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HOW MOTOR-SKILL EXPERIENCES MODULATE

EXECUTIVE CONTROL:

DIFFERENTIATION OF PROACTIVE AND REACTIVE CONTROLS

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How Motor-Skill Experiences Modulate Executive Control: Differentiation of Proactive and Reactive Controls

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A thesis submitted in partial fulfilment of the requirements

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ABSTRACT

People with motor-skill expertise have higher level of executive control than the novices. There are two types of motor skills: open skills mostly require players to react in changeable and externally-paced environments (e.g., badminton) and closed skills mostly require players to perform in stable and self-paced environments (e.g., track and field). Proactive and reactive controls of executive function are dissociated in the practices between open with closed skills. This study was aimed to: 1) examine the differences in the behavioral performance of proactive and reactive controls for task switching between open and closed-skilled participants; 2) investigate the effects of open and closed-skilled experiences on modulating the neural processes associated with proactive and reactive controls for task switching; and 3) examine the correlations between proactive and reactive control processes and the performance on task switching between the open- and closed-skilled participants, and their control counterparts.

Fifty-four participants who were open-skilled (n = 18) and closed-skilled sport athletes (n = 18), and university students (n = 18) completed the cued task-switching paradigm and the simple reaction task. The cued task-switching paradigm drew on proactive and reactive controls of executive function, whereas the simple reaction task tapped on processing speed. The electrical activities associated with the task performance were captured with a 64-channel electroencephalogram (EEG) machine.

Behavioral results showed marginally significant validity × group effects (P = 0.053) on the switch cost of response time when the cue was 100% valid. When the cue was 100% valid, the open-skilled participants showed significantly lower switch cost of response time than the closed-skilled participants (P = 0.023) and the

control participants (P < 0.001). When the cue was 50% valid, the open and closed-skilled participants had comparable switch cost of response time (P = 0.473), of whom the switch costs of response times (open-skilled: P < 0.001; closed-skilled: P = 0.033) were significantly less than the control participants. These behavioral findings suggested that the open-skilled participants had better performance on the proactive control for task switching than the closed-skilled participants, while both the open- and closed-skilled participants had better performance on the reactive control for task switching than the control participants. However, there were no significant differences in the response times (P = 0.372) and accuracy rates (P = 0.940) among the three groups in the simple reaction task, suggesting that the processing speed performances were comparable among the open- and closed-skilled participants, and the control participants.

The open-skilled participants were found to elicit less positive-going cue-locked P3 at the parietal region in switch trials than that in repeat trials in the 100% validity condition (P = 0.011). In contrast, the cue-locked P3 of the control participants were more positive-going (P = 0.004), while the closed-skilled participants had no significant differences in the cue-locked P3 (P = 0.523). Findings on the cue-locked P3 suggested that, when engaging in proactive control for task switching, the open-skilled participants appeared to deploy less attentional resources than the closed-skilled and control participants to update the new action rule when the cue was predictive of the subsequent stimulus. However, both open- and closed-skilled participants yielded comparable results when engaging in reactive control for task switching, i.e. 50% validity condition. Less positive-going stimulus-locked P3 at the parietal region in switch trials than that in repeat trials was elicited by the participants with open (P < 0.001) and closed (P = 0.038) skills. No difference in the stimulus-locked P3 at the parietal region between switch and repeat trials was found in the control participants (P = 0.838). The ERP findings in the 50% validity condition suggested that in the reactive control for task switching, both the open and closed-skilled participants deployed less switch-related attentional resources than the control participants to update the new action rule when the cue was not predictive of the subsequent stimulus.

Better proactive control for task switching in terms of lower switch cost of response time in the 100% validity condition was found associated with the differences in the amplitudes of the cue-locked P3 between switch and repeat trials for the open-skilled participants (β = 0.475, P = 0.007), but not for the closed-skilled and control participants. However, better reactive control for task switching in terms of lower switch cost of response time in the 50% validity condition was associated with the differences in the amplitudes of the stimulus-locked P3 between switch and repeat trials for the control participants (β = -0.550, P = 0.020).

The behavioral and electrophysiological findings suggested that firstly, intensive experience of open-skilled training modulated the proactive control for task switching process, because the open-skilled participants showed higher efficiency in updating the environment changes in advance anticipation than the closed-skilled and control participants. Secondly, both intensive experience of open- and closed-skilled training modulated the reactive control for task switching process, because the closed-skilled participants showed higher efficiency in updating the unpredictable environment changes in the imperative response than the control participants.

PUBLICATIONS AND CONFERENCE PRESENTATIONS ARISING FROM THIS THESIS

Journals

Yu, Q.-H., Fu, A. S., Kho, A., Li, J., Sun, X.-H., & Chan, C. C. (2016). Imagery perspective among young athletes: Differentiation between external and internal visual imagery. *Journal of Sport and Health Science, 5*(2), 211-218. doi:10.1016/j.jshs.2014.12.008

Yu, Q.-H., Chan, C. C., Chau, B., Fu, A. S. (In Press). Motor Skills Experience Modulates Proactive and Reactive Switching Control. *Acta Psychologica*.

Conferences

Yu, Q.-H., Fu, A. S., & Chan, C. C. (November, 2012). Influence of Sport Type and Skill Level on Visual Imagery Perspectives of Young Athletes. Presented at the 8th Pan-Pacific Conference on Rehabilitation. Manila, Philippines.

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Introduction

The first chapter provides an overview of a study on the effects of different types of motor-skill experiences modulating proactive and reactive controls for task switching. It begins with a statement of purpose and background, rationale, and objectives for this study. This chapter ends with the organization of the thesis.

Statement of Purpose

Motor-skill training has been shown to be effective for improving executive functions. Proactive and reactive controls are dissociable cognitive processes of executive functions. The association of these two concepts could shed light on the potential of further developing motor-skill training to be a major intervention augmenting cognitive functions in rehabilitation. This study was aimed at exploring how different types of motor-skill experiences could modulate proactive and reactive controls for task switching. The rationale was that taking both proactive and reactive controls into account rather than treating executive control as a unified entity can enable us to gain a better understanding of the effects of motor-skill experiences on each of the refined processes. The use of event-related potentials (ERPs) in the study could help us to go beyond behavioral observations to explore the neural processes associated with proactive and reactive controls, which addresses the underlying mechanisms of the motor-experience modulation.

Background and Justification

Experts with motor skills have better executive functions than do non-experts

(Chan, Wong, Liu, Yu, & Yan, 2011; Verburgh, Scherder, van Lange, & Oosterlaan, 2014). For instance, high-fit fencing experts showed fewer errors in a Nogo condition than did high-fit non-experts in a Go/Nogo task, suggesting that fencing expertise is associated with better action inhibition (Chan et al., 2011). The underlying mechanism for the enhancement of executive functions could be due to the synaptic development of the brain as a result of the aerobic-fitness and cognitive training in long term of sport training (Voss, Kramer, Basak, Prakash, & Roberts, 2010a). However, there is still a question of whether it would have different effects on the executive functions based on the different subtypes of motor-skill training.

Motor skills could be divided into open skills that are externally-paced and require players to respond to a dynamically changing environment (e.g., athletes participating in badminton), and closed skills that are self-paced and require players to respond to a highly consistent, stationary, and environment (e.g., athletes participating in sprint) (Allard & Starkes, 1991; Yu et al., 2016). The main difference between these two motor skills is the activity context. The activity context for open skills is changeable, and players are required to give rapid responses to environmental changes (Allard & Starkes, 1991; Di Russo et al., 2010; Yu et al., 2016). This is in contrary to the activity context for closed skills, which is stable and features fewer changes. The differences in the activity context have effects on involving different cognitive demands between open- and closed-motor skills. Compared with experts with closed skills, experts with open skills were found to be required to anticipate the outcomes of opponents' actions so as to provide rapid and accurate responses within limited time periods (Aglioti, Cesari, Romani, & Urgesi, 2008; Nakamoto & Mori, 2012). In addition, open-skilled experts were required to have higher demands regarding flexibility in cognitive skills, which involved visual attention, decision-making, action inhibition, and shifting, to give imperative responses to unpredictable environment changes (Taddei, Bultrini, Spinelli, & Di Russo, 2012).

Based on the different activity contexts and cognitive demands of these two types of motor skills, it is necessary to explore the effects of the experiences of open- and closed-skills on executive functions. Previous studies had explored the difference in executive functions between experts with open and closed skills by using the stop-signal task (Wang et al., 2013) and the non-sport specific Go/Nogo task (Nakamoto & Mori, 2008). For example, Wang et al. (2013) reported that open-skilled experts showed a stronger inhibitory function in a stop-signal task than did closed-skilled ones. Nevertheless, Nakamoto and Mori (2008) failed to find the differences in the inhibition function between experts with open and closed skills by using the non-sport specific Go/Nogo task. The plausible reason for the inconsistent findings of the two studies is that the stop-signal task is more sensitive to differentiating the inhibition function of the open-skilled group from that of the closed-skilled group, as it requires a higher level of response inhibition ability than does the Go/Nogo task (Enriquez-Geppert, Konrad, Pantev, & Huster, 2010). In addition, the proactive and reactive controls are dissociative processes, which could provide a better understanding of the dynamic process of executive control (Braver, 2012; Karayanidis & Jamadar, 2014). As a result, this study was aimed at revisiting the enhancement of executive functions among open- and closed-skilled experts using a cued task-switching paradigm based on the proactive and reactive control model, which is deemed more sensitive to detecting the between-group difference, if any.

Proactive and reactive controls are two components of a dual cognitive control model (Braver, 2012; Braver, Gray, & Burgess, 2007). Proactive control is regarded as a form of early selection process before cognitively demanding events occur. This early selection could optimally bias attention, perception, and action systems in a goal-driven manner (Braver, 2012). On the other hand, reactive control is used to resolve interference imperatively after cognitively demanding events appear (Braver, 2012; Karayanidis & Jamadar, 2014). The model of proactive and reactive controls could provide a comprehensive understanding of executive control and be more sensitive to detecting the between-group difference in executive control. The proactive and reactive controls of executive functions can also be examined by using a cued task-switching paradigm. In a cued task-switching paradigm, the neural process for proactive control elicited by the cue requires people to use more attentional resources to update the new task goal or action rule before it is required to give the actual behavioral response. Meanwhile, the neural process for reactive control requires people to deploy more cognitive resources to implement stimulus-response mapping after the occurrence of the response-demanding stimulus when the cue is predictable (Gajewski & Falkenstein, 2011) or to update the upcoming task goal and/or action rule when there was no predictive cue (Scisco, Leynes, & Kang, 2008). Thus, this paradigm allows us separately to investigate cue-related ERPs associated with proactive control, and stimulus-related ERPs associated with reactive control.

The P3 component in the parietal region was an important ERP component in proactive and reactive controls for task switching based on previous studies (Gajewski & Falkenstein, 2011; Tarantino, Mazzonetto, & Vallesi, 2016). Thus, P3 elicited by the task cue (cue-locked P3) before the target stimulus was related to the proactive control. Meanwhile, P3 elicited by the target stimulus (stimulus-locked P3) after the target stimulus was related to the reactive control. Generally, the cue-locked P3 (350-550 ms) at the parietal site accounts for task-set reconfiguration, which means updating the task goals and/or action rule in the working memory during task preparation (Gajewski & Falkenstein, 2011). However, the stimulus-locked P3 (300-600 ms) at the parietal site accounts for the implementation of the new stimulus-response mapping when the cue is predictive, or updating the upcoming task goal and/or action rule when the cue is non-predictive (Swainson, Jackson, & Jackson, 2006) or no task cue occurs before the target stimulus (Scisco et al., 2008). In the predictive cue requiring the highest level of proactive control, there is a more positive cue-locked P3 in the switch trials than in the repeat trials, suggesting more attentional resources for updating the new task goal and/or action rule in proactive control for task switching (Jamadar, Hughes, Fulham, Michie, & Karayanidis, 2010a; Jost, Mayr, & Rosler, 2008). These findings supported that the cue-locked P3 was related to proactive control. However, in the non-predictive cue requiring the highest reactive control, the stimulus-locked P3 was more positive in switch trials than that in repeat trials, suggesting more attentional resources for updating the new task goal and/or action rule in reaction control for task switching (Hillman, Kramer, Belopolsky, & Smith, 2006; Scisco et al., 2008). These findings supported that the stimulus-locked P3 was related to proactive control. Thus, in the present study, the cue-locked P3 in proactive control and the stimulus-locked P3 in reactive control could help with distinguishing between the neural processes in proactive and reactive controls for task switching between the participants with differences of motor skills, and hence provide a better understanding of the neural mechanism of how motor-skill experiences modulate executive control.

The study had three objectives as follows:

1. To examine the behavioral differences in the proactive and reactive controls for task switching between open- and closed-skilled participants.

2. To investigate the differences in the neural processes associated with proactive and reactive controls for task switching between open- and closed-skilled participants.

3. To examine the different correlations between neural processes in proactive and reactive controls and the performance of three group participants.

Organization of Chapters

There are six chapters in this thesis, and the present one is the introduction. Chapter II is the literature review, which addresses the differences between open and closed motor skills; the theory of proactive and reactive controls, including the proactive and reactive controls of executive functions; and the neural processes of proactive and reactive controls. The research gaps and hypothesis will be presented. Chapter III is the methods, which includes participant recruitment, the cued task-switching paradigm, the simple reaction task, neuropsychological tests, the physical-related assessments used in the study, electroencephalogram (EEG) data acquisition, data collection procedures, and data analysis strategies. Chapter IV reports the results of the analyses on the behavioral and EEG data. The findings obtained from this study are discussed in Chapter V. Chapter VI provides a conclusion for this thesis.

Chapter II

Literature Review

This chapter firstly reviews the relationship between motor skills and cognitive functions, the differences between open and closed motor skills, and the effects on executive functions between open and closed motor-skill experiences. Secondly, it introduces the theory of proactive and reactive controls, including the definitions and differences of proactive and reactive controls, the proactive and reactive controls in the context of executive functions, the neural substrates and neural processes for proactive and reactive controls for task switching, and the differences of proactive and reactive controls between open and closed skills. Thirdly, the research gap for this study is elaborated. At last, it shows the study objective and hypothesis.

Motor Skills and Cognitive Functions

Relationship between Motor Skills and Cognitive Functions

Cognitive Functions for Motor Skill Development

During motor skill development, besides sport-specific knowledge (e.g., sport-related theoretical knowledge), visuo-motor coordination, rapid visual search, anticipation, pattern recognition, and executive functions are necessary to sport performance. For example, visuo-motor coordination rather than muscle power was found to play a more important role in sport performance, which required athletes to better coordinate the timing of inter-segmental joint velocities for rapid motor responses based on the visual information (Roberts, Bain, Day, & Husain, 2013). For the visual search strategy, referring to the way in which the eyes move around the external environment to guide the visual attention to the relevant information in the environment, expert athletes were able to select useful visual information to be processed (Williams & Davids, 1998). In sports with high time pressure, plenty of evidence showed that expert athletes could quickly pick up the opponent's body kinematics for predicting the trajectory of the shot (Aglioti et al., 2008; Jin et al., 2011; Müller & Abernethy, 2012). The response would be based on the analysis of the trajectory of the ball or shuttle. This is called an anticipation process, with which the athletes would have enough time to prepare potential actions ahead of action execution, leading to the enhancement of motor response (Amoruso et al., 2014; McPherson & Kernodle, 2007). Successful anticipation depends on the higher ability of pattern recognition of the athletes as well as on the classification of domain-specific memory into different recognizable units in the long-term memory (McRobert, Ward, Eccles, & Williams, 2011). These recognizable units could be accessed rapidly and flexibly during the competition (McRobert et al., 2011). On the basis of the previous evidence, these cognitive functions could help expert athletes to outperform in sport competitions.

Executive functions—higher-order cognitive functions—also play a crucial role in the types of sports involving constantly changing environments, e.g., fencing. The environment herein refers to both human and non-human environments. Executive functions are tapped on when athletes are to modify their action plans/tactics for coping with changeable opponent behaviors (Verburgh et al., 2014; Wang et al., 2013). The executive functions may include updating the context, inhibiting proponent action tendency, and shifting the action rules (Hofmann, Schmeichel, & Baddeley, 2012; Taddei et al., 2012).

Physical Activities Enhancing Executive Functions

Executive functions play an important role in motor skill development. In return, physical activities can also improve executive functions. For instance, a 12-week jogging training was reported to improve participants' inhibitory function, which was reflected by the higher accuracy rates in the Go/Nogo task that the participants performed (Harada, Okagawa, & Kubota, 2004). Another functional magnetic resonance imaging (fMRI) study that Colcombe et al. (2004) conducted indicated that older adults who received a six-month aerobic exercise training showed increased neural activities in the prefrontal and parietal cortices than did the stretching and toning control group when performing the Eriksen Flanker task. The results in Colcombe et al.'s (2004) study suggested that aerobic exercise training enhanced conflict monitoring functions among the participants. A few ERP studies reported that participants engaging in regular physical activities had more positive stimulus-locked P3 than did participants engaging in sedentary activities when performing on a non-cued task-switching paradigm (Hillman et al., 2006; Scisco et al., 2008). As stimulus-locked P3 was related to updating the task goal and action rule, more positive-going P3 suggested that the participants with regular physical activities tended to allocate attentional resources more efficiently for updating the task sets than did those in the sedentary group (Hillman et al., 2006; Scisco et al., 2008). There were two drawbacks in these studies, however. First, these studies did not compare the dissociated effects of the different types of motor skills on the executive functions. It is important to separate different types of motor skills, as different demands regarding cognitive functions are required in motor-skill development due to their different activity contexts (Di Russo et al., 2010; Yu et al., 2016). Second, these studies only regarded executive control as a unified entity and did not separate the executive control processes into proactive and reactive control processes. Executive control is a dynamic process in which proactive control could facilitate the performance of reactive control (Chikazoe et al., 2009). Thus, it is very important to explore the effects of different motor-skill experiences on the proactive and reactive controls of executive functions.

