation to focus on external or internal information to achieve certain behavioral goals. Concurrent action observation and motor imagery were selected as the context for studying such a cognitive phenomenon. In this study, the executive control was required to modulate the shifting of attention between two sources of information, i.e., perceptual information of action-related images and internal representations of visuomotor and kinesthetic images. Furthermore, the neural processes underlying concurrent action observation and motor imagery included not only the modulation of attention orientation between external information and internal representation but also the generation and maintenance of representation. Attention needed to be directed internally when the visual representation of an action was generated and maintained. The relatively large amount of external sensory stimuli required external attention to select the most relevant information for the current goal, and the generation of the internal representation requires internal-oriented attention to select relevant schema from long-term storage. Internalizing visual information into internal motor format required the activation of action representations stored in the motor repertoire. Figure 6.1 shows the conceptual schema about the flow of information during visuomotor and kinesthetic motor imagery. A working memory study investigating the negative impact of external interference on working memory performance has shown that external irrelevant stimuli such as distraction and interruption showed lower accuracy compared to the no interference condition (Clapp et al., 2010). The study asked the participants to remember a landscape or a face and recall it after a period of time; an interference picture was presented in some of the trials before the recall. Lower accuracy was found in trials with distracting irrelevant stimuli. The internal-oriented attention was responsible for maintaining the relevant information until the recall probe, while the external stimuli interfered with the suppression of irrelevant representation, which resulted in lower accuracy. The selection of relevant information from external and internal-oriented attention might interfere with each other, resulting in inefficiency in filtering out irrelevant information. Altogether, the demand on executive control may be overwhelming, as it requires control over external-to-internal attention, internal inspection, and the generation of kinesthetic senses. Clapp (2010) has demonstrated that an external distraction would influence the internal processing on the maintenance of relevant representation, as signified by lower accuracy. Executive control was required to handle not only the attentional orientation from external to internal and internal inspection, but also the control on generating the kinesthetic representation in this study. Therefore, it was suggested that the efficiency of suppressing irrelevant information would decrease.

Figure 6.1

Schematic Representation of Executive Control monitoring the attention orientation and the control of generation of motor imagery



Note. Executive control was required to modulate the shifting of attention between two sources of information, i.e., perceptual information of action-related images and internal representations of visuomotor and kinesthetic images. Concurrent action observation and motor imagery included the modulation of attention orientation between external information and internal representation and the generation and maintenance of representation.

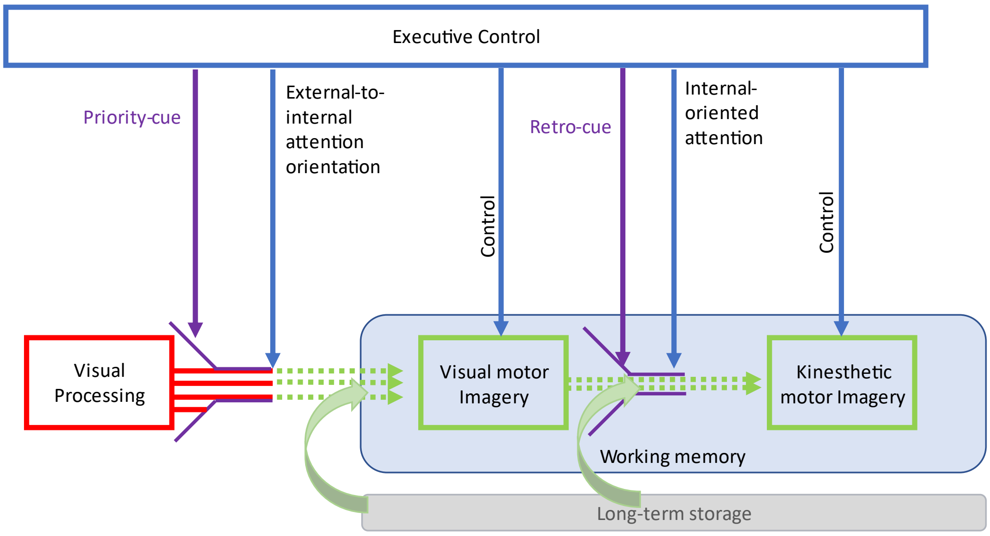
6.2 Facilitating Effect of Visual Cues on Executive Control

Thus, the motivation of this study was to suggest using two types of visual cues, i.e., priority cue and retro-cue, to facilitate the attention processing of the incoming motor-related information from the external context and the generation and maintenance of the visuomotor and kinesthetic images in the working memory buffer. Visual cues have been suggested to be an effective cognitive strategy for facilitating the selection of relevant information from both external and internal sources (Zerr et al., 2021). Utilizing visual cues is one method that may be used to regulate the top-down executive control that is present in AOMI. Externally oriented attention can be manipulated by using priority-cue and internally oriented attention can be manipulated by using retro-cue and doing so results in greater accuracy and a shorter response time (Griffin & Nobre, 2003; Nobre et al., 2004; Li & Saiki, 2015). Indeed, priority-cue manipulated the selection of external information into an internal representation, whereas retro-cue helped to select the relevant information within an internal representation that had been generated and maintained in the working memory buffer under executive control. As the visual cues facilitated the selection processes externally and internally, the demand on executive control to modulate attention on internalizing visual external information to internal visual representation and internal oriented attention on internally generated representation might become lower. Executive control could allocate more resources to generating and inspecting the action representation, in which the maintenance of the representation was facilitated in this study, signified by lower alpha-band power in parietal areas. Together with improvements in joint precision, it was speculated that executive control could allocate resources reserved from modulating attention orientation to generate and inspect the action representation. However, executive control might be interfered with by the presence of visual cues. Although there was a facilitation in joint precision, there was an additional recruitment of prefrontal regions during the presence of retro-cue. Therefore, an evaluation of the desirability of the cognitive strategies for facilitating the efficiency of executive control is required. Figure 6.2 shows the conceptual schema that summarize the main findings about executive control modulate attention orientation using priority-cue and retro-cue and the most relevant representation could enter the working memory buffer. Higher accuracy rate and faster reaction time were found in Study One could demonstrate the facilitating effect of visual cues compared with the no cue conditions in which the participants were asked to imagine the visual representation and recall during the recall probe.

On the other hand, enhanced precision in Study Two could demonstrate the facilitating effect of visual cues with the no cue condition in which the participants were required to orient attention from external-to-internal representation and generate the kinesthetic senses. It is suggested that the presence of priority-cue in this study could facilitate the filtering of the relevant information from external information, and the presence of retro-cue in this finding could facilitate the filtering of the relevant representation internally. Priority-cue was suggested to draw attention to a specific feature and generate the specific representation internally through mental imagery (Fazekas & Nanay, 2017). On the other hand, the presence of retro-cue in a working memory study showed a facilitation of suppressing the irrelevant internal representation (Rerko et al., 2014). The participants in Rerko's study were required to remember six color dots in different locations. A higher accuracy and faster reaction time were observed in the retro-cue condition of Rerko's (2014) study. Therefore, the retro-cue could facilitate the filtering of relevant representation in the working memory buffer. Therefore, the demand on executive control to modulate external-to-internal attention and internal-oriented attention became lower. This is supported by the reduction of alpha-band power over the parietal cortex in conditions with visual cues of this study, which indicated that executive control can allocate more resources to maintaining and inspecting action representation in visual and kinesthetic form. Klimesch (2012) has suggested that alpha-band power reduction can be interpreted as a release from inhibition. The finding indicated that retrieval of well-integrated information elicits more cortical excitation. A working memory study also found a reduction in alpha-band power and a lower error rate with the presence of retro-cue (Günseli et al., 2019).

Figure 6.2

Schematic Representation of the Modulatory effect of Executive Control on Attention Orientation



Note. The priority-cue and retro-cue are supposed to select the most relevant information from external and internal to reduce the demand on attention orientation. Executive control could allocate resources to generate the kinesthetic senses.