Differences between Open and Closed Motor Skills

Physical activities could be categorized into open and closed motor skills. Participants engaged in open-skilled sports were required to react in dynamically changing environments, e.g., badminton, tennis, or football (Di Russo et al., 2010; Wang et al., 2013), and those in closed-skilled sports were required to perform in highly consistent and stationary environments, e.g., swimming or athletics (Di Russo et al., 2010; Wang et al., 2013). The main difference between open and closed motor skills was suggested to be in the activity context, particularly the environment within which the activity is performed (changeable verse stable) (Di Russo et al., 2010; Yu et al., 2016).

There are two main characteristics of the changing environment for open-skilled experts and the relatively stable environment for closed-skilled experts. First, there is a much wider variability of environmental changes in the changing environment relative to the stable environment. For example, a soccer player needs to give a rapid response to the variable changes on the field (e.g., changing positions of the ball and other players), with the environmental changes commonly affecting the soccer player's performance (Verburgh et al., 2014). In contrast, a swimmer does not really need to give a response to other opponent swimmers, and hence, the relatively stable environment does not affect the swimmer's performance as much

(Wang et al., 2013). Second, the motor responses generated from experts with open skills are more diverse than those generated from experts with closed skills (Allard & Starkes, 1991). The reason is that experts in closed-skilled sports follow set patterns, and hence, motor response in them is more consistent than that of experts in open-skilled sports. In contrast, the responses in open skills are variable, as the actions are contingent on the environment in that particular instance (Allard & Starkes, 1991; Di Russo et al., 2010).

The changing environment and hence the diversity of the motor responses under high time pressure would lead to differences in cognitive demands between those with open skills and those with closed skills. Compared to closed skills, open motor skills are more demanding when it comes to making a prediction about opponents' action kinematics information for rapid and accurate responses under high time pressure (Jin et al., 2011; Müller & Abernethy, 2012). In addition, open skills have higher demands regarding flexibility in cognitive skills, including visual attention, making a decision, action inhibition, and shifting action rules, to give an imperative response to an unpredictable environment (referring to an immediate action in response to the unpredictable environment's changes) (Taddei et al., 2012).

Table 2.1. Summary of two studies exploring the difference of executive functions between open- and closed-skilled participants in sport-specific tasks

Study	Group	Task	Results	Conclusions of the study
Nakamoto and Mori (2008)	Open (baseball) vs. Closed (athletics)	• Sport-specific Go/Nogo task (the sport-specific stimulus-response (S-R) mapping in the task design simulated a real baseball batting situation). • Four squares were arranged in a line on the target stimulus. When one of two center squares changed from black to green, the participants needed to give responses. However, when one of the non-centered squares changed from black to green, the participants were required to inhibit the response.	• In the sport-specific Go/Nogo task, shorter response time was shown in open group than in closed group. • For the ERP results, more positive frontal P300 was found in open group than in closed group.	• Compared with those in closed sports, experts in open sports had stronger inhibition in relation to specific S–R mapping due to batting-specific training.
Yamashiro et al. (2015)	Open (baseball) vs. Closed (athletics, or swimming)	• Somatosensory Go/Nogo task (somatosensory elicited by constant current was delivered to second [Nogo condition] or fifth [Go condition] digits of right hand). • Baseball requires more fine somatosensory discrimination or motor control of the hand than do athletics and swimming, so somatosensory Go/Nogo task featured more sport-specific content, leading to better performance for baseball group than swimming group.	• The baseball participants showed more negative frontal N200 in the Nogo trials, which was related to motor inhibition.	• Specific athletic training may induce neuroplastic changes in the sensorimotor inhibitory control process.

Table 2.2. Summary of two studies exploring the difference of executive functions between open- and closed-skilled participants in non-sport-specific tasks

Study	Group	Task	Results	Conclusions of the study
Wang et al. (2013)	Open (tennis player) vs. Closed (swimmer) vs. Control	• Stop-signal task	• Participants engaged in tennis had shorter stop-signal reaction times (SSRTs) than did those engaged in swimming and sedentary controls. • But no difference was found between participants engaged in swimming and sedentary controls.	• Inhibitory function was stronger for the athletes with open-skill training than those with closed-skill training. • Open skills could be a potential clinical intervention for those with impairment in inhibitory control.
Nakamoto and Mori (2008)	Open (baseball) vs. Closed (athletics)	• Non-sport-specific Go/Nogo task (four target stimuli were assigned either in the order of "Go, Nogo, Go, and Nogo" or in the order of "Nogo, Go, Nogo, and Go")	• No differences in RTs and ERs were shown between baseball and athletics players in the non-sport-specific Go/Nogo task. • There were no differences in ERP results of non-sport-specific Go/Nogo task.	• Experts in open sports had no difference in the inhibition function from those in closed sports in the non sport-specific task.

The Effects on Executive Functions between Different Motor-Skill Experiences

Previous studies reported that open-skilled athletes had better inhibitory ability due to the sport-specific training that these participants received (Nakamoto & Mori, 2008; Yamashiro et al., 2015) (see Table 2.1). The drawback of these studies, however, was the use of sport-specific tasks for testing the executive functions among the open-skilled athletes, of which the results would be confounded by their superior knowledge of sports. Two studies employed non-sport-specific tasks (see Table 2.2). One study found that experts in open-skilled sports had a superior ability of inhibitory function when performing on the stop-signal task compared with those in closed-skilled sports (Wang et al., 2013). This finding was inconsistent with that revealed in another study employing a non-sport-specific task, that there were no significant differences in the inhibitory functions between experts in open- and closed-skilled sports (Nakamoto & Mori, 2008). The only caution is that a non-sport-specific Go/Nogo task was used in the second study, which was different from the stop-signal task used in the first study. The stop-signal task required a higher level of response inhibition ability than did the Go/Nogo task, as the stop-signal task required the participants to stop an already triggered motor response, whereas the Go/Nogo task only required the participants to reactively inhibit the development of a motor plan after the target stimulus (Enriquez-Geppert et al., 2010; Zheng, Oka, Bokura, & Yamaguchi, 2008). This is a plausible reason to account for why Nakamoto and Mori (2008) failed to find differences in the inhibitory function between the two groups of experts in the non-sport-specific Go/Nogo task. In addition, one main drawback for these two studies was that proactive and reactive executive controls were not taken into account in executive functions, as proactive and reactive controls could lead to a better understanding of executive control. The goal of the present study was to explore the differences in proactive and reactive control functions between open- and closed-skilled experts by using a cued task-switching paradigm. The cued task-switching paradigm, in which the level of demands for proactive and reactive controls can be manipulated, was deemed more sensitive to detecting the between-group differences compared to the stop-signal task (Wang et al., 2013) or Go/Nogo task (Nakamoto & Mori, 2008).

Proactive and Reactive Controls

Definitions

The dual cognitive control model that Braver et al. (2007) proposed introduced two different operating modes for cognitive control: proactive control verse reactive control. Proactive control is a form of early selection, during which some goal-relevant information is actively maintained in a sustained manner before response demanding events occurs. This early selection could optimally bias attention, perception, and action systems in a goal-driven manner (Braver, 2012; Braver et al., 2007; Miller & Cohen, 2001). For example, one would like to go shopping after work and has the intention about two hours before off hours. The goal of going shopping, which is a proactive control strategy, may bias the schedule of a late meeting to get off work early to go shopping. Reactive control is a form of late correction, occurring in a just-in-time manner, as soon as a high-interference event is detected (Braver, 2012; Braver et al., 2007). For instance, one would remember going shopping after work by a salient trigger event (when seeing a food poster on the way home) instead of by a goal activated before work.

It is important to compare proactive and reactive controls with feedforward and feedback controls, which is one of the motor control theories (Desmurget &

Grafton, 2000; Seidler, Noll, & Thiers, 2004). Feedforward control is where a motor command is determined prior to the onset of movement without the usage of online feedback (Seidler et al., 2004). This motor command would not change until the movement is done. Nevertheless, feedback control is where motor planning and execution involve ongoing feedback from different systems (Seidler et al., 2004). The movement could be refined by the ongoing feedback. As mentioned in the previous paragraph, proactive control is an early-selection process, in which goal-related information could bias the preparatory attention without considering responses (Braver, 2012). The preparatory processes in proactive control are similar to the pre-determination processes for motor command in feedforward control. Reactive control is to resolve the cognitive interference elicited by the cognitive demanding events before motor execution (Braver, 2012). The processes in reactive control are similar to the cognitive process elicited by the feedback stimulus in feedback control. However, proactive/reactive controls are also disassociated with feedforward/feedback controls. Proactive and reactive controls are the cognitive processes related to the goal-directed regulation of thoughts or actions with the involvement of higher-order cognitive functions, which are predominantly mediated by the fronto-parietal network (Braver, 2012; Braver et al., 2007). In contrast, feedforward and feedback controls are related to motor control processes, which are predominantly mediated by both cortical and sub-cortical areas (Desmurget & Grafton, 2000; Seidler et al., 2004) .

Differences between Proactive and Reactive Controls

Proactive and reactive controls are different in three domains. First, the timing for mental processes between proactive and reactive controls is different.

Proactive control is to anticipate and prevent interference before the cognitively demanding event occurs, whereas reactive control is to detect and resolve the interference after the onset of the cognitively demanding event (Braver, 2012). Second, they are also different in terms of the demand of working memory. The demand of working memory in proactive control is high, as the upcoming task goal or action rule is activated in advance and is maintained in working memory to prepare for the upcoming task. Meanwhile, the demand of working memory in reactive control is lower because the interference in performing the response is to be solved transiently after the target stimulus (Aron, 2011; Braver & Cohen, 2000). Third, there are differences in the neural processes associated with proactive and reactive controls as reflected in the results of a few brain imaging studies. For similarities, an increase in activations in the supplementary motor area (SMA) was reported to exist in proactive control for preparation and reactive control for motor responses (Chen, Scangos, & Stuphorn, 2010). For differences, dorsolateral prefrontal cortex (DLPFC) was more activated when participants proactively inhibited an action than reactively inhibited it (Aron, 2011), whereas the activation of the right inferior frontal gyrus (rIFG) was more activated when participants reactively inhibited an action than proactively inhibited it (Chikazoe et al., 2009). The activation differences of these two neural substrates were due to the difference in the neural processes mediated by them. For example, DLPFC was related to preparatory goal-directed activation and the maintenance of the task information in proactive control (Karayanidis et al., 2010; Ruge, Jamadar, Zimmermann, & Karayanidis, 2013). In contrast, rIFG was related to the implementation of the inhibitory process in reactive control (Aron, 2011).

Proactive and Reactive Controls in Context of Executive Functions

Executive functions include updating (Locke & Braver, 2008), inhibition (Kopp & Lange, 2013), and shifting (Hofmann et al., 2012). Updating refers to the changed allocation of attentional resources or the ‘‘updating’’ of the new stimulus representation once a new stimulus is detected (Polich, 2007). The inhibition function refers to the ability to inhibit the prepotent action (Hofmann et al., 2012). The shifting function refers to the ability to shift between multiple tasks or mental sets (Hofmann et al., 2012). Executive functions could involve proactive or reactive control (Criaud, Wardak, Ben Hamed, Ballanger, & Boulinguez, 2012). For example, the preparation for the action inhibition before the onset of the target stimulus was called proactive inhibitory control, whereas reactively inhibiting the response after the Nogo stimulus was called reactive inhibitory control. An example of the proactive and reactive inhibitory controls is the mixed Go/Nogo task, in which an uncertain cue indicated that the upcoming stimulus might be either the Go condition or Nogo condition (including proactive and reactive inhibitory controls). Meanwhile, a certain cue only indicated that the upcoming stimulus was a pure Go condition (without proactive and reactive inhibitory controls). The process between an uncertain cue and the target stimulus involved proactive inhibitory control, whereas the process after the Nogo target stimulus involved reactive inhibitory control (Criaud et al., 2012).

A cued task-switching paradigm could be used to explore the proactive and reactive controls for task switching. In the cued task-switching paradigm, a task cue occurs prior to the target. The task cue could indicate whether an individual needs to repeat the previous task or switch to a new task before the stimulus (Kiesel et al., 2010; Meiran, 2010). Proactive control for task switching elicited by the task cue is that one person prepares to switch to a new task prior to the onset of a stimulus (Swainson et al., 2006). Proactive control for task switching demands more cognitive resources to update the new task goal and then maintain it in a sustained manner when compared with repeating the previous task (Kiesel et al., 2010). In contrast, reactive control for task switching is that one person switches to a new task in response to a stimulus. Reactive control for task switching would require more cognitive resources to implement the new stimulus-response set when a cue indicated the task set conveyed by the stimulus (Gajewski & Falkenstein, 2011), or require updating the new task goal and its corresponding stimulus-response rule when there was no task cue (Scisco et al., 2008). The levels of proactive and reactive controls for task switching could be manipulated by cue validity, referring to the probability of an upcoming task for the target stimulus (Linssen, Sambeth, Riedel, & Vuurman, 2013). In the present study, the cue with 100% validity, which is a predictive cue certainly indicating the upcoming task for the stimulus, elicits the highest proactive control but requires the lowest reactive control for task switching. In contrast, the cue with 50% validity, which is a non-predictive cue without indicating any information for the stimulus, elicits the lowest proactive control but requires the highest reactive control for task switching. On the trials with 75% cue validity, the proactive and reactive controls for task switching were between those on the trials with 100% and 50% cue validities.

The switch cost is defined as a decrease in the reaction time and/or an increase in the error rate when one person switches to a new task compared to repeating the previous task (Kiesel et al., 2010). The switch cost could be employed in exploring the differences in behavioral performance between proactive and reactive controls for task switching (Tarantino et al., 2016), as a lower switch cost is related to a longer interval between the cue and the stimulus because a longer interval enables better proactive control for task switching (Kiesel et al., 2010). However, previous studies showed that the switch cost did not decrease when the interval increased to 600 ms or more, and it left a residual switch cost (Kiesel et al., 2010; Monsell, 2003). This residual switch cost suggested that reactive control for task switching is necessary after the target stimulus whether a task cue for proactive control is presented or not (Cooper, Garrett, Rennie, & Karayanidis, 2015). The residual switch cost was negatively associated with the working memory loads required to implement the new stimulus-response set in the reactive control when switching to a new task (Jamadar et al., 2010a; Li, Wang, Zhao, & Fogelson, 2012).

Neural Substrates and Neural Processes in Proactive and Reactive Controls for Task Switching

Neural Substrates Involved in Proactive and Reactive Controls for Task Switching

In proactive control, DLPFC was related to the goal-directed behavior and preparatory activation of abstract task goals and action sets (Kim, Cilles, Johnson, & Gold, 2012; Ruge et al., 2013), while the posterior parietal cortex (PPC) contributes to the representation or updating of a task goal and action rule (Jamadar et al., 2010a; Kim et al., 2012). Jamadar et al. (2010a) conducted an ERP-fMRI study to explore the spatial and temporal dynamics of anticipatory task preparation when the participants performed a cued task-switching paradigm. They found that the differences of DLPFC activity between prepared and unprepared conditions were related to the early positivity (300-400 ms) of the cue-locked ERP difference waveform (prepared waveform minus unprepared waveform) in the preparation interval. In contrast, the differences of PPC activity between the switch and repeat conditions were related to the late positivity (450-550 ms) of the cue-locked ERP difference waveform (switch waveform minus repeat waveform). These findings suggested that both DLPFC and PPC were the important neural substrates in proactive control for task switching. Other fMRI studies also found differential switch-related activation (more activation in switch trials than repeat trials) in DLPFC and PPC (Crone, Wendelken, Donohue, & Bunge, 2006; Ruge, Muller, & Braver, 2010).

In reactive control, the differential switch-related activation was found in the widespread fronto-parietal brain regions, when there was no task cue for eliciting proactive control (Hyafil, Summerfield, & Koechlin, 2009; Karayanidis et al., 2010; Ruge et al., 2013). As a result, the front-parietal network is involved in both proactive and reactive controls for task switching.

Neural Processes of Proactive and Reactive Controls for Task Switching

Adopting the cued-task switching paradigm allows us to investigate ERPs that are related to proactive control (the cue-related neural process) and reactive control (the stimulus-related neural process) separately. Previous studies have shown that the P3 component of the parietal region is related to the updating of a new task or response rule in proactive or reactive controls (Gajewski & Falkenstein, 2011; Scisco et al., 2008). Thus, arguably, P3 elicited by the cue (cue-locked P3) is associated with proactive control, whereas P3 elicited by the stimulus (stimulus-locked P3) is associated with reactive control. These two ERPs are the focus components in this study.

Cue-Locked P3 in Proactive Control

The parietal cue-locked P3, which is elicited about 300-600 ms after the appearance of a predictive cue and before the occurrence of the stimulus, is an important component in proactive control (Tarantino et al., 2016; West, Bailey, Tiernan, Boonsuk, & Gilbert, 2012). This component is related to the anticipatory updating of the task goal and/or action rule in working memory (Gajewski & Falkenstein, 2011; Nicholson, Karayanidis, Bumak, Poboka, & Michie, 2006). A number of ERP studies reported more positive-going cue-locked P3 in the switch trials than in the repeat trials, as higher demands of cognitive efforts (attentional resources) were required in the anticipatory updating of the new task (Gajewski & Falkenstein, 2011; Jamadar et al., 2010a; Jost et al., 2008). Table 2.3 shows the details of some previous studies showing cue-locked P3 with a positive difference between switch and repeat trials. In addition, the positive difference in cue-locked P3 between switch and repeat trials was negatively related to the switch cost of the response time, suggesting that cue-locked P3 in proactive control was related to the performance in task switching (Li et al., 2012).

In addition, contingent negative variant (CNV), also related to proactive control, is a slow wave and peak at the time of the target stimulus presentation (S2) (Funderud et al., 2013; Grane et al., 2016). The cognitive function of CNV is associated with anticipatory attention and motor preparation for the upcoming imperative stimulus (Grane et al., 2016). However, the amplitude of CNV is affected by the response-related parameters (e.g., cue validities) (Linssen et al., 2013; Scheibe, Schubert, Sommer, & Heekeren, 2009). For instance, CNV under the cue with 100% validity was more negative than those under the cues with 50% and 20% validities (Linssen et al., 2013). However, the response-related parameters indicated by the task cues in the cued task-switching paradigm did not differ between repeat or switch conditions, leading to comparable levels of motor preparation reflected by no differences in the amplitudes of CNV between repeat and switch conditions (Gajewski & Falkenstein, 2015). Thus, CNV was less important than cue-locked P3 in proactive control for task switching and will not be considered in the present study.