6.3 Additional Facilitation with Priority-cue and Retro-cue

The cognitive strategies using priority-cue and retro-cue were proposed to facilitate the external selection of relevant external information and the internal selection of relevant schema. However, there was a lack of a priority-cue effect in accuracy and reaction time. The priority-cue was shown to filter the external action information through external-oriented attention, but it might not be able to suppress the action schema triggered by the external action movement. Internalizing visual information into internal motor format required the activation of comparable action representations stored in the motor repertoire. Imagery would still generate a relatively large amount of possible action associations from the long-term storage. There was a high demand on executive control to modulate attention internally to select relevant representation. The external visual stimuli triggered comparable schemas internally, which still posited a high demand on executive control to direct attention toward maintaining and inspecting the kinesthetic representation internally. Theta-band power enhancement was revealed in the control condition during the presence of retro-cue in this study, which might indicate a higher demand on executive control to modulate attention internally.

The combined usage of priority-cue and retro-cue showed an additive benefit in terms of higher accuracy and faster reaction time in Study One. Retro-cue facilitated the selection of relevant schema internally and suppressed the activation of irrelevant schema from long-term storage. The demand on executive control to modulate external-to-internal attention and internal-oriented attention became lower as the information was filtered and the most relevant representation was maintained. The significant increase in accuracy during the priority-cue and retro-cue condition in this study indicated that attention modulation may facilitate the generation of internal representations. Although there was an additive facilitating effect on the generation and inspection of internal representation, there was a lack of a priority-cue effect in accuracy and reaction time. The absence of a priority cue effect on accuracy and reaction time in the experiment might be due to the feature relationship between orientation and angle. The feature relationship between orientation and angle features is unlike the discrete relationship between color and orientation in Ye's study (2016). Because the angle feature is part of the orientation feature, the two features are closely related in terms of schema. The participants might have encoded the entire image due to their close relationship in features, no matter what orientation or angle feature was cued in the priority-cue phase.

6.4 Executive Control Alternative Recruitment

In this study, executive control was required to modulate the attention orientation between external information and internal representation, which also included the generation and maintenance of representation through internal-oriented attention. It was found that the demand on executive control was higher with priority-cue and retro-cue, as reflected by enhanced frontal theta-band power. Visual cues were shown to facilitate the filtering of relevant information from external sources and the filtering of relevant schema from long-term storage in this study, indicated by improved joint precision. Although both conditions showed a frontal theta-band power enhancement, there was an additional theta-band enhancement in the condition with priority-cue and retro-cue compared with the control condition over the left lateral prefrontal region. Specifically, the topographical distribution of frontal theta-band power appeared to be lateralized to the left prefrontal region. Therefore, an additional recruitment in the prefrontal region is needed to control the burden brought by the presence of both visual cues. A study involving external and internal processing also found a unique pattern of activation over the left prefrontal region, which suggested that the left prefrontal region was responsible for shifting the attentional focus frequently between external and internal sources of information (Emerson et al., 2021).

6.5 Limitations

There are a number of limitations in the study. In Study Two, the comparison of the AOMI condition with the AOMI condition with visual cues only provided the integrated effect of priority-cue and retro-cue on generating kinesthetic representation. However, the priority-cue only or retro-cue only effects cannot be examined separately. Instead, the experimental design in Study One including the control, priority-cue only, retro-cue only, and priority-cue and retro-cue condition may be able to manifest the integrative function of two cues or dissociate the effectiveness of priority-cue and retro-cue. Although the involvement of four conditions in Study Two might provide a more in-depth investigation on the utility of two visual cues, this might bring forth another issue. In this study, the automatic imitation task was used to test participants' precision on joint regeneration. If there were four conditions implemented in Study Two, the participants would have needed to practice the relatively simple task repeatedly. This might have created a learning effect, especially in relatively simple tasks involving the elbow and wrist joints only. Indeed, there was a transition from more simple single joint movement measurement in the pilot study to involving two joint angles in Study One and Study Two. Training on AOMI and the repetition might influence the facilitating effect or reach a plateau with a simple task. It is therefore suggested that future studies might use more complex movements to examine the facilitation of motor learning.

6.6 Implications and Future Studies

This study contributed to a new perspective investigating the optimal point of higher center executive control on cooperating with lower attention and imagery networks using priority-cue and retro-cue. In Study One, it was discovered that the combined use of priority-cue and retro-cue could facilitate attention orientation and enhance the efficiency of executive control. In Study Two, the combined use of cues showed a facilitation in motor precision. The external and internal selection of relevant information could facilitate executive control, executive control could allocate less resources on attention orientation and enhance the resources in working memory to generate internal representation. This study sheds light on the collaboration between the higher center and the lower sensory network. Studies in AOMI or related motor learning studies often focus on the neural mechanisms involved in motor learning and motor output (Emerson et al., 2018). The involvement of visual cues to modulate attention in motor contexts was rarely seen. This study showed that the facilitation of motor precision can shed light on ways to design efficient training programs to learn or relearn motor movement. A future study could use visual cues to indicate the core of more complex exercise during AOMI, for example, by focusing attention on the elbow joint angle when viewing an archery demonstration.

Moreover, the mechanism to optimize efficiency in executive control could be investigated in individuals with attentional control deficits. For example, elderly people with mild cognitive impairments often have deficits in stimulus-driven, bottom-up attentional control (He et al., 2021). The involvement of priority-cue and retro- cue, which are supposed to facilitate the selection of external information and internal representation, should have a beneficial effect on the elderly with attentional control deficits. These cuing techniques can enhance the prioritization process both externally and internally, helping older adults with MCI better allocate their limited attentional resources towards the most relevant information.

By using these cuing mechanisms, future research could explore how older individuals with MCI compensate for their deficits in suppressing irrelevant external visual stimuli. The visual cues may help redirect their attention and internal representations, shielding them from the flow of distracting external information.

Additionally, examining the executive control efficiency of individuals with ADHD could provide a comparison to the MCI group. ADHD is characterized by core deficits in attentional control, which could manifest different behavioral and EEG results compared to the age-related changes observed in MCI. Investigating the unique attentional profiles of these two groups could explore the interplay between developmental, age-related, and clinical factors impacting executive control. This approach could pave the way for more tailored interventions and support strategies for these vulnerable populations.

CHAPTER SEVEN

CONCLUSION

Concurrent motor imagery and action observation (AOMI) has been shown to heighten the cortical activations in the Action Observation Network (AON) and imagery network. AOMI involves attentional orientation from external images of action to internally generated kinesthetic images. Research that has investigated the neurophysiological effects of AOMI instructions has previously focused on the neural mechanisms involved in motor planning and motor output (Eaves et al., 2016; Emerson et al., 2018). The combined AOMI instruction requires participants to synchronise the internally generated kinesthetic representation of their imagined action with an externally presented movement in real time (Emerson et al., 2018). The AOMI study suggested that some form of higher order cognitive control would be needed to maintain the alignment between these two parallel and dynamic representations (Eaves et al., 2016). The presence of visual cues may then facilitate executive control in aligning the two parallel tasks, resulting in an increase in theta-band power over the lateral prefrontal cortex and a decrease in alpha-band power over the parietal cortex. This study provides further evidence for the role of the prefrontal cortex in aligning external visual information with internal kinesthetic representation. The findings of this study will shed light on the influence of executive control through priority-cue and retro-cue on attention orientation and the maintenance of internal representation. Furthermore, this study' results provide insights on how the higher executive center cooperates with the lower attention and imagery networks and the role of visual cues on attention orientation. This study provides a better understanding of executive control and attention orientation for motor improvement. This study may also give insights on the training approaches used to enhance the executive control of individuals who requires to process a continual flow of external and internal information.