Table 2.3. The details of some previous studies which displayed a more positive switch-related cue-locked P3 when the cue was predictive

Studies	Task	Results	Mental Process
Jost et al. (2008)	• Shifting between color and shape tasks. The letters “G” and “S” indicated the color task; “W” and “B” indicated the shape task.	• from 400 to 600 ms: more positive at parietal site in switch condition than repeat condition	• Accounting for updating the task goal in the working memory
Jamadar et al. (2010a)	• Shifting between letter and digit tasks with informative and non-informative cues • The fixation in hot color as the cue indicated letter task, while the fixation in cold color as the cue indicated digit task. The fixation in gray was the non-informative cue.	• from 450 to 550 ms: more positive at parietal site in switch condition than repeat condition	• Accounting for reloading the new relevant task-set rule prior to stimulus onset
Nicholson et al. (2006)	• Shifting between parity and magnitude tasks • Circle indicated parity task, whereas diamond indicated magnitude task.	• from 300 to 600 ms: more positive at parietal site in switch condition than repeat condition	• Accounting for task set reconfiguratio n process
Gajewski and Falkenstein (2011)	• Shifting between parity and magnitude tasks • Square as the cue indicated parity task, whereas diamond as the cue indicated magnitude task. This paradigm also included the Go/Nogo task depending on the color of target stimulus (green is Go trial; red is Nogo trial).	• from 300 to 600 ms: more positive at Fz, Cz, and Pz sites in switch condition than repeat condition, regardless of whether the previous trial was a Go or No/go trial	• Accounting for the new task-set updating in working memory

Stimulus-Locked P3 in Reactive Control

The parietal stimulus-locked P3 component after the response-demanding stimulus is an important component of reactive control (Swainson et al., 2006; Tarantino et al., 2016). Stimulus-locked P3 accounts for a stimulus-response set implementation when the cue is predictive (Gajewski & Falkenstein, 2011; Jamadar et al., 2010a). However, stimulus-locked P3 accounts for updating the task goal and/or action selection rule in reactive control when the cue is not predictive (Swainson et al., 2006) or when there is no task cue before the stimulus (Hillman et al., 2006; Scisco et al., 2008). When the cue was predictive, stimulus-locked P3 was found to be consistently less positive going in switch trials than in repeat trials (Gajewski & Falkenstein, 2011; Hsieh & Wu, 2011). Table 2.4 summarizes the details of the studies that found less positive switch-related stimulus-locked P3 with a predictive cue. The potential explanation for less positive stimulus-locked P3 in switching trials compared to repeat trials was proposed by Barcelo, Munoz-Cespedes, Pozo, and Rubia (2000), who observed a progressive increase of the parietal stimulus-locked P3 amplitude in repetitive trials following switch trials, as the representation of the stimulus-response set was stronger when repeating the same task than that when switching to a new task.

However, when the cue was non-predictive (Swainson et al., 2006) or when there was no task cue before the stimulus (Hillman et al., 2006; Scisco et al., 2008), stimulus-locked P3 was more positive going in switch trials than in repeat trials, as it required more attentional resources allocated to updating the task goal and action rules when switching to a task. Table 2.5 summarizes the details for the studies that showed more positive switch-related stimulus-locked P3 with a non-predictive cue or without a task cue. In addition, the amplitude difference of stimulus-locked P3 between switch and repeat trials was negatively related to the switch cost of the response time when the cue was predictive (Li et al., 2012), which suggested that stimulus-locked P3 in reactive control was related to the performance in task switching.

Table 2.4. The details of some previous studies that displayed less positive switch-related stimulus-locked P3 with a predictive cue

Studies	Task	Results	Mental Process
Gajewski and Falkenstein (2011)	• Shifting between parity and magnitude tasks. Square as the cue indicated parity task, whereas diamond as the cue indicated magnitude tasks. • This paradigm also included the Go/Nogo task depending on the color of the target stimulus (green is Go trial; red is Nogo trial).	• from 300 to 600 ms: less positive at parietal site in switch condition than in repeat condition regardless of whether the previous trial was a Go or No/go trial	• Related to the updating task-set for response selection • The representation of stimulus-response mapping was initially relatively weak after switching and was strengthened by successive repetition trials, which was the reason for less positive stimulus P300 in switch trials than in repeat trials.
Hsieh and Wu (2011)	• Shifting two sets of response mapping by using “stay” and “switch” as the cues • “Stay” and “switch” indicated that the participants should repeat or switch the response mapping, respectively.	• from 400 to 700 ms: less positive at centro-parietal sites in switch condition than in repeat condition	• Related to task rehearsal or implementation during response execution (repeat trials with more practiced eliciting larger P300 amplitude)
Rushworth, Passingham, and Nobre (2005)	• Shifting between color and shape tasks. • “Stay” and “switch” as the cues indicated that the participants should repeat or switch the attention, color, or shape of the target stimulus.	• from 240 to 520 ms: less positive at parietal site in switch condition than in repeat condition	• Related to the process of stimulus-response mapping implementation (without explanation of less positivity of P300 in switch trials than in repeat trials)

Table 2.5. The details of some previous studies that displayed a more positive switch-related stimulus-locked P3 with a non-predictive cue or without a task cue

Studies	Task	Results	Mental Process
Hillman et al. (2006)	• Without a task cue • Shifting between parity and magnitude tasks	• from 275 to 750 ms: more positive at parietal site for switch condition than repeat condition	• Accounting for attentional allocation for subsequent memory updating • Larger P300 amplitude for switch than repeat trials was due to greater demand of attentional resources updating in switch condition.
Scisco et al. (2008)	• Without a task cue • Shifting between parity and magnitude tasks	• from 475 to 525 ms: more positive at centro-parietal site for switch condition than repeat condition	• Accounting for attentional allocation for subsequent memory updating • Larger P300 amplitude for switch than repeat trials was due to greater demand of attentional resources for updating in switch condition.
Swainson et al. (2006)	• With non-predictive and predictive cues • Shifting between "go" and "wait" tasks • Give a response at stimulus onset in green arrow stimulus (go task), and give a response at stimulus offset in red arrow stimulus (wait task). • The white fixation (cue) is no-informative condition. The green fixation (cue) indicated the go task, whereas the red fixation (cue) indicated the wait task.	• from 524 to 808 ms: more positive at parietal site for switch condition than repeat condition	• Accounting for target evaluation • Larger amplitude of P300 in switch trials than in repeat trials

The Differences of Proactive and Reactive Controls between Open and Closed Skills

Little evidence has explored the effects between the experience of open motor skills and that of closed motor skills on proactive and reactive controls of executive functions. However, some previous studies have suggested that experts with open skills outperformed in anticipation during training and competitive contexts compared to normal participants (Aglioti et al., 2008; Müller & Abernethy, 2012; Rosalie & Müller, 2013). For example, basketball experts predicted the success of free basket shots more accurately by observing the earlier body kinematics compared to the expert watchers (coaches or sports journalists) and novices (Aglioti et al., 2008). More importantly, the results of transcranial magnetic stimulation (TMS) in the Aglioti et al.'s (2008) study showed that more cortical excitability could be found when basketball experts observed accurate shots than when they observed inaccurate shots, whereas the differential cortical excitability between observing accurate and inaccurate shots wasn't found in the expert watchers and novices. Both the behavioral and TMS findings suggested that the expert athletes' anticipation relied more on the kinematics of the hand muscles when the ball just left the opponents' hand to predict the trajectories of the ball; in contrast, the expert watchers and novices relied more on the later ball trajectory near the basketball stand (Aglioti et al., 2008). The earlier and more accurate anticipation for changed action and tactics could update the environment changes, bias the preparatory attention, and hence a better preparation (proactive control) before motor response (McRobert et al., 2011). In addition, Nakamoto and Mori (2012) adopted a velocity prediction task that required the participants to press a button when the moving target arrived at the end of the trackway with a change or unchanged velocity. The results of the

Nakamoto et al.'s (2012) study showed that open experts had significantly smaller errors of timing reprogramming than the closed experts in the predictive task. The potential reason was that before giving a response, open-skilled experts showed quicker detection of changed target velocity, and then update of the S-R relationships for the changed environment before the response than closed-skilled experts. These pieces of evidence suggested that open-skilled experts might be different from closed-skilled ones in proactive control.

For reactive control, some ERP studies using the non-cued task-switching paradigm found that the participants with regular physical activities, including open- and closed-motor skills, had more positive stimulus-locked P3 in reactive control after target stimulus than the sedentary group regardless of switch or repeat conditions, which suggested that the participants with regular physical activities allocated attentional resources to update the task goal and action rule in reaction control in an efficient manner compared to the sedentary group (Hillman et al., 2006). But the limitation for these studies is the absence of comparing the effects of different kinds of motor skills on the reactive controls. Thus, the present study was meant to explore the differences in proactive and reactive controls among open- and closed-skilled experts and the underlying neural mechanism and, hence, to understand how motor-skill experiences modulate executive control.

Research Gap

A lot of research evidence has shown that motor-skill experience could enhance the executive functions (Chan et al., 2011; Kida, Oda, & Matsumura, 2005; Verburgh et al., 2014). Some of these previous studies differentiated the executive functions in the experts with different motor skills (Nakamoto & Mori, 2008; Wang et al., 2013; Yamashiro et al., 2015). The drawback of these studies is only treating executive control as a unity, which couldn't provide a comprehensive understanding of executive control. The reason is that executive control is a dynamic process, which could be separated into proactive and reactive controls (Criaud et al., 2012). Proactive control could reduce the level of cognitive demands for reactive control and hence enhance the performance of executive control (Criaud et al., 2012; Jahfari et al., 2012). That is to say, proactive control could modulate the cognitive demands in reactive control and hence affect the performance of executive control. Thus, the proactive and reactive controls could be more sensitive to detect the between-group differences treating executive control as a unity (Yu, Chan, Chau, & Fu, Under Review). In addition, even though reactive control is very common in everyday life, combining proactive and reactive controls into the model of executive control is more meaningful in our daily activities. Proactive control could selectively allocate the preparatory attention before the response tendency is triggered, which is very important for the self-regulated behaviors, e.g., cocaine addicts having an advance goal of abstaining from drugs could effectively help them abstain from taking drugs (Aron, 2011). Thus, the dual cognitive control model, including proactive and reactive controls, could better display the executive control processes in our daily life.

The present study took both proactive and reactive controls into account, which could provide a more comprehensive understanding to how executive control could benefit from the experience of motor-skill training and hence provide clinical implications about which type of motor-skill training could be an effective intervention method for treating those with impaired proactive controls on executive functions, thereby improving their self-regulated behavior.

Study Objectives and Hypothesis

Study Objectives

This study aims to explore how open- and closed-skilled experiences modulate the proactive and reactive controls of executive functions. The main study employed a cued task-switching paradigm in which participants were instructed to switch between two sets of response rules. The paradigm involved different cues that were fully, partially, or not predictive of the response sets so that the demands for switching control varied from strongly proactive and less reactive, to partially proactive and partially reactive, and then to only strongly reactive. Electroencephalogram (EEG) measurements were employed to investigate the neural processes in proactive and reactive controls for task switching (Figure 2.1).

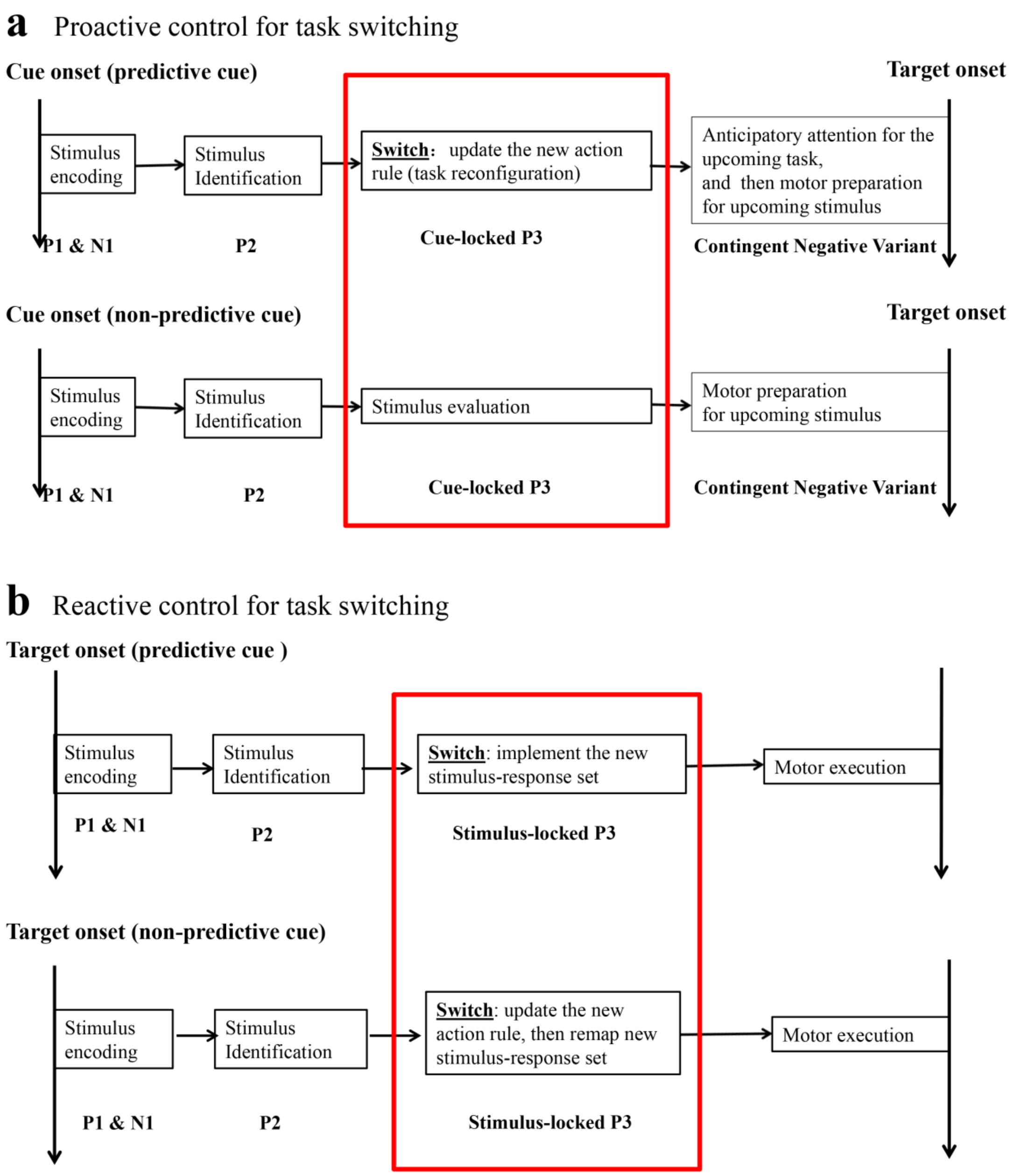
This study was aimed to:

1. Examine the behavioral differences in the proactive and reactive controls for task switching among open-skilled, closed-skilled and control participants.

2. Investigate the differences on neural processes associated with proactive and reactive controls for task switching among open-skilled, closed-skilled and control participants.

3. Examine the correlations between neural processes (cue-locked P3 and stimulus-locked P3) in proactive and reactive controls and the performance in task switching among three groups.

Figure 2.1. The cognitive processes and ERP components in proactive and reactive controls for task switching (predictive cue vs. non-predictive cue) in the present study. **2.1a** The upper panel shows proactive control with the predictive cue, whereas the lower panel shows proactive control with the non-predictive cue. The cue-locked P3 in the red square is the key component in proactive control. **2.1b** The upper panel shows reactive control with the predictive cue, whereas the lower panel shows reactive control with the no predictive cue. The stimulus-locked P3 in the red square is the key component in reactive control.



Hypothesis

Open-skilled trainings, including the trainings of anticipatory responses for predictable changes and imperative responses for unpredictable changes, could enhance both proactive and reactive controls for task switching when compared with closed-skilled and control groups, whereas closed-skilled trainings, also including the trainings of imperative responses for the unpredictable changes but less anticipatory responses, could enhance reactive but not proactive control than controls. Firstly, we hypothesized that open-skilled participants had less switch cost under the fully predictive cue than closed-skilled participants and controls, while both open- and closed-skilled participants had less switch cost under the non-predictive cue than the control group. Secondly, it is hypothesized that a relatively less positive difference of cue-locked P3 between switch and repeat trials was elicited by open-skilled participants under the fully predictive cue, which showed higher efficiency to update the new task than closed-skilled counterparts and control participants in proactive control. The reason was their training experience of quickly updating the environment changes in advance anticipation and preparation within a limited time period. Thirdly, it was hypothesized that a less positive difference of stimulus-locked P3 was elicited by open- and closed-skilled groups compared to controls under the non-predictive cue, which showed that both open- and closed-skilled experts had higher efficiency to update the new task in reactive control. The reason was due to their training experience of updating new S-R relationship for an imperative response in an unpredictable changed environment. At last, better performance in proactive control for task switching was associated with cue-locked P3 for open-skilled participants, while better performance in the reactive control for task switching was associated with stimulus-locked P3 for three groups of participants.

Chapter III

Methods

This chapter is an overview of the experiment design and the equipment and instruments used. It also describes the acquisition of the ERP data and experimental procedure and finally introduces the approaches for statistical analyses.