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APPENDICES

Appendix I Informed Consent (Chinese Version)

香港理工大學康復治療科學系科研同意書

科研題目：
視覺提示對同步動作觀察及意象的影響:電生理指標研究

科研人員：
蔡駿威先生、陳子頌博士

科研內容：

研究目的：探討視覺提示對同步動作觀察及意象的腦部活動的影響

研究程序：你需要填寫個人資料問卷及接受認知功能的甄別試。然後你將會參與一項有關視覺認知的實驗。整個實驗約三小時完成。研究員會帶領你進行實驗程序的每個部份。若在過程中感到覺疲倦或不適時，你可稍作休息

潛在危險性：在實驗的過程中不會令你帶來不適。所有收集的數據將絕對保密。你亦有權在任何時間及任何理由下終止問卷調查而不會受到任何懲處

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 4310 來聯繫此次研究課題負責人，陳子頌博士。若本人對此研究人員有任何投訴，可以聯繫鍾小姐（部門科研委員會秘書），電話：2766 4329。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 II Informed Consent (English Version)

The Hong Kong Polytechnic University
Department of Rehabilitation Sciences

Research Project Informed Consent Form

Project title:
Modulatory effect of visual cue on Concurrent Action Observation and Motor Imagery enhancing Motor Precision: An Electrophysiological Study

Investigators:
Mr. Tom C. W. Tsoi, Dr. Sam C. C. Chan

Project information:
Study Aim: To investigate the modulatory effect of visual cue on action observation and motor imagery in cognitive recognition task

Study Procedure: You will first complete a demographic questionnaire and cognitive function screening tests. You will then be asked to participate in an experiment involved visual recognition task. It will take approximately 3 hours. You will be given breaks whenever needed.

Potential Risks and Rights:

The experimental procedure should not result in any undue discomfort. All information related to you will remain confidential. You have every right to withdrawn from the study before or during the measurement without penalty of any kind.

You have every right to withdrawn from the study before or during the measurement without penalty of any kind. All information related to you will remain confidential.

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, Dr Sam Chan at telephone 2766 4310 for any questions about this study. If I have complaints related to the investigator(s), I can contact Ms Vangie Chung, Secretary of the Departmental Research Committee, at 2766 4329. I know I will be given a signed copy of this consent form.

Signature (subject):
Date: ______________________

Signature (witness): ______________________ Date: ______________________

Appendix III Edinburgh Handedness Inventory

EDINBURGH HANDEDNESS INVENTORY

Surname.................................... Given Names....................................

Date of Birth.................... Sex....................

Please indicate your preferences in the use of hands in the following activities *by putting + in the appropriate column.* Where the preference is so strong that you would never try to use the other hand unless absolutely forced to, *put ++*. If in any case you are really indifferent *put + in both columns.*

Some of the activities require both hands. In these cases the part of the task, or object, for which hand preference is wanted is indicated in brackets.

Please try to answer all the questions, and only leave a blank if you have no experience at all of the object or task.

		LEFT	RIGHT
1	Writing		
2	Drawing		
3	Throwing		
4	Scissors		
5	Toothbrush		
6	Knife (without fork)		
7	Spoon		
8	Broom (upper hand)		
9	Striking Match (match)		
10	Opening box (lid)		
i	Which foot do you prefer to kick with?		
ii	Which eye do you use when using only one?		

L.Q.		Leave these spaces blank	DECILE	

Appendix IV Vividness of Movement Imagery Questionnaire-2 Part A

Vividness of Movement Imagery Questionnaire-2

Name: **Age:**

Gender: **Sport:**

Level at which sport is played at (e.g., Recreational, Club, University, National, International, Professional)

Years spent participating in this sport competitively:

Movement imagery refers to the ability to imagine a movement. The aim of this questionnaire is to determine the vividness of your movement imagery. The items of the questionnaire are designed to bring certain images to your mind. You are asked to rate the vividness of each item by reference to the 5-point scale. After each item, circle the appropriate number in the boxes provided. The first column is for an image obtained watching yourself performing the movement from an external point of view (External Visual Imagery), and the second column is for an image obtained from an internal point of view, as if you were looking out through your own eyes whilst performing the movement (Internal Visual Imagery). The third column is for an image obtained by feeling yourself do the movement (Kinaesthetic imagery). Try to do each item separately, independently of how you may have done other items. Complete all items from an external visual perspective and then return to the beginning of the questionnaire and complete all of the items from an internal visual perspective, and finally return to the beginning of the questionnaire and complete the items while feeling the movement. The three ratings for a given item may not in all cases be the same. For all items please have your eyes CLOSED.

Think of each of the following acts that appear on the next page, and classify the images according to the degree of clearness and vividness as shown on the RATING SCALE.

RATING SCALE. The image aroused by each item might be:

Perfectly clear and as vivid (as normal vision or feel of movement)	....	RATING 1
Clear and reasonably vivid	....	RATING 2
Moderately clear and vivid	....	RATING 3
Vague and dim	....	RATING 4
No image at all, you only "know" that you are thinking of the skill.	....	RATING 5

Item	Watching yourself performing the movement (External Visual Imagery)					Looking through your own eyes whilst performing the movement (Internal Visual Imagery)					Feeling yourself do the movement (Kinaesthetic Imagery)				
	Perfectly clear and vivid as normal vision	Clear and reasonably vivid	Moderately clear and vivid	Vague and dim	No image at all, you only know that you are thinking of the skill	Perfectly clear and vivid as normal vision	Clear and reasonably vivid	Moderately clear and vivid	Vague and dim	No image at all, you only know that you are thinking of the skill	Perfectly clear and vivid as normal feel of movement	Clear and reasonably vivid	Moderately clear and vivid	Vague and dim	No image at all, you only know that you are thinking of the skill
1.Walking	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
2.Running	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
3.Kicking a stone	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
4.Bending to pick up a coin	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
5.Running up stairs	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
6.Jumping sideways	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
7.Throwing a stone into water	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
8.Kicking a ball in the air	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
9.Running downhill	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
10.Riding a bike	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
11.Swinging on a rope	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
12.Jumping off a high wall	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5

Appendix V Vividness of Movement Imagery Questionnaire-2 Part B

1. Please indicate if you have a preference for using a particular visual imagery perspective on this scale (if you have no preference then circle 5):

0	1	2	3	4	5	6	7	8	9	10
Strong preference internal			Moderate preference internal		No preference		Moderate preference external			Strong preference external

2. Please indicate on the following questions the extent to which you "switched" between imagery perspectives, when completing the two visual columns of the adapted VMIQ:

a) When completing the *watching yourself do it* (External Visual Imagery) column, what perspective did you use?

0	1	2	3	4	5	6	7	8	9	10
Completely internal perspective		minimal switching to an external perspective			switched regularly			minimal switching to an internal perspective		completely external perspective

b) When completing the *looking through your own eyes* (Internal Visual Imagery) column, what perspective did you use?

0	1	2	3	4	5	6	7	8	9	10
Completely internal perspective		minimal switching to an external perspective			switched regularly			minimal switching to an internal perspective		completely external perspective

3. When completing the two visual imagery columns please specify if you used kinaesthetic imagery at the same time as the designated visual imagery perspective:

EVI

0	1	2	3	4	5	6	7	8	9	10
No kinaesthetic imagery use										high kinaesthetic imagery use

IVI

0	1	2	3	4	5	6	7	8	9	10
No kinaesthetic imagery use										high kinaesthetic imagery use

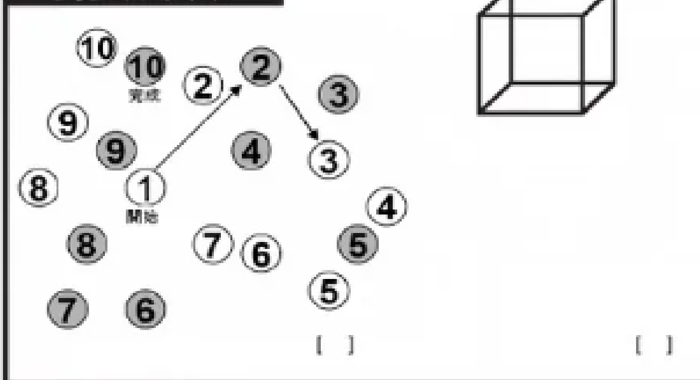
4. If you used kinaesthetic imagery at the same time as the designated visual perspective please denote (Using the numbers 3 = most often, 1 = least often) the order in which visual and kinaesthetic imagery were used