Participants

Fifty-four participants were classified as open-skilled, closed-skilled, and control participants. The selection criteria for the participants were 1) aged between 18 and 28, 2) right handed, 3) having normal or corrected-to-normal vision, and 4) having no history of neurological disorders, cardiovascular diseases, or clinical conditions that required medication. For the participants in the open- or closed-skilled groups, they were sportsmen with open or closed skills in the sport teams of The Hong Kong Polytechnic University, with five or more years of sports training experience and having won prizes in open competitions of their own sports. Besides, they did not receive regular training on other types of sports. For the participants in the control group, they had not been receiving sports training or had not been participating in any formal sports competition. Among them, the participants engaging in open-skilled sports (n = 18; 8 females and 10 males) were recruited from the university badminton team. The participants engaging in closed-skilled sports (n = 18; 7 females and 11 males) were recruited from the university athletics team. The control group participants (n = 18; 9 females and 9 males) were university students. Compared with the contrast of athletes and non-athletes, the direct contrast of open- and closed-skilled athletes could remove some confounding effects for motor-skill experiences, e.g., fitness, selection biases, etc. The procedures of the study were explained (Appendices 3.1 and 3.2), and then the informed consent was collected from each participant (Appendices 3.3 and 3.4). Ethical approval for the present study was obtained from The Hong Kong Polytechnic University (Appendix 3.5). All participants received a reimbursement of HKD$200 (around USD$26) for covering the meals and travel expenses.

Instruments and Experiment Design

Cued Task-Switching Paradigm

Proactive and reactive control processes were tested by a cued task-switching paradigm. In each trial, the participant was required to make a response by switching to a new rule or repeating the same rule as that in the previous trial (Hsieh & Liu, 2005; Rushworth, Passingham, & Nobre, 2002). The time course of one typical trial in the cued task-switching paradigm is illustrated in Figure 3.1. At the beginning of each trial, a task cue (4 cm × 4 cm) appeared in the center of the screen that lasted for 1500 ms. Then the target stimulus (4 cm × 4 cm) was displayed in the center of the screen. The participant was required to make a two-key sequential response according to the exact combination of the task cue and target stimulus presented (Table 3.1). Once the participant completed performing the response or after 3000 ms passed, an inter-trial interval lasting for 1000 ms occurred by showing a blank screen prior to the onset of the next trial. The participant was required to put in the effort to respond as quickly as possible and as accurately as possible.

Figure 3.1. Schematic illustration of one typical trial of the cued task-switching paradigm. The task starts by a task cue (a square in the example) for 1500 ms. Then the target stimulus (“2” in square) follows and retains for 3000 ms, during which the participant must give a response (pressing the “x” and then “m” or “z” and then “m” on the keyboard) as quickly and accurately as possible. After that, an inter-trial interval by displaying a blank screen lasts for 1000 ms before the onset of the next trial.

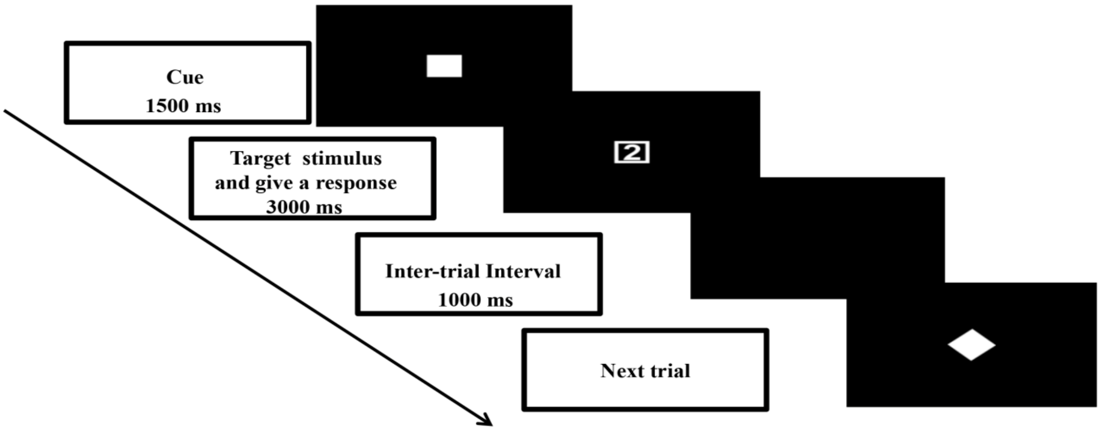
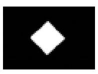


Table 3.1. The cue-target-response set mappings in the cued task-switching paradigm

	Cue with 100% validity	Cue with 75% validity	Cue with 50% validity	Target stimuli	Response sets
Response rule 1					z→n (or x→n)
					x→m (or z→m)
Response rule 2					x→n (or z→n)
					z→m (or x→m)

The combinations of task cues, target stimuli, and associated response selection rules in the cued task-switching paradigm were shown in Table 3.1. The response selection rules were denoted by a digit (1 or 2) and a shape (square or diamond). The response set for each trial was a two-step sequential movement (Table 3.1). When the target stimulus was “1” or “2” in a square, the participant needed to press “z” and then “n” or “x” and then “m” on the keyboard, respectively. When the target stimulus was “1” or “2” in a diamond, the participant pressed “x” and then “n” or “z” and then “m”, respectively. In addition, the cues with high (100%) and low (75%) validity were shown with a solid square (or diamond) and a hollow square (or diamond), respectively (Table 3.1). On the trials with 75% validity, if the cue was a hollow square and the target stimulus was the digit 1 or 2 in a square, the cue was regarded as a 75% valid cue due to its congruence with the target stimulus. If the cue was a hollow square but the target stimulus was the digit 1 or 2 in a diamond, the cue was invalid due to its incongruence with the target stimulus. The exclusion of invalid trials in the comparisons in this study was due to the more complex neural processes after the target stimulus on the invalid trials than those on the trials with 100%, 75%, and 50% validities. On the cue with 50% validity “”, which did not indicate any information of the subsequent target stimulus, it was not possible for the participants to prepare any response set before the onset of a target stimulus. The participants could only have the movement selection and give a response after the onset of a target stimulus. The combinations of cues (square vs. diamond) and two kinds of response selection rules were randomly assigned to each participant.

In the cued task-switching paradigm, cue validity could monitor the levels of proactive and reactive controls for task switching. If the validity of the cue was 100%, proactive control for task switching elicited by the cue was highest and reactive control for task switching was lowest. If the validity of the cue was 50%, no proactive control for task switching could be elicited by the cue and the demand of reactive control for task switching was highest. Finally, if the validity of the cue was 75%, the demand of proactive or reactive controls was between those with 100% and 50% validities.

The cued task-switching paradigm included nine blocks with 140 trials in each block. There were a total of 1260 trials with all trials pseudo-randomized. There were two types of trials: repeat and switch trials. In repeat trials, the response selection rule was the same as that of the previous trial; however, in switch trials, the response selection rule was different from that of the previous trial. The ratio of repeat to switch trials was equal. Both repeat and switch trials had four types of cue validities so that each block consisted of eight kinds of trials. They were repeat/switch trials with a 100% valid cue, repeat/switch trials with a 75% valid cue, repeat/switch trials with a 50% valid cue, and repeat/switch trials with an invalid cue. Each participant was required to prepare the response selection rules based on the information provided by the cue (except for the cue with 50% validity). The accuracy rates and the response times of the first step were recorded by the computer. Each block of the cued task-switching paradigm took about nine minutes. The break between two blocks was about four to five minutes. Before testing, there was a practice session for the participant.

Acquisition of Electroencephalogram (EEG) Data

The electroencephalogram (EEG) signals were also acquired during the cued task-switching paradigm. The participants' EEG signals were captured by a 64-channel cap equipped with 90 mm Ag/AgCl sintered electrodes (NeuroScan Inc., Sterling, VA, USA). The reference electrodes were placed on the left and right mastoids, and the ground electrode was placed on the forehead in front of the vertex electrode (Cz). Bipolar vertical electrooculogram (VEOG) was recorded with one pair of electrodes placed on the supra- and infra-orbital areas of the left eye. Bipolar horizontal electrooculogram (HEOG) was recorded from the left and right orbital rims of both eyes. Both VEOG and HEOG were used to monitor eye movements and ocular artefacts. The 64-channel Quikcap was connected to one head-box of the SynAmps^2 Digital DC EEG Amplifier (manufactured by NeuroScan Inc., Sterling, VA, USA). The configuration of the electrode positions was predefined according to the SynAmps^2 Digital. The signals were sampled at a rate of 1000 Hz/channel. Reference impedances were set to below 5 kΩ.

The CURRY 7 software (NeuroScan Inc., Sterling, VA, USA) was used for signal acquisition as well as offline signal pre-processing of the EEG data. Continuous EEG was digitally filtered with a band pass from 0.01 Hz to 30 Hz and 24 dB/oct. Epochs between -200 ms before the cue to 1,500 ms after the cue were obtained for cue-locked ERP waveforms, whereas epochs between -200ms before the target to 1000 ms after the target were obtained for stimulus-locked ERP waveforms. After that, baseline correction against the pre-stimulus interval was conducted for each epoch. Then the epochs with amplitude exceeding ± 80 μv in any of the scalp channels were excluded from the subsequent averaging procedure. It was anticipated that approximately 80% of the trials per condition remained for each subject after the artefact rejection. Both the cue- and stimulus-locked ERP waveforms were averaged for each of the electrodes separately for the six conditions. The six conditions were 100% cue validity (repeat versus switch), 75% cue validity (repeat versus switch), and 50% cue validity (repeat versus switch).

Simple Reaction Task

A simple reaction task was administered to evaluate participants' behavioral performance when proactive or reactive control for task switching was not required. The time course of a single trial (Figure 3.1) and the set of cue and target stimuli (see Table 3.1) in the simple reaction task were similar to that of the cued task-switching paradigm. Every trial in the simple reaction task started with a cue, which was presented for 1500 ms. Following the offset of the cue, the target stimuli was then presented. Participants were required to perform the same sequence of button presses in 3000 ms for all target stimuli that were presented, which was different from the cued task-switching paradigm. In each block, one of four types of responses was randomly assigned to each participant and made known to the participant before the task began (Table 3.1). There were two blocks for this task and 40 trials per block. Each block in the simple reaction task lasted about two to three minutes with a break of about two minutes. The accuracy rates of the participants and the time required for a response for the first step were recorded.

Color Trails Test (CTT)

The CTT (D'Elia, Satz, Uchiyama, & White, 1996), including CTT 1 and 2, required the participant to connect the consecutive encircled number from 1 to 25 on a sheet of paper as soon as possible. In CTT 1, even numbers were in a yellow background and odd numbers were in a pink background. The participant was instructed to connect the circles in ascending order. In CTT 2, two sets of the 25 numbers were in pink and yellow respectively. The participant was instructed to connect the numbers in consecutive order while alternating between the two color sets. CTT 1 assessed perception tracking and sustained attention, whereas CTT 2 assessed not only perception tracking and sustained attention but also divided attention and executive functions (e.g., shifting function) (Lin et al., 2014). Scoring was calculated by measuring the error rates, completion time (up to 240 seconds), and Interference Index, which was the composite score by the following equation: (CTT 2 time raw score minus CTT 1 time raw score) ÷ CTT 1 time raw score. The Interference Index is an approach to partial out the effects of sustained attention and perception tracking required in CTT 2.

Physical Related Assessments

Two physical related assessments, which were Global Physical Activity Questionnaire—Chinese Version (GPAQ-C, Appendix 3.6) and Queen's College step test (QCT), were conducted after the neuropsychological assessments.

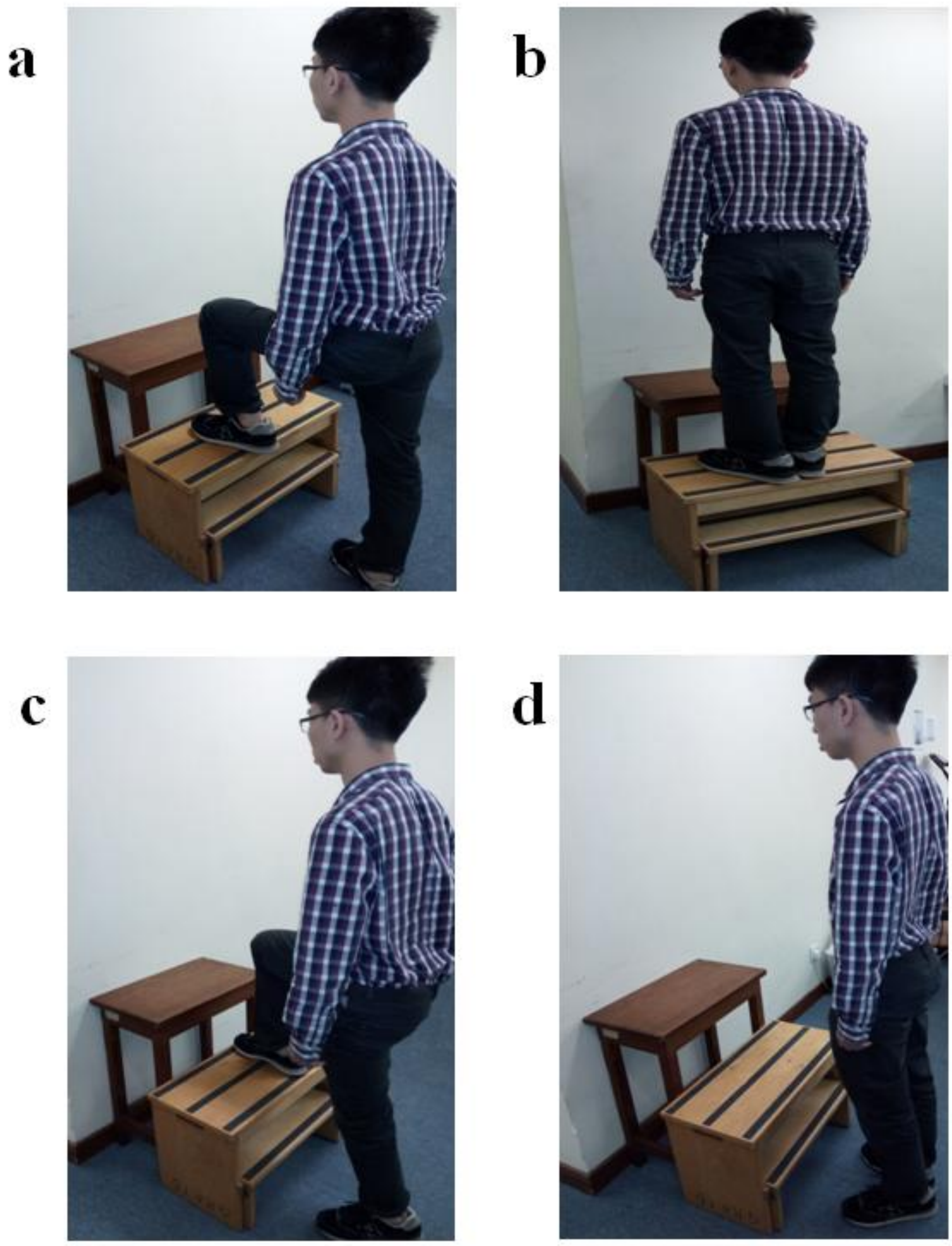
Global Physical Activity Questionnaire—Chinese Version (GPAQ-C)

The GPAQ-C (Armstrong & Bull, 2006) was a reliable and valid instrument used for the estimation of the amount of physical activity during a typical week. It consisted of 16 items that assess the frequency and duration of physical activity in a typical week (e.g., "In a typical week, on how many days do you do vigorous-intensity activities as part of your work?"). There were three subdomains, which were work, transportation, and recreation. The participant was asked to indicate how many days per week and how long per day s/he engaged in each activity listed in the questionnaire. The WHO stepwise approach (WHO, 2005) was the guideline for the scoring of GPAQ-C. High reliability (test-retest reliability: rho = 0.92~1.00) and validity (concurrent validity: rho = 0.60~0.81) for the GPAQ-C were reported in the previous study (Bull, Maslin, & Armstrong, 2009).

Queen's College Step Test (QCT)

QCT was employed for the evaluation of cardiorespiratory fitness in young adults (Chatterjee, Chatterjee, & Bandyopadhyay, 2005; Chatterjee, Chatterjee, Mukherjee, & Bandyopadhyay, 2004; McArdle, Katch, Pechar, Jacobson, & Ruck, 1972). The QCT was performed on a bench of 41 cm height in a sport laboratory for a total duration of three minutes. It adopted the standardized procedures established by McArdle et al. (1972). The cadences, which were 88 beats/min for females and 96 beats/min for males, were set by a metronome. The participant was required to follow the cadence and step up and down at the bench (Figure 3.2). After three minutes, s/he was asked to stop and stand for five s. Then the investigator recorded the pulse at the carotid artery for a period of 15 s. This 15-s pulse rate was converted into beats per minute, and the following equations were used to predict the participant's maximum oxygen uptake capacity (male: VO_{2max} [ml/kg/min] = 111.33−[0.426*pulse rate in beats/min] (Chatterjee et al., 2004); female: VO_{2max} [ml/kg/min] = 65.81−[0.1847*pulse rate in beats/min] (Chatterjee et al., 2005). The total time for QCT was around five minutes.

Figure 3.2. The illustration of the movement steps in QCT. Figure a and d show the sequence of stepping up and down in QCT.



Data Collection Procedure

At the beginning of the experiment, the participant was given an information sheet and the aims and procedures of the study were explained. The participant then completed an informed consent form and demographic information sheet that collected personal information, e.g., time spent on sports training per week, years of formal training experience, sports categories, and other expertise besides sports (Appendix 3.7). The participant also completed GPAQ-C for estimating the amount of physical activity. After that, the participant was seated on a comfortable chair in front of a computer monitor in an upright, relaxed position. A 15-inch CRT monitor for displaying the visual stimuli was placed at a distance of 65–75 cm. Before testing, the participant first learned the instructions of the cued task-switching paradigm and learned two types of response selection rules by 100 practice trials. The time course of the practice trial was the same as that in Figure 3.1. Then the participant performed in a testing session containing 50 trials and was required to reach 90% accuracy before the ERP experiment. The cued task-switching paradigm was instrumented using Neuroscan Stim2 software (NeuroScan Inc., Sterling, VA, USA). The participant was required to be relaxed, to minimize eye blinks, and to keep his/her eyes at the center of the monitor as much as possible. At the same time, the EEG signals were recorded by CURRY 7.07 (NeuroScan Inc., Sterling, VA, USA). The simple reaction task was conducted after the cued task-switching paradigm. After the simple reaction task, the participant completed the QCT and CTT. At last, the descriptive characteristics for the participant, which were height, weight, and Body Mass Index (BMI), were collected. The participant completed the whole experiment within half a day.

Data Analysis

Behavioral Data

Differences in demographic variables across groups (open-skilled, closed-skilled, and control) were tested using a one-way ANOVA. The work-related items in

GQAP-C, which estimated the amount of physical activity at work, were excluded from the analysis because all the participants were full-time students in a university without full-time work. Post-hoc pairwise comparisons with Bonferroni adjustments were applied for any significant main effect observed.

A two-way repeated-measures ANOVA was employed to analyze the behavioral data of the cued task-switching paradigm. The two-way ANOVA analysis included the within-subject factor: validity (100%, 75%, or 50%); and the between-subject factor: group (open-skilled, closed-skilled, or control group). The switch cost of response times (the difference in response time between switch and repeat trials) and the switch cost of error rates (the difference in error rate between switch and repeat trials) were the outcome variables. Reaction times were measured from the trials with correct responses only. The first trial for each block wasn't included in the data analysis. The Greenhouse-Geisser correction was applied when Mauchly's test of sphericity was violated. When significant main or interaction effects were found, post-hoc pairwise comparisons with the Bonferroni adjustment were conducted.

The group effect on the behavioral data of the simple reaction task and CTT was tested using one-way ANOVA. Post-hoc pairwise comparisons with Bonferroni adjustment were conducted when a significant group difference was found. The significance level was set at $p < 0.050$. Pearson's correlations were used to explore the relationships between the switch costs of response times and error rates and the scores on CTT (Interference Index).

BMI, VO2max, CTT (Interference Index), amount of physical activity, and training experiences were found to be significantly related with executive functions in previous studies (Batterink, Yokum, & Stice, 2010; Scisco et al., 2008; Wang et al., 2013). A hierarchical stepwise regression analysis was performed to test whether the results from the ANOVA were confounded by BMI, VO2max, CTT (Interference Index), the amount of physical activity for transportation, and the amount of physical activity for recreation and training experiences of open and closed skills. The amount of physical activity for work for each participant was excluded from the regression analysis. Before performing this regression model, a bivariate Pearson correlation was conducted to examine the correlations between the switch cost variables and all the covariate variables. The results of correlations revealed that three switch costs of response times rather than error rates were associated with the covariate variables. Thus, three hierarchical regression models for the switch costs of response times were conducted based on their correlations between the covariate variables. The switch cost of response time on each cue validity was the dependent variable in each regression model, while the basic factors (including BMI, VO_{2max}, CTT (Interference Index), amount of physical activity for transportation, and amount of physical activity for recreation) and the group factors (including training experiences of open and closed skills) were the independent variables. In this model, the basic factors were included in the first step, while the group factors were then included in the second step. Multicollinearity between independent variables was defined as the variance inflation factor (VIF) $\geq$ 10 and/or Pearson's correlation coefficient $\geq$ 0.85. The group factors were established based on the methods adopted by Wang et al. (2013). The control group was the reference category, and two group factors for training experiences of open or closed skills were established: (1) training experiences of open skills = years of training experiences in open-skilled sports, or 0 if none; and (2) training experiences of closed skills = years of training experiences in closed-skilled sports, or 0 if none.

EEG Data

The analysis for the ERP data was conducted at frontal, central and parietal sites, because the switching effects were maximal at the frontal, central and parietal except the Occipital site and the selection of these three sites (frontal, central and parietal sites) made reference to those employed in previous studies (Gajewski & Falkenstein, 2011; Hsieh & Wu, 2011; Li et al., 2012). Repeated measures ANOVA was conducted on each of the identified ERP components (cue-locked P3 at the cue phase for proactive control and stimulus-locked P3 at the target phase for reactive control). To test the differences of the mean amplitudes of the grand average ERP waveforms at the midline electrode sites for cue-locked P3 and stimulus-locked P3 components, the four-way repeated measures ANOVA model of cue validity (100%, 75% versus 50%) × trial type (repeat versus switch) × site (Fz, Cz versus Pz) × group (open, closed versus control) were used. In addition, to examine the hemispheric differences of the mean amplitudes of the grand average ERP waveforms for cue-locked P3 and stimulus-locked P3 components, the five-way repeated measures ANOVA model of cue validity (100%, 75% versus 50%) × trial type (repeat versus switch) × site (F3/4 C3/4 versus P3/4) × hemisphere (left versus right) × group (open, closed versus control) were used. The first trial of each block was excluded for the ERP data analysis. Post-hoc pairwise comparisons with Bonferroni adjustment were applied when significant main or interaction effects were observed. The significance level was set at $p < 0.050$. The Greenhouse-Geisser correction was used when Mauchly's test of sphericity was violated.

To test the differential correlations between cue-locked P3 and stimulus-locked P3 and the performance of the participants, a hierarchical stepwise regression analysis was performed to analyze the switch cost of response time on 100%, 75%, and 50% validity separately. In the analysis, the first step included regressors of the mean amplitude differences between switch- and repeat-trial types of cue-locked P3 (cP3S-cP3R) and that of stimulus-locked P3 (sP3S-sP3R) and two regressors indicating group identity (with the controls as the reference group). The second step further included two-way interaction terms between neural processes and group identity, i.e., cP3S-cP3R × open-skill, cP3S-cP3R × closed-skill, sP3S-sP3R × open-skill, and sP3S-sP3R × closed-skill. This regression model was based on the methods used by Dichter, van der Stelt, Boch, and Belger (2006). The variance inflation factor (VIF) ≥ 10 and Pearson's correlation ≥ 0.85 were used to determine multicollinearity between the independent variable with other independent variables for all hierarchical regression models. None of the variables demonstrated strong multicollinearity in this model. Due to the significant differences in the years for formal training experiences between open- and closed-skilled groups (showed in Table 4.1), partial correlation was applied to explore the relationships between sP3S-sP3R and task performance for open- and closed-skilled groups by adjusting the years for formal training experiences. All the analyses were conducted by using Predictive Analytics Software Statistics (PASW) Version 20.0 (IBM, Illinois, USA).

Chapter IV

Results

This chapter reports the results of this study. Firstly, the demographic data of the participants in the open-skilled, closed-skilled, and control groups were compared. Secondly, the behavioral results in the task-switching paradigm, simple reaction task, and CTT were completed across the three groups. Finally, the EEG data captured when participants performed on the cued task-switching paradigm were compared across the three groups.

Demographic Data

Table 4.1 summarizes the demographic data of the three groups of participants. There were no significant differences in age, height, and amount of physical activity for the transport subdomain ($P > 0.050$) across the closed-skilled, open-skilled, and control groups. Statistically significant differences were found among the three groups of participants in weight, BMI, years of formal training experiences, amount of physical activity for the recreation subdomain, amount of physical activity (total score), and VO_{2max} ($P < 0.050$).

Table 4.1. Demographic characteristics of participants in the open-skilled, open-skilled and control groups

	Open-skilled	Closed-skilled	Control	*F*-value	Post-hoc comparisons
Age, M (SD)	21.06 (2.18)	21.11 (2.02)	21.83 (2.07)	$F(2,51)=0.77$ $P=0.466$	
Weight kg, M (SD)	67.17 (11.56)	58.33 (9.40)	57.11 (10.15)	$F(2,51)=5.00$ $P=0.010$	open > closed open > control closed ≈ control
Height cm, M (SD)	170.33 (8.38)	169.89 (7.43)	165.06 (7.46)	$F(2,51)=2.55$ $P=0.088$	
BMI kg/m^2, M(SD)	22.94 (2.36)	20.11(1.97)	20.89 (2.63)	$F(2,51)=7.06$ $P=0.002$	open > closed open > control closed ≈ control
Years for formal training experiences, M(SD)	11.3 (2.7)	7.9 (1.6)	0	$F(2,51)=173.28$ $P<0.001$	open > closed open > control closed > control
Amount of physical Activity, transport kcal/week, M (SD)	1028.95 (188.50)	973.15 (210.36)	946.87 (208.45)	$F(2,51)=0.77$ $P=0.468$	
Amount of physical Activity, recreation kcal/week /week, M (SD)	5077.34 (1328.13)	4927.91 (1379.73)	733.50 (673.63)	$F(2,51)=79.67$ $P<0.001$	open ≈ closed open > control closed > control
Amount of physical Activity, total score kcal/week, M (SD)	6106.30 (1400.45)	5901.06 (1432.41)	1680.37 (749.49)	$F(2,51)=73.67$, $P<0.001$	open ≈ closed open > control closed > control
VO_{2max} mL*kg^{-1}*min^{-1}, M(SD)	54.92 (9.28)	55.04 (10.24)	47.44 (10.42)	$F(2,51)=3.42$ $P=0.040$	open ≈ closed open > control closed > control

Note: M (SD) denotes mean (standard deviations); ≈ denotes no difference between two groups; > denotes that the group at the left side is larger than that at the right side

Behavioral Data

Task-Switching Paradigm

Switch Cost of Response Time

The validity and group effects on the switch cost of response time were statistically significant, $F(2, 102) = 10.60$, $P < 0.001$, *partial eta*$^2 = 0.172$; $F(2, 51) = 8.86$, $P < 0.001$, *partial eta*$^2 = 0.258$, respectively (Table 4.2). The validity × group effects were marginally significant, $F(4, 102) = 2.43$, $P = 0.053$, *partial eta*$^2 = 0.087$. In trials with 50% validity, there was no significant difference in the switch cost of response time between the open- and closed-skilled group ($P = 0.473$); however, the open-skilled group ($P < 0.001$) and closed-skilled group ($P = 0.033$) had significantly less switch cost of response time than the control group. In the 100% validity trials, the switch cost of response time of open-skilled group was significantly lower than those of the closed-skilled group ($P = 0.023$) and the control group ($P < 0.001$). However, the differences were less clear cut in the 75% validity trials. The open-skilled group showed only a marginally significantly less switch cost of response time than the control group ($P = 0.069$) and showed no significant difference with the closed-skilled group ($P = 0.520$). The results from the 100% and 50% conditions suggested that participants with open skills performed better on proactive control of task switching than those with closed skills. Participants with open- and closed-skills, however, showed comparable performances on reactive control for task switching and better performances than the control participants.

Table 4.2. Three groups of participants' switch cost of response times and response time for repeat and switch trials in the cued task-switching paradigm for each validity condition

Conditions		Open-skilled		Closed-skilled		Control	
		Original-RT(ms)	Switch cost RT(ms)	Original-RT(ms)	Switch cost RT(ms)	Original-RT(ms)	Switch cost RT(ms)
		mean (95% CI)	mean (95% CI)	mean (95% CI)	mean (95% CI)	Mean (95% CI)	mean (95% CI)
100 %	repeat	514.75 (459.24, 570.26)	46.24 (29.99, 62.52)	563.90 (508.39, 619.42)	78.13 (61.87, 94.40)	703.52 (648.01, 759.03)	94.85 (78.59, 111.12)
	switch	560.63 (497.82, 623.45)		642.04 (579.23, 704.85)		798.37 (735.56, 861.18)	
75%	repeat	607.23 (549.18, 665.18)	64.24 (46.50, 82.06)	665.85 (607.85, 723.85)	81.57 (63.79, 99.36)	790.77 (732.77, 848.76)	93.62 (75.83, 111.40)
	switch	670.80 (606.20, 735.35)		747.42 (682.84, 811.99)		884.38 (819.81, 948.96)	
50%	repeat	658.41 (605.38, 711.44)	67.69 (46.15, 89.24)	708.23 (655.21, 761.26)	89.46 (67.91, 111.01)	801.18 (748.15, 854.21)	129.55 (108.01, 151.10)
	switch	725.76 (684.51, 808.27)		797.13 (732.71, 862.67)		930.73 (865.75, 995.71)	

Note: Switch cost of response time=response time of switch trials –response time of repeat trials; RT denotes response time; 95% CI denotes 95% confidence interval; 100% denotes 100% valid cue; 75% denotes 75% valid cue; 50% denotes 50% valid cue

Switch Cost of Error Rate

The validity and group effects on switch cost of error rate were not statistically significant [$F(1.64, 83.85) = 0.14$, $P = 0.830$, *partial eta*^{2}=0.003; $F(2, 51) = 0.63$, $P = 0.535$, *partial eta*^{2} = 0.024, respectively (Table 4.3)]. The validity × group effects were not significant [$F(3.29, 83.85) = 1.57$, $P = 0.198$, *partial eta*^{2} = 0.058].

Table 4.3. Three groups of participants' switch cost of error rates and accuracy rates of repeat and switch trials in the cued task-switching paradigm for each validity condition

Conditions		Open-skilled		Closed-skilled		Control	
		Original-ACC(%)	Switch cost ER(%)	Original-ACC(%)	Switch cost ER(%)	Original-ACC(%)	Switch cost ER(%)
		mean (95% CI)	mean (95% CI)	mean (95% CI)	mean (95% CI)	Mean (95% CI)	mean (95% CI)
100%	repeat	97.37 (96.03,98.71)	3.84 (2.50, 5.17)	96.29 (94.95,97.63)	4.33 (3.00, 5.67)	97.77 (96.43,99.11)	4.06 (2.73, 5.40)
	switch	93.56 (91.17,95.96)		91.95 (89.55,94.35)		93.71 (91.31,96.11)	
75%	repeat	96.53 (95.38,97.69)	3.37 (1.45, 5.28)	96.44 (95.28,97.60)	5.21 (3.29, 7.12)	97.61 (96.45,98.76)	3.18 (1.26, 5.09)
	switch	93.18 (90.57,95.79)		91.40 (88.79,94.01)		94.43 (91.82,97.04)	
50%	repeat	95.94 (94.20,97.68)	4.66 (2.70, 6.61)	94.80 (93.06,96.54)	4.00 (2.00, 5.91)	97.44 (95.69,99.18)	2.84 (0.88, 4.79)
	switch	91.30 (88.35,94.25)		91.12 (88.17,94.07)		94.60 (91.65,97.55)	

Note: Switch cost of error rate = error rate of switch trials – error rate of repeat trials;
ER denotes error rate; ACC denotes accuracy rate; Error rate = 1 – accuracy rate; 95% CI denotes 95% confidence interval
100% denotes 100% valid cue; 75% denotes 75% valid cue; 50% denotes 50% valid cue.

Color Trails Test (CTT)

Error Rates, Completion Times, and Interference Index

The group effects on the error rates of number sequence in CTT 1 and CTT 2, the error rate of color sequence in CTT 2, and the completion time of CTT 1 were not statistically significant (P > 0.050) (Table 4.4). The group effects on the completion time of CTT 2 and Interference Index were statistically significant [F(2,51) = 1.01, P = 6.009, *partial eta*^{2} = 0.005; F(2,51) = 0.06, P = 6.025, *partial eta*^{2} = 0.004, respectively]. Both the open- and closed-skilled groups (P = 0.047 and

P = 0.005, respectively) had faster completion time of CTT 2 than the control group. But no significant difference in the completion time of CTT 2 between open- and closed-skilled groups ($P = 0.999$). For Interference Index, the open and closed-skilled groups ($P = 0.039$ and $P = 0.005$, respectively) had lower index values than the control groups. However, no statistical differences were found in the index values between the open- and closed-skilled groups ($P = 0.999$). Lower index values suggested that participants had better performances on the CTT and hence shifting the function.

Relationships between CTT and Switch Cost Variables

The switch cost of the response time for each of the validity conditions were moderately and positively related with the interference index of CTT ($0.455 < r < 0.677$, $P < 0.010$) (Table 4.5). Switch cost of response time for 100% and 50% validity conditions ($r = 0.373$, $P < 0.010$; $r = 0.491$, $P < 0.001$, respectively) were moderately and positively related with the completion time of CTT 2.

Table 4.4. Participants' error rates, completion times, and interference index of CTT by three groups

Group	Open skilled	Closed skilled	Control	*df*	*F*-value	*P*-value	*partial eta*^{2}
Error rate of number sequence in CTT 1 (%)	0.20 ±0.90	0.00 ±0.00	0.00 ±0.00	2,51	1.00	0.375	0.038
Error rate of number sequence in CTT 2 (%)	0.00 ±0.00	0.00 ±0.00	0.00 ±0.00	2,51	_	_	_
Error rate of color sequence in CTT 2 (%)	0.20 ±0.90	0.70 ±1.50	0.00 ±0.00	2,51	1.92	0.157	0.070
Completion time of CTT 1 (s)	25.11 ±6.63	24.76 ±6.01	26.27 ±6.87	2,51	0.27	0.768	0.010
Completion time of CTT 2 (s)	47.89 ±13.53	43.93 ±11.10	59.73 ±17.34	2,51	6.01	0.005**	0.191
Interference index	0.92 ±0.33	0.83 ±0.43	1.30 ±0.54	2,51	6.03	0.004**	0.191

Note: ** denotes <0.01; CTT denotes color trails test; *df* denotes degree of freedom

The error rate of number sequence in CTT 2 was zero for three groups, so the *F*-value could not be calculated.

Table 4.5. Correlation analysis for the error rates, completion times, and interference index of CTT, and all switch cost variables.

Variables	1	2	3	4	5	6	7	8	9	10	11
1. Error rate of number sequence in CTT 1	-										
2. Error rate of color sequence in CTT 2	-.039	-									
3. Completion time of CTT 1	.053	-.336*	-								
4. Completion time of CTT 2	.105	-.260	.642**	-							
5. Interference index	.070	.034	-.252	.527**	-						
6. Switch cost of RT with 100% valid cue	-.031	.088	-.159	.373**	.651**	-					
7. Switch cost of RT with 75% valid cue	-.023	.264	-.148	.223	.430**	.746**	-				
8. Switch cost of RT with 50% valid cue	-.104	.148	-.007	.491**	.635**	.612**	.463**	-			
9. Switch cost of ER with 100% valid cue	.058	.294*	-.126	.189	.363**	.433**	.440**	.459**	-		
10. Switch cost of ER with 75% valid cue	.197	.451**	-.180	-.069	.136	.189	.150	.228	.643**	-	
11. Switch cost of ER with 50% valid cue	-.121	.077	-.179	-.139	-.009	-.024	-.109	.250	.569**	.399**	-

Note: * denotes <0.05; ** denotes <0.01; CTT denotes color trails test; RT denotes response time; ER denotes error rate

The error rate of number sequence in CTT 2 was excluded out of the correlation analysis, because this variable was zero for three groups.

Possible Confounding Effect

The correlations between switch cost variables with the BMI, VO_{2max}, CTT (Interference Index), the amount of physical activity for transportation and the amount of physical activity for recreation, and training experiences of open and closed skills are shown in Table 4.5 and Table 4.6.

A hierarchical stepwise regression analysis was performed to tease out the possibility of covariate factors confounding the results on the switch cost of reaction times. The results of the hierarchical stepwise regression analysis were showed in Table 4.7. The first step of the regression model for the switch cost of the response time with 100% valid cue was significant, $R^2 = 0.216$, $F(1, 53) = 7.03$, $P = 0.002$. CTT (Interference Index) ($\beta = 0.288$, $P = 0.025$) and the amount of physical activity for recreation ($\beta = -0.388$, $P = 0.003$) were significant predictors, suggesting CTT (Interference Index) and the amount of physical activity for recreation were associated with the switch cost of the response time in the 100% validity condition. However, other basic factors (e.g., BMI, VO_{2max}, and the amount of physical activity for transportation) did not show significant impacts in the model. In addition, the second step of this regression model was also significant, $R^2 = 0.295$, $F(3, 53) = 6.98$, $P = 0.001$, and showed a significant change to the model, $\triangle R^2 = 0.079$, $F(1, 50) = 5.61$, $P = 0.022$. Only training experience of open-skill showed significant impact in the second step ($\beta = -0.323$, $P = 0.022$), which suggested that the training experience of the open-skill group was the most important predictor for switch cost of response time in the 100% validity condition.

Table 4.6. Correlation analysis for BMI, VO_{2max}, training experience, the amount of physical activity and group factors, and all switch-cost variables

Variables	1	2	3	4	5	6	7	8	9	10	11	12
1. BMI	-											
2. VO_{2max}	.189	-										
3. Physical activity GPAQ transportation score	.463**	.260	-									
4. Physical activity GPAQ recreation score	.285*	.485**	.227	-								
5. Training experiences of open skills	.422**	.180	.203	.465**	-							
6. Training experiences of closed skills	-.345*	.192	.002	.384**	-.465**	-						
7. Switch cost of RT with 100% valid cue	-.217	-.127	-.065	-.366**	-.461**	.114	-					
8. Switch cost of RT with 75% valid cue	-.134	-.182	-.148	-.280*	-.261	.007	.746**	-				
9. Switch cost of RT with 50% valid cue	-.126	-.285*	.001	-.401**	-.398**	-.141	.612**	.463**	-			
10. Switch cost of ER with 100% valid cue	.209	-.005	.233	.013	-.092	.064	.433**	.440**	.459**	-		
11. Switch cost of ER with 75% valid cue	.180	-.082	.255	.150	-.090	.239	.189	.150	.228	.643**	-	
12. Switch cost of ER with 50% valid cue	.176	.098	.263	.247	.050	.043	-.024	-.109	.250	.569**	.399**	-

Note: * denotes <0.05; ** denotes <0.01; GPAQ denotes global physical activity questionnaire; RT denotes response time; ER denotes error rate

Table 4.7. Results of hierarchical stepwise regression analysis on switch cost of response time

	100% Validity	75% Validity	50% Validity
	Step 1	Step 1	Step 1
	Basic factors	Basic factors	Basic factors
BMI	-.123	-.039	-.098
VO_{2max}	.066	-.038	-.128
CTT (Interference Index)	.288*	.090	.197
Amount of physical activity, transportation	.019	-.075	.140
Amount of physical activity, recreation	-.388**	-.241	-.357*
R^2	.216	.096	.226
Adjusted R^2	.185	.001	.145
F	7.03**	1.02	2.80*

	Step 2	Step 2	Step 2
	Group factors	Group factors	Group factors
BMI	-.070	-.001	-.193
VO_{2max}	.061	-.053	-.164
CTT (Interference Index)	.236[a]	.057	.145
Amount of physical activity, transportation	.032	-.070	.206
Amount of physical activity, recreation	-.234	-.130	.245
Training experiences of open skill	-.323**	-.195	-.712**
Training experiences of closed skill	-.003	.056	-.616*
R^2	.295	.112	.368
Adjusted R^2	.253	-.023	.272
F	6.98**	.83	3.83**
$\triangle R^2$	.079	.016	.143
$\triangle F$	5.61*	.42	5.20**

Note: * denotes <0.05; ** denotes <0.01; a denotes 0.057

RT denotes response time

100% denotes 100% valid cue; 75% denotes 75% valid cue; 50% denotes 50% valid cue;

Entries represent standardized regression coefficients (β).

No significant factors could be found in the regression model for the switch cost of response time in the 75% validity condition, which suggested that the switch cost of response time with the 75% valid cue could not be predicted by demographic factors, physiological factors, and group factors.

In the 50% validity condition, the first step of the regression model was significant, $R^2 = 0.226$, $F(5, 53) = 2.80$, $P = 0.027$. Only the amount of physical activity for recreation showed a significant impact, $\beta = -0.357$, $P = 0.021$, which suggested that the amount of physical activity during leisure time was most associated with the switch cost of response time with the 50% valid cue, compared with other basic factors (e.g., BMI, VO_{2max}, and the amount of physical activity for transportation). In addition, the second step of this regression model was also significant, $R^2 = 0.368$, $F(7, 53) = 3.83$, $P = 0.002$, and showed a significant change to the model, $\triangle R^2 = 0.143$, $F(2,46) = 5.20$, $P = 0.009$. Both the training experiences of open- and closed-skills rather than the basic factors were the significant predictors ($\beta = -0.712$, $P = 0.002$; $\beta = -0.616$, $P = 0.011$, respectively). These results indicated that both experiences of open and closed skills were the most important predictors for the switch cost of response time in the 50% validity condition.

Simple Reaction Task

The group effects on the response time and accuracy rates for the simple reaction task were not statistically significant, $F(2,51) = 1.01$, $P = 0.372$, *partial eta*^{2} = 0.038; $F(2,51) = 0.06$, $P = 0.940$, *partial eta*^{2} = 0.002, respectively (Table 4.8).

Table 4.8. Participants' response times and accuracy rates (mean ± SD) of simple reaction task by three groups

Group	Response time (ms)	Accuracy rate (%)
Open skilled	220.11±47.11	99.04±1.17
Closed skilled	224.63±45.50	98.98±1.08
Control	240.70±45.37	99.12±1.23

Electrophysiological Data

An independent component analysis (ICA), decomposing ERP signals into spatial fixed and temporal independent components (Table 4.9), helps confirm the time windows for: 1) cue-locked P3 (350-550 ms), which is associated with anticipatory updating the task goal and task rules in proactive control, 2) stimulus-locked P3 (300-600 ms), which is associated to updating the task after the onset of a target stimulus in a reactive control. Below are the results of the 4-way repeated measure ANOVA conducted to test the effects of group (open skilled, closed skilled, and control), site (Fz, Cz, and Pz), validity (100%, 75%, and 50%), and trial type (repeat and switch) on the amplitudes of the cue-locked P3 and stimulus-locked P3.

Table 4.9. The time windows identified by ICA for cue- and stimulus-locked P3 in each condition. Table a is for cue-locked P3; Table b is for stimulus-locked P3

a

		Open (ms)	Closed (ms)	Control (ms)
Cue-locked P3	100% repeat	320-500	320-550	320-550
	100% switch	320-550	320-580	320-580
	75% repeat	320-600	280-600	280-600
	75% switch	320-600	280-600	280-600
	50%	270-600	270-600	270-600

b

		Open(ms)	Closed(ms)	Control(ms)
Stimulus-locked P3	100% repeat	280-550	278-610	278-610
	100% switch	280-550	300-700	300-700
	75% repeat	250-600	261-700	261-700
	75% switch	250-600	262-700	262-700
	50% repeat	236-700	229-650	229-650
	50% switch	200-610	224-630	224-630

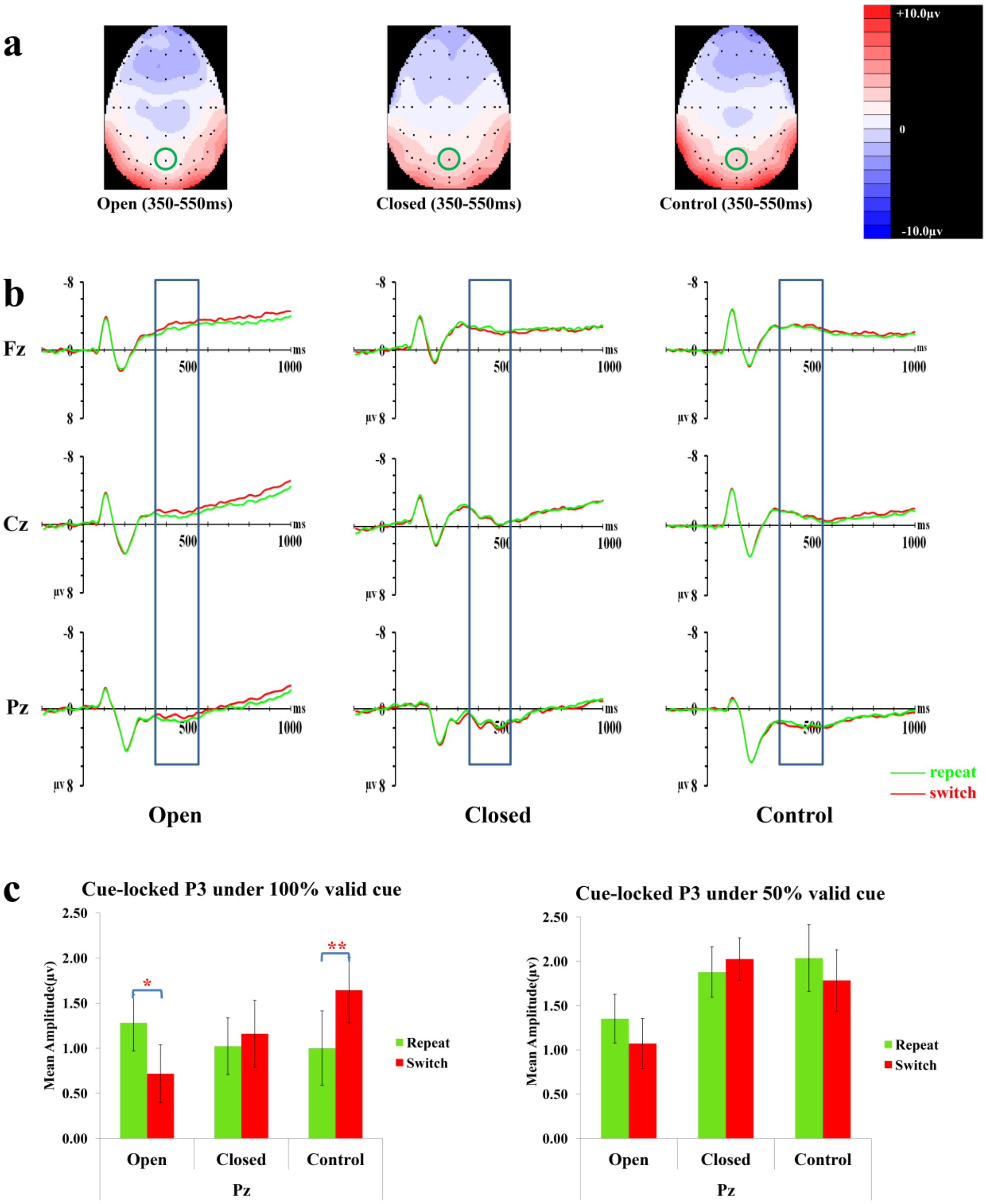
Cue-Locked P3 for Proactive Control (350-550 ms)

The topographic maps of the cue-locked P3 for participants in the open-skilled, closed-skilled, and control groups are shown in Figure 4.1a. The cue-locked ERP waveforms were derived from Fz, Cz, and Pz separately for the repeat and switch trials (Figure 4.1b). It was hypothesized that when the cue was predictive (i.e., 100% validity trials), less positive difference of the cue-locked P3 at parietal region between switch and repeat trials was elicited by open-skilled participants, whereas more positive difference of cue-locked P3 between switch and repeat trials was for control and closed-skilled participants.

The validity [$F(2, 102) = 13.00$, $P < 0.001$, *partial* $eta^2 = 0.203$] and site effects [$F(1.486,75.773) = 174.66$, $P < 0.001$, *partial* $eta^2 = 0.774$] on the amplitudes of the cue-locked P3 were significant. The trial type [$F(1, 51) = 0.76$, $P = 0.387$, *partial* $eta^2 = 0.015$] and group effects [$F(1, 51) = 0.16$, $P = 0.856$, *partial* $eta^2 = 0.006$] were not significant. The validity × trial type × site × group effects [$F(6.367, 162.350) = 2.28$, $P = 0.035$, *partial* $eta^2 = 0.082$] were significant. Post-hoc analysis was conducted on trial type × site × group effects for each of the three validity conditions. The results showed significant three-way interaction effects only on the 100% validity condition [$F(3.351,85.442) = 5.46$, $P = 0.001$, *partial* $eta^2 = 0.177$], but not on the 75% [$F(2.752,70.179) = 1.11$, $P = 0.348$, *partial* $eta^2 = 0.042$] and 50% validity condition [$F(3.249,82.856) = 0.13$, $P = 0.952$, *partial* $eta^2 = 0.005$]. Hence, the trial type × site effects were further tested for the 100% validity condition for each of Fz, Cz, and Pz. Significant trial type × group effects were revealed at Fz [$F(2,51) = 6.82$, $P = 0.002$, *partial* $eta^2 = 0.211$] and Pz [$F(2,51) = 8.03$, $P = 0.001$, *partial* $eta^2 = 0.239$], but not at Cz [$F(2,51) = 1.32$, $P = 0.28$, *partial* $eta^2 = 0.049$]. At the Fz site, the open-skilled group showed marginally less positive-going cue-locked P3 in the switch than in the repeat trials ($P = 0.056$). The closed-skilled group, however, had significantly more positive-going cue-locked P3 at Fz in the switch than repeat trials ($P = 0.003$). The control group did not show significant between-trial differences in the cue-locked P3 amplitudes at Fz ($P = 0.822$). At the Pz site, the open-skilled group showed a less positive-going cue-locked P3 in the switch than repeat trials ($P = 0.011$). The closed-skilled group, however, did not show significant between-trial differences in the amplitudes of the cue-locked P3 at Pz ($P = 0.523$). The control group showed an opposite trend to the open-skilled group that the amplitude of the cue-locked P3 was more positive-going at Pz in the switch than in the repeat trials ($P = 0.004$) (Figure 4.1c).

In summary, the between-trial differences in cue-locked P3 were found in the parietal region for the open-skilled group but not the closed-skilled group. This only occurred in the 100% validity condition. The cue-locked P3 in the task-switching paradigm was related to updating the new action rule in a proactive control. The results suggested that in the 100% validity condition the open-skilled participants appeared to deploy less switch-related attentional resources to update the action rule when the cue indicated switching to a new task during proactive control. In contrast, the closed-skilled participants appeared to deploy comparable attentional resources between the two types of trials, whilst the control participants appeared to deploy more switch-related attentional resources. Similar effects were revealed in the frontal region despite the effect having tended to be less robust.

Figure 4.1. The cue-locked P3 component in the proactive control. ***4.1a***, the topographical distributions of cue-locked P3 with a time window (350–550ms) during the cue phase in open-skilled, closed-skilled, and control groups. The green circle indicates the Pz site. ***4.1b***, the grand average cue-locked ERP waveforms of repeat (green) and switch (red) trial types extracted from Fz, Cz, and Pz in each group. The blue squares indicate the time window of extracting the cue-locked P3 component. In ***4.1c***, the **left panel** shows the comparisons of the mean amplitudes of cue-locked P3 between repeat and switch trial-types at Pz among three groups in the 100% validity condition; the **right panel** displays the mean amplitudes of cue-locked P3 between repeat and switch trial-types at Pz among three groups in the 50% validity condition.



Error bars indicate SEM ; * denotes $p < 0.050$; ** denotes $p < 0.010$

Stimulus-Locked P3 for Reactive Control (300–600 ms)

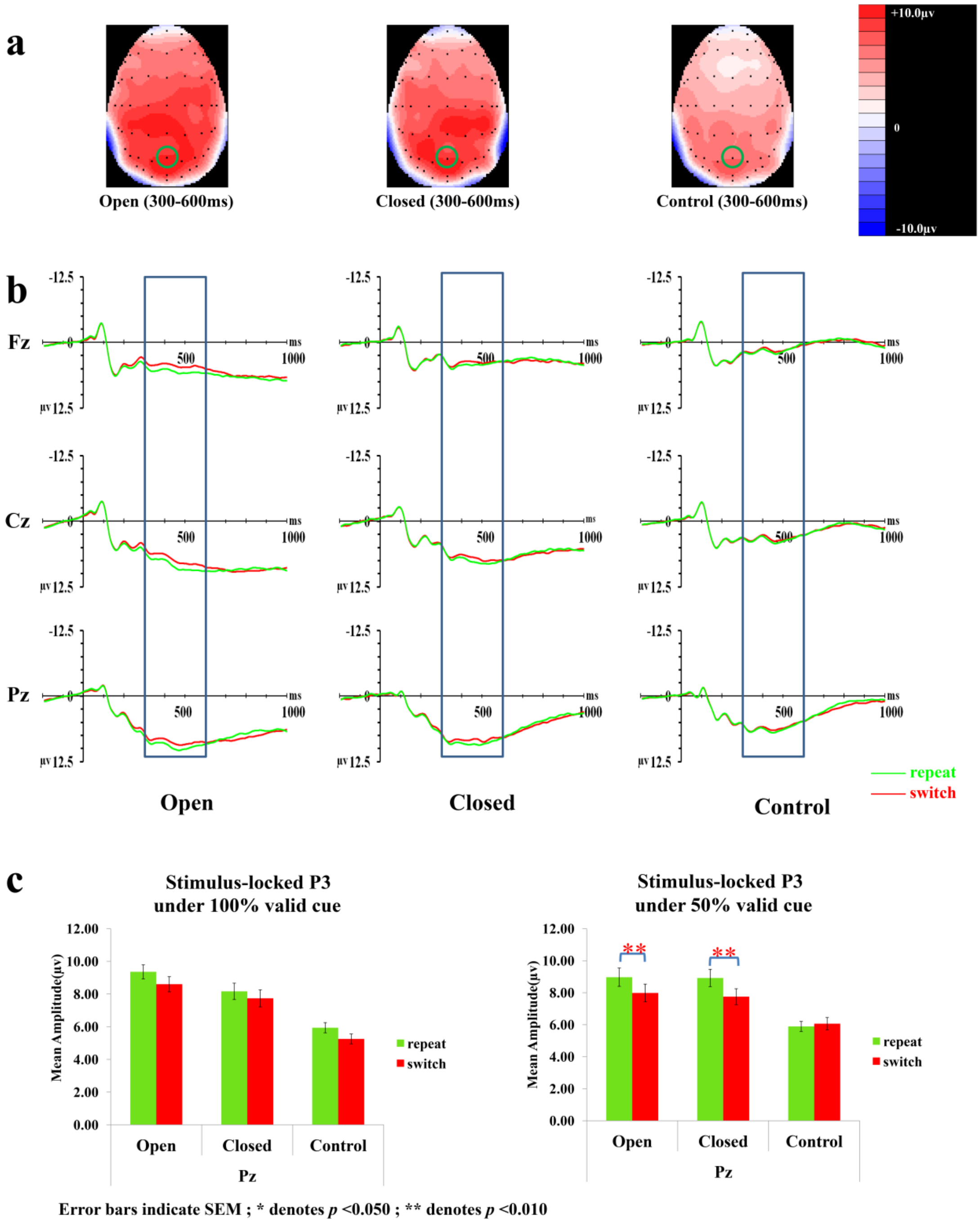
A cue-locked P3 is an important component in proactive control before the presentation of a response-demanding target stimulus. In contrast, after the onset of target stimulus, stimulus-locked P3 was linked to the updating of action selection rules in reactive control. The topographic maps of the stimulus-locked P3 in the open-skilled, closed-skilled, and control groups are shown in Figure 4.2a. The stimulus-locked ERP waveforms were derived from Fz, Cz, and Pz separately for the repeat and switch trials (Figure 4.2b). It was hypothesized that when the cue was non-predictive such as in the 50% validity condition, the open- and closed-skilled groups would show less positive-going differences in the amplitudes of the stimulus-locked P3 at the parietal region between the switch and repeat trials. In contrast, the control group would show relatively more positive-going differences in the amplitudes of the stimulus-locked P3 between the two types of trials.

The group [$F(2, 51) = 5.91$, $P = 0.005$, *partial eta*$^2 = 0.188$], site [$F(1.475, 75.225) = 53.31$, $P < 0.001$, *partial eta*$^2 = 0.511$], and trial type [$F(1, 51) = 28.29$, $P < 0.001$, *partial eta*$^2 = 0.357$] effects were all significant, except the validity effect, which was marginally significant [$F(2, 102) = 5.11$, $P = 0.080$, *partial eta*$^2 = 0.091$] in the 4-way repeated measure ANOVA. The validity × trial type × site × group effects [F (5.691, 145.128) = 2.37, $P = 0.035$, *partial eta*$^2 = 0.085$] were significant. Post-hoc analysis on the trial-type × site × group effects was conducted for each of the three validity conditions. The three-way interaction effects were significant in the 50% validity condition [$F(3.234, 82.479) = 3.30$, $P = 0.022$, *partial eta*$^2 = 0.115$] (Figure 4.2c), but not in the 100% [$F(2.819,71.888) = 2.50$, $P = 0.118$, *partial eta*$^2 = 0.075$] and 75% validity condition [$F(2.903,74.022) = 0.80$, $P = 0.495$, *partial eta*$^2 = 0.030$]. Interestingly, these results were different from those found in cue-locked P3, in which the three-way interaction effects were significant in 100% validity trials instead.

This was followed by testing the trial type × group effects for trials in the 50% validity condition for each of the Fz, Cz, and Pz. The trial type × group effects were significant at the Cz and Pz [$F(2,51) = 3.52$, $P = 0.037$, *partial eta*$^2 = 0.121$; $F(2,51) = 4.14$, $P = 0.021$, *partial eta*$^2 = 0.140$, respectively], but not at the Fz [$F(2,51) = 2.02$, $P = 0.143$, *partial eta*$^2 = 0.073$]. Further post-hoc analyses revealed that in the 50% validity condition the amplitude of the stimulus-locked P3 was significantly less positive-going at Pz in the switch than in the repeat trials for the open-skilled ($P = 0.008$) and closed-skilled groups ($P = 0.002$). No significant differences were found in the stimulus-locked P3 amplitudes at Pz between the switch and repeat trials in the control group ($P = 0.630$) (Figure 4.2c). Similar to the results obtained in Pz, the stimulus-locked P3 amplitudes were significantly less positive-going at Cz in the switch than in the repeat trials in the open-skilled ($P < 0.001$) and closed-skilled ($P = 0.038$) groups; whereas no between-trial differences were revealed in the control group ($P = 0.838$).

Overall, in the 50% validity condition, open- and closed-skilled groups showed similar results on the stimulus-locked P3 amplitudes in the parietal region, of which they were differed from the control group. A similar, yet less robust effect, was also found in the central region. Stimulus-locked P3 in the task-switching paradigm was related to the updating of the new action rule in reactive control. The findings suggested that in the reactive control both the open- and closed-skilled participants appeared to deploy less attentional resources for updating the new action rule, whereas those in the control group deployed comparable attentional resources between the switch and repeat trials.

Figure 4.2. The stimulus-locked P3 component in the reactive control. ***4.2a***, the topographical distributions of stimulus-locked P3 with a time window (300–600 ms) during the target phase in open-skilled, closed-skilled, and control groups. The green circle indicates the Pz site. ***4.2b***, the grand average stimulus-locked ERP waveforms of repeat (green) and switch (red) trial types extracted from Fz, Cz, and Pz in each group. The blue squares indicate the time window of extracting the stimulus-locked P3 component. In ***4.2c***, the L**eft panel** displays the mean amplitudes of stimulus-locked P3 between repeat and switch trial types at Pz among three groups when the cue was 100% valid; the **right panel** shows the comparisons of the mean amplitudes of stimulus-locked P3 between repeat and switch trial-types at Pz among three groups when the cue was 50% valid.



a
Open (300-600ms)
Closed (300-600ms)
Control (300-600ms)
+10.0µv
0
-10.0µv
b
Fz
Cz
Pz
-12.5
0
µv 12.5
ms
500
1000
repeat
switch
Open
Closed
Control
c
Stimulus-locked P3
under 100% valid cue
Stimulus-locked P3
under 50% valid cue
Mean Amplitude(µv)
12.00
10.00
8.00
6.00
4.00
2.00
0.00
Open
Closed
Control
Pz
**
**
repeat
switch
Error bars indicate SEM ; * denotes p <0.050 ; ** denotes p <0.010

ERP Data—Correlations between P3 in Proactive and Reactive Controls and Task Performance

A hierarchical-stepwise-regression analysis was conducted to test the differential correlations between the cue-locked and stimulus-locked P3 and the performance on task switching across the three groups (Table 4.10). The first step of the model included four regressors for predicting the switch cost of response time. The regressors were: differences of mean amplitudes between switch and repeat trial-types of cue-locked P3 ($cP3_S$_$cP3_R$), differences of mean amplitudes between switch and repeat trial-types of stimulus-locked P3 ($sP3_S$_$sP3_R$), and two regressors indicating group-identity-training categories of open or closed skills. The second step of the model included the two-way interaction factors between neural processes and group identity, which are $cP3_S$_$cP3_R$ × open skill, $cP3_S$_$cP3_R$ × closed skill, $sP3_S$_$sP3_R$ × open skill, and $sP3_S$_$sP3_R$ × closed skill. The same analysis was performed for each of the 100%, 75%, and 50% validity conditions.

In the 100% validity condition, the first step of the regression model for the switch cost of response time was significant, $R^2 = 0.226$, $F(4,49) = 3.58$, $P = 0.012$. Only the training category of open skill showed a significant impact ($\beta = -0.573$, $P = 0.001$). However, other variables (i.e., $cP3_S$_$cP3_R$ and $sP3_S$_$sP3_R$, training category of closed skill) were not significant predictors for the model ($|\beta| < 0.285$, $P > 0.057$). The second step showed a significant change in the variance explained ($\triangle R^2 = .182$, $F(4, 45) = 3.46$, $P = 0.015$). The effect of $cP3_S$_$cP3_R$ × open skill was significant ($\beta = 0.475$, $P = 0.007$), whereas the effects of $cP3_S$_$cP3_R$ ($\beta = -0.431$, $P = 0.072$) and $cP3_S$_$cP3_R$ × closed skill ($\beta = 0.247$, $P = 0.205$) were not significant (Figure 4.3a). These suggested that the magnitude of $cP3_S$_$cP3_R$, which was associated with proactive control, was only related to the performance in the open-skilled participants, but not in the closed-skilled and control participants.

In the 75% validity condition, the first step was significant, R^2 = 0.255, F(4, 49) =4.20, P=0.005. Both $cP3_S$-$cP3_R$ (β = 0.320, P = 0.023) and $sP3_S$-$sP3_R$ (β = -0.378, P = 0.004) showed significant impact, but other variables (training categories of open- and closed-skills) were not significant predictors, which indicated that $cP3_S$_$cP3_R$ and $sP3_S$-$sP3_R$ regardless of any training category were related to switch cost of response time under the cue with 75% validity. However, there were no significant factors in the second step of the regression model (R^2 = 0.277, F(8,45) =2.15, P = 0.050) (Figure 4.3b).

In the 50% validity condition, the first step was significant, R^2 = 0.211, F(4, 49) = 2.78, P = 0.037. Both the training categories of open and closed skills showed significant impacts (β = -0.474, P = 0.003; β = -0.397, P = 0.012), but $cP3_S$–$cP3_R$ and $sP3_S$–$sP3_R$ were not significant predictors. Moreover, the second step showed a significant change in the variance explained, △ R^2 = 0.157, F(4,45) = 3.057, P = 0.043). $sP3_S$–$sP3_R$ (β = -0.550, P = 0.020), the training category of open skill (β = -0.363, P = 0.031), the training category of closed skill (β = -0.347, P = 0.023), $sP3_S$–$sP3_R$ × open skill (β = 0.464, P = 0.022), and $sP3_S$–$sP3_R$ × closed skill (β = 0.519, P = 0.012) were the significant predictors, suggesting that in the 50% validity condition the correlations between $sP3_S$–$sP3_R$ and switch cost of response time in the open- and closed-skilled participants significantly differed from that of the control participants. A follow-up analysis suggested that such correlation was significant and negative in value in the control group (r = -0.534, P = 0.022) (Figure 4.3c). However, the results of partial correlation showed no significant partial correlations in the open-skilled (partial r = 0.266, P = 0.303) and closed-skilled groups (partial r = 0.256, P = 0.321) by adjusting the years for formal training experiences.

Table 4.10. Summary of results of hierarchical-stepwise regression predicting the switch cost of response times of three cue validity

	100% Validity	75% Validity	50% Validity
	Step 1	Step 1	Step 1
	Standardized regression coefficients (β)	Standardized regression coefficients (β)	Standardized regression coefficients (β)
$cP3_S\_cP3_R$	-.075	.320*	-.008
$sP3_S\_sP3_R$	.029	-.378**	-.062
Training category of open skill	-.573**	-.139	-.474*
Training category of closed skill	-.284	-.051	-.397**
R^2	.226	.255	.185
Adjusted R^2	.163	.195	.119
F	3.579*	4.203**	2.782*

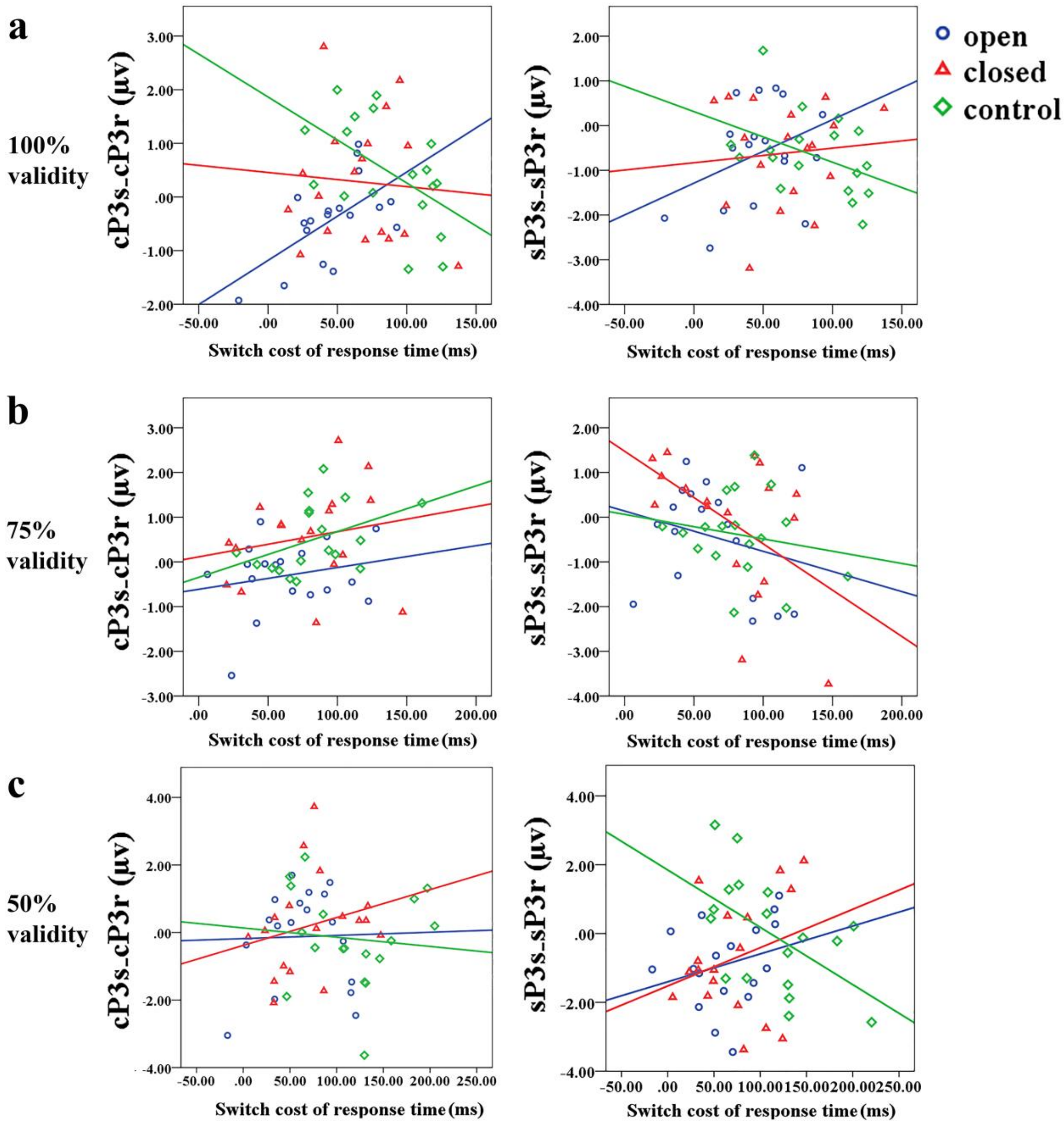
	Step 2	Step 2	Step 2
	Standardized regression coefficients (β)	Standardized regression coefficients (β)	Standardized regression coefficients (β)
$cP3_S\_cP3_R$	-.431	.445	.010
$sP3_S\_sP3_R$	-.262	-.138	-.550*
Training category of open skill	-.393*	-.133	-.363*
Training category of closed skill	-.265	-.057	-.347*
$cP3_S\_cP3_R$ × open skill	.475**	-.070	.066
$cP3_S\_cP3_R$ × closed skill	.247	-.099	.131
$sP3_S\_sP3_R$ × open skill	.293	-.096	.464*
$sP3_S\_sP3_R$ × closed skill	.225	-.255	.519*
R^2	.408	.277	.342
Adjusted R^2	.303	.148	.225
F	3.876**	2.151	2.925**
$\triangle R^2$	.182	.021	.157
$\triangle F$	3.455*	.329	2.685*

Note: * denotes <0.050; ** denotes <0.010

RT denotes response time; $cP3_S\_cP3_R$ denotes difference of mean amplitudes between switch and repeat trial-types of cue-locked P3; $sP3_S\_sP3_R$ denotes difference of mean amplitudes between switch and repeat trial-types of stimulus-locked P3.

100% denotes 100% valid cue; 75% denotes 75% valid cue; 50% denotes 50% valid cue

Figure 4.3. Scatter plots indicating the relationships between the differences of mean amplitudes between switch- and repeat-trial types of cue-locked P3 ($cP3_{S\_}cP3_{R}$) and that of stimulus-locked P3 ($sP3_{S\_}sP3_{R}$) and the switch cost of response time for three groups under three validity conditions. ***4.3a***, 100% validity condition. cP3s_cP3r of open-skilled group shows significant correlation (blue line, r = 0.605, *P* = 0.008). ***4.3b***, 75% validity condition. None of cP3s_cP3r or sSP3s_sP3r of any group shows significant correlation. ***4.3c***, 50% validity condition. Only sP3s_sP3r of control group shows significant correlation (green line; r = -0.534, *P* = 0.022).



Hemispheric Models for Cue-Locked and Stimulus-Locked P3

For the amplitudes of the cue-locked P3, five-way repeated measure ANOVA showed that the validity [F(2, 102) = 13.37, P < 0.001, *partial eta*^{2} = 0.208] and site effects [F(1.304,66.527) = 189.85, P < 0.001, *partial eta*^{2} = 0.788] were significant. However, trial type [F(1, 51) = 0.75, P = 0.392, *partial eta*^{2} = 0.014], hemisphere [F(1, 51) = 0.29, P = 0.592, *partial eta*^{2} = 0.006] and group effects [F(1, 51) = 0.16, P = 0.898, *partial eta*^{2} = 0.004] were not significant. The validity × trial type × site × hemisphere × group effects [F(6.424, 163.810) = 0.65, P = 0.705, *partial eta*^{2} = 0.025] were also not significant.

For the amplitudes of the stimulus-locked P3, the ANOVA results showed that trial type [F(1,51) = 32.37, P < 0.001, *partial eta*^{2} = 0.388], site [F(1.273, 64.941) = 36.88, P < 0.001, *partial eta* ^{2} = 0.420] and group [F(1,51) = 5.43, P = 0.007, *partial eta*^{2} = 0.176] effects were significant. However, validity [F(2,102) = 2.15, P = 0.122, *partial eta*^{2} = 0.040], and hemisphere [F(1,51) = 0.02, P = 0.893, *partial eta*^{2} = 0.001] were not significant. No significant validity × trial type × site × hemisphere × group effects [F(6.585, 167.914)=0.43, P = 0.871, *partial eta*^{2}=0.017] were also found. These findings suggested that no significant hemispheric differences in the amplitudes of the cue- and stimulus-locked P3 were observed between the switch and repeat trials and among the three participant groups.

Chapter V

Discussion

Summary of Findings

This study investigated how different types of motor-skill experiences would modulate proactive and reactive controls of executive functions. Behaviorally, the main findings are that participants with experiences in open skills exhibited better proactive control for task switching than participants with experience in closed skills. This is supported by the results that the open-skilled participants showed lower switch costs than the closed-skilled participants in trials of which the cues were predictive of the subsequent stimulus (100% validity condition). In contrast, both the participants with experiences in open and closed skills exhibited better reactive control for task switching than that of the control participants. This is supported by the results that both open- and closed-skilled participants showed lower switch costs than those of the control participants in trials of which the cues were not predictive of the subsequent stimulus (50% validity condition). For the findings from the ERP data, the open-skilled participants were found to deploy less attentional resources than the close-skilled participants and control participants when updating the alternate task goals and rules in the proactive control process when the cue was predictive of the stimulus (100% validity condition), in which the responses predominantly relied on proactive control of task switching. This observation is supported by the less positive-going cue-locked P3 elicited at the parietal region (switch vs. repeat trial) for the open-skilled participants in the 100% validity condition. The results on the cue-locked P3 were different in both the closed-skilled participants and the control participants, suggesting their more attentional resources would have been deployed when engaging in the proactive control of the task-switching processes. Interestingly, both the open and closed-skilled participants were found to deploy less attentional resources than the control participants when updating the alternate goals and rules in the reactive control when the task cue was not predictive (50% validity condition), which tapped on reactive control of task switching. This observation is supported by less positive-going stimulus-locked P3 elicited in the parietal region (switch vs. repeat trials) for the open- and closed-skilled participants than control participants in the 50% validity condition. The results on the regression analysis supported the notion that better proactive control for task switching was associated with the difference of magnitude in the cue-locked P3 between switch and repeat trials for the open-skilled participants, while better reactive control for task switching was associated with the difference of magnitude in the stimulus-locked P3 between switch and repeat trials for the three groups of participants.

Behavioral Differentiation of Executive Control between Open- and Closed-Skilled Participants

Participants with experience in open skills performed at a higher level of proactive control for task switching than those with experience in closed skills in the 100% validity condition, while both open- and closed-skilled participants performed at a higher level of reactive control for task switching than the control participants are new findings. First, previous studies did not incorporate both proactive and reactive controls in the same paradigm that allowed direct comparisons. For instance, Brady (1996) employed a Bassin Anticipation Timer, which required participants to watch a light as it travelled down a runway and press the button as close to the arrival time of the light at the target location as possible. This task required the participants to anticipate the arrival time of the light, which is comparable to the 100% validity condition as in this study. The results showed that experts with open skills could anticipate the light reaching the target faster and more accurately than their counterparts with closed skills. Other studies also indicated that that open-skilled experts could successfully anticipate the forthcoming events more accurately by the use of earlier occurring sources of information than novices could (Aglioti et al., 2008; Rosalie & Müller, 2013). Because the anticipatory processes seem to be similar to those of proactive control, high ability of anticipation would lead to a higher level of proactive control. The superior performance in proactive control for open-skilled experts also shed further light on what was found in Nakamoto and Mori (2008) and Wang et al. (2013). Both of these studies reported that the open-skilled experts outperformed in inhibitory control compared to the closed-skilled experts. In Nakamoto and Mori's study (2008), the between-group differences was only found in sport-specific tasks, and in the present study, the between-group differences exist in nonsport-specific task, which is the cued-task-switching paradigm. In Wang et al.'s study (2013), the inhibitory control involved in the stop-signal task did not combine the model of proactive and reactive controls, which could not better interpret the differences in executive control between different types of motor-skilled groups.

In the present study, the open-skilled experts were the athletes in a badminton team who would need to employ the opponent's body kinematics information to anticipate the trajectory of the shuttle and prepare a response (Jin et al., 2011). In contrast, the closed-skilled experts in the athletics team would need to follow a set pattern with less anticipation required (Di Russo et al., 2010). When they performed on the task-switching paradigm, the open-skilled participants were found to have a better preparation for switching from one action rule to a new one by using the information provided by the cues with 100% validity. The enhancement of the proactive control for task switching for open-skilled experts would be due to their experience in open-skill training (i.e., badminton training).

Both open- and closed-skilled participants had a shorter switch cost of response times in the trials with a 50% cue validity, which suggested that they were better in reactive controls for task switching than the control participants. This finding supported the results in Diamond (2006) using a Go/Nogo task and Kamijo and Takeda (2010) employing a noncued-task-switching paradigm. These two studies revealed that a long term of physical training, no matter the sport type, enhanced the participants' performance of executive control. However, based on the notion that training-induced enhancements on executive functions would be related to the activity context in the training, it would be intuitive to expect that open-skilled participants have better reactive control for task switching than that of closed-skilled participants. The players in badminton often were required to give more imperative responses to their opponents without anticipation or preparation due to the dynamically changing environment, whereas the players in athletics had fewer requirements to give imperative responses due to the relatively stable environment. But why the ability in reactive control of open-skilled participants was not different from that of closed-skilled participants despite the different activity context? One plausible explanation is that the ability of open-skilled participants in reactive control on the trials with a 50% valid cue could have been interfered by their higher dependence on proactive control in their daily training. In other words, the ability development of imperative responses to the changeable environment would have been hindered by more experience of anticipation and preparation for open-skilled participants. This is supported by the previous studies, which suggested that experts in open skills would make less use of imperative responses as they more depend on anticipation and preparation to make responses within limited time (Aglioti et al., 2008; Müller & Abernethy, 2012). In addition, proactive control (e.g., anticipation) could make a contribution to the reactive control, because proactive and reactive controls for action inhibition involve similar fronto-parietal regions for inhibition function (Chikazoe et al., 2009). Another study found that supplementary motor area (SMA) was activated both in proactive control for adjusting the level of motor preparation and in reactive inhibition of unwanted movements during a stop-signal task, based on the single-unit and multiunit activity and intracranial local field potentials (LFPs) recorded in the monkeys. These findings were supported by the conclusion from another brain imaging study that advanced the preparation of action plans reduces the cognitive demands required in reactive control to make voluntary actions mediated by the fronto-basal ganglia (Jahfari et al., 2012). In other words, the anticipation and preparation that the open-skilled experts had during the sport training and competition would have interference in the development of their ability in reactive control

The correlations between the response time of a switch cost on 50% validity and VO_{2max} suggested that a higher level of reactive control for task switching may be related to better aerobic fitness. This finding concurs with those revealed in other studies, indicating that the neural activations for reactive inhibition in frontal-parietal regions were highly correlated with aerobic fitness (Colcombe et al., 2004; Harada et al., 2004). Other brain imaging studies reported aerobic fitness training increased the correlation between functional connectivity in the frontal executive network and the improvement in reactive controls for task switching (Voss et al., 2010b) and exhibited stronger activations in the prefrontal cortex in reactive control (Colcombe et al., 2004). However, despite the correlation between the switch cost with VO_{2max}, results in the regression model for behavioral results showing that training experiences of open and closed skills rather than VO_{2max} were significant predictors for switch cost of response time under 50% validity. The potential reason was that training experience of open and closed skills leads to better performance in reactive control due to both of cognitive training and aerobic fitness training during the development of motor skills (Voss et al., 2010a).

The results of regression analysis for exploring the possible confounding effects demonstrated that training experiences of open and closed skills significantly predicted the switch cost of response time on the trials with a 50% valid cue, whereas only training experiences of open skills significantly predicted a switch cost of response time on the trials with a 100% valid cue. These findings were acquired by teasing out the effects from the confounding factors (e.g., demographic or physiological factors, including BMI, VO_{2max}, CTT (Interference index), the amount of physical activity for transportation, and the amount of physical activity for recreation). These findings from regression analysis for behavioral data further substantiate our findings that benefits from open-skill training is beneficial to proactive control for task switching, whereas both open- and closed-skill training is beneficial to reactive control for task switching. The findings were partly supported by the findings in Wang et al.'s study (2013), which showed that open-skill training rather than closed-skill training is beneficial to inhibition ability after teasing out the effects from other demographic and physiological factors. However, Wang et al. did not consider the proactive and reactive controls into executive functions. In the present study including proactive and reactive controls model, the benefits from open-skilled training were higher than those from close-skilled training in proactive control of executive function rather than reactive control of executive function after teasing out the effects from other demographic and physiological factors. It seems that the findings in present study could provide a better differentiation between open- and closed-skilled experiences on executive functions.

The results of the 75% validity condition was between those of the 50% and 100% validity conditions, which was consistent with our hypothesis. In the trials with a 75% valid cue, the difference in the switch cost of response time was marginally significant between the open-skilled and control participants, and a nonsignificant difference could be found between the participants with open and closed skills. The findings could not indicate the superiority of open-skilled group in proactive control relative to the closed-skilled group on the 75% validity condition. The plausible explanation was the “expect the unexpected” strategy adopted by open-skilled experts in the uncertain environment (Pesce & Audiffren, 2011). The strategy of “expect the unexpected” was that under the uncertain cue the open skilled experts would deploy more attentional resources to prepare for invalid conditions and deploy less attentional resources to prepare for valid conditions (Pesce & Audiffren, 2011). Thus, the level of variations in allocating cognitive resources across trials, which could confound the switch costs of response time, was higher in open-skilled participants than that in closed-skilled and control participants on the 75% validity condition, particularly among the open-skilled participants. Future studies could monitor the level of attentional resources allocated by the participants, which could help us verify the strategy of “expect the unexpected.”

Three group participants in the present study showed comparable performance on the simple reaction task, which suggested that these participants had a similar level of processing speed with little involvement of executive functions. This finding was consistent with that found by Nakamoto and Mori (2008). These results could rule out the confounding effects of lower-level cognitive functions to our results that the superior performance of open- and close-skilled participants in proactive and reactive controls task switching.

The findings in CTT revealed that open and closed-skilled participants had better a shifting function than that of the control participants because both open- and closed-skilled participants had a lesser Interference Index of CTT than that of the control participants. The positive correlations between the Interference Index in CTT and the switch cost of response times in task-switching paradigms regardless of validities, indicating that the participant having a higher shifting ability in the CTT test had a better ability to switch to a new task. This finding further supported us that the cued task-switching paradigm could tap on the shifting function without the consideration of proactive and reactive controls because Interference Index of CTT tests on the capacity of a shifting function (Lin et al., 2014).

Neural Processes Associated with Proactive and Reactive Controls for Task Switching

Cue-Locked P3 in Proactive Control

Previous studies showed that the neural processes associated with cue-related proactive control for task switching involved P1 and N1 reflecting cue encoding (Rushworth et al., 2002), P2 reflecting cue identification (Hsieh & Wu, 2011; West, Langley, & Bailey, 2011), P3 reflecting task-set reconfiguration (Gajewski & Falkenstein, 2011; Tarantino et al., 2016), and CNV reflecting preparatory attention to the task set (Karayanidis, Provost, Brown, Paton, &

Heathcote, 2011; Tarantino et al., 2016). Among these processes, the P3, which associates with task-set reconfiguration, was found to significantly be associated with performances in task switching (Gajewski & Falkenstein, 2011; Tarantino et al., 2016; Travers & West, 2008). In particular, larger switch-related positivity of cue-locked P3 in the parietal region was related to smaller switch cost of response time (Li et al., 2012). The switch-related positivity of cue-locked P3 in the parietal region suggested that greater cognitive efforts were required in updating the new task in the proactive control (Jamadar, Michie, & Karayanidis, 2010b; Nicholson, Karayanidis, Poboka, Heathcote, & Michie, 2005). The greater cognitive efforts were related to attentional resources, because when the cue was changed, attentional resources were reorientated to the new task goal and action rule in the updating (Jamadar et al., 2010b; Rushworth et al., 2002; Tarantino et al., 2016). Besides task switching, cue-locked P3 is also related to the orientation of attentional resources and reactivation of the response rules before the onset of stimulus in the proactive control for inhibition (Grane et al., 2016). The task employed in the present study is switching between two sets of action rules, which is similar to that in Rushworth et al.'s study (2002). Thus, the amplitudes of cue-locked P3 in the present study are associated to attentional resources involved in anticipatory updating of an action rule.

The ERP results in the 100% validity condition showed a less positive-going cue-locked P3 elicited mainly in the parietal region in switch trials than that in the repeat trials in the open-skilled group, of which the between-trial differences (switch vs. repeat) were not observed in the closed-skilled group. However, the control group showed a more positive-going cue-locked P3 in the parietal region in switch trials than that in repeat trials, which was opposite to the open-skilled group. These findings suggested that when the cue was fully predictive, which predominantly would elicit proactive control for task switching, the open-skilled participants tended to deploy less attentional resources than that of the closed-skilled participants for updating the new action task rule for the subsequent stimulus. This was found to couple with a better performance on the proactive control for task switching in the 100% validity condition by the open-skilled participants than closed-skilled and control participants. That is to say, the open-skilled participants would have a higher efficiency in updating the new action rules in a proactive control than that of the closed-skilled and control participants, which is supported by the findings reported in previous studies. For instance, some previous studies indicated that experts' intensive experience of cognitive training could lead to a higher efficiency in the corresponding neural process, hence employing less cognitive resources as reflected from the reduced in amplitudes of the associated event-related components, e.g., fencer (Zhang, Ding, Wang, Qi, & Luo, 2015); car experts (Herzmann & Curran, 2011), and art experts (Pang, Nadal, Muller-Paul, Rosenberg, & Klein, 2013). For instance, Zhang et al. (2015) revealed that fencers (open-skilled) showed higher accuracy rates and less positive-going P3 than nonfencers, which is deemed reflecting the inhibitory process in the Nogo condition. The reason for these findings was that intensive fencing training could enhance the neural efficiency of inhibition processing, and hence require a minimization of cognitive resources in inhibitory control (Zhang et al., 2015). In the proactive control process, an ERP study conducted by Nakamoto and Mori's study (2012), who asked the participants to predict a moving target with changeable velocities and press a button once the target arrived at the end of a trackway. The findings in Nakamoto and Mori's study (2012) indicated smaller timing errors, augmented switch-related frontal N200 and later switch-related frontal P300b in open-skilled group than those found in closed-skilled groups. This suggested that open-skilled experts could detect the changed velocity quickly and update the stimulus-response relationship for the changed velocity than could the closed-skilled group in the anticipation. Other studies reported that experts in open-skilled sports had higher accuracy rates in the anticipation by deploying information significantly earlier than their novice counterparts (Aglioti et al., 2008; Müller & Abernethy, 2012; Rosalie & Müller, 2013). McRobert et al. (2011) also proposed that more accurate anticipation in the changeable environment requires open-skilled participants to have more online updating of the changed actions or strategies from their opponents to adjust the judgement in anticipation. It is therefore plausible that open-skilled experts' higher efficiency to update the new action rule in proactive control is likely to be attributable to the intensive experience of online updating the environment changes for anticipation during training on the open-skilled sports. In the present study, the open-skilled participants engaged in the badminton team had more experience of advanced updating changing the environment (e.g., updating the opponent's changed kinematics information and overcoming the interferences from the previous deceptive movement pattern) during anticipation and preparation (Müller & Abernethy, 2012), whereas the closed-skilled participants engaged in the athletics team had less experience to update the environment changes in the relatively stable environment because the performance was less affected by the environment (Di Russo et al., 2010). As a result, open-skilled experts with intensive experience of anticipatory updating the environment changes would tend to deploy less attentional resources in updating the new action rule in proactive control than that of the closed-skilled and control participants, and they performed better in task switching.

The results that no between-group differences were revealed in the cue-locked P3 between switch and repeat trials in the cue with 50% validity condition are consistent with those reported in previous studies (Jamadar et al., 2010a; Swainson et al., 2006). The reason was that the cues with 50% validity were not predictive of the identity of target stimulus in repeat and switch trials, and hence no differences in the proactive preparation in repeat and switch conditions could be elicited.

Stimulus-Locked P3 in Reactive Control

The neural processes associated with stimulus-related reactive control for task switching are similar to those associated with proactive control, except that the stimulus-locked P3 reflects the implementation of a new stimulus-response set with the predictive cue before the stimulus (Jamadar et al., 2010a; Tarantino et al., 2016) or