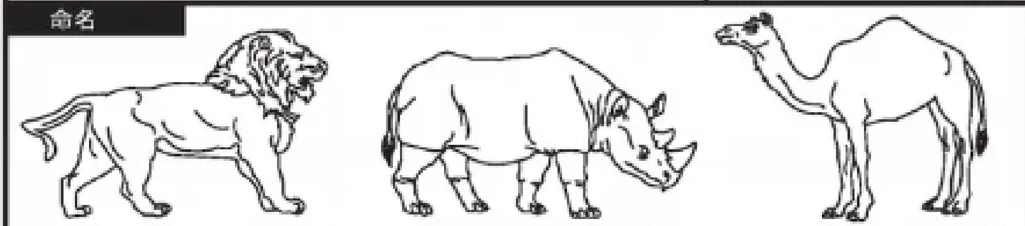
EVI		IVI	
Visual and Kinaesthetic imagery at the same time	______	Visual and Kinaesthetic imagery at the same time	______
Visual then kinaesthetic imagery	______	Visual then kinaesthetic imagery	______
Kinaesthetic then visual imagery	______	Kinaesthetic then visual imagery	______

Appendix VI Montreal Cognitive Assessment Hong Kong version (HK-MoCA)

Montreal Cognitive Assessment Hong Kong version (HK-MoCA)
蒙特利爾認知評估香港版

姓名:
教育程度:
姓別/年齡: 日期:

視覺空間/執行性	複製圖形	畫時鐘 (十一點十分) (3 分)	分數
 [ ]	[ ]	[ ] 輪廓 [ ] 數字 [ ] 時分針	___/5

命名		
 [ ] [ ] [ ]	___/3

記憶		面孔	絲絨	教堂	雛菊	紅色	不用計分
讀出詞語再由病者重複 以上步驟做兩次 5分鐘後回憶	第一次嘗試						
	第二次嘗試						

專注	讀出數字 (每秒一個) 病者須把數字向前重複 [ ] 2 1 8 5 4 病者須把數字向後重複 [ ] 7 4 2	___/2
	讀出數字: 當數字 '1' 出現時病者必須用手敲打桌面 (如≥2錯誤便不給予分數) [ ] 5 2 1 3 7 4 1 1 8 0 6 2 1 5 1 7 4 5 1 1 1 4 1 7 0 5 1 1 2	___/1
	由100開始連續 7減算 [ ] 93 [ ] 86 [ ] 79 [ ] 72 [ ] 65 4 或 5 個正確減算得 3 分, 2 或 3 個正確得 2 分, 1個正確得 1 分, 沒有正確得 0 分	___/3
語言	重複: 姨丈買魚腸 [ ] 西施四十四歲 [ ]	___/2
	流暢: 一分鐘內能說出的動物名稱的數目 [ ] (N ≥ 11 個名稱)	___/1
抽象	相似點, 例如: 香蕉 – 橙 =生果 [ ] 火車 – 單車 [ ] 手錶 – 間尺	___/2

延遲記憶	須回憶詞語 不可給提示	面孔 [ ]	絲絨 [ ]	教堂 [ ]	雛菊 [ ]	紅色 [ ]	分數只給予沒有提示的正確回憶	___/5
	類目提示 (見下表)							
	多項選擇 (見下表)							

定向	[ ] 日	[ ] 月	[ ] 年	[ ] 星期	[ ] 地點	[ ] 地區	___/6

延遲記憶備註表

	類目提示	多項選擇
面孔	身體的一部分	鼻子、面孔、手
絲絨	紡織品的一種	牛仔布、棉花、絲絨
教堂	建築物的一種	教堂、學校、醫院
雛菊	花的一種	玫瑰、雛菊、鬱金香
紅色	一種顏色	紅色、藍色、綠色

總分 如≤6年教育加1分 22分或以上為正常 ___/30

Appendix VII Stroop Test – Chinese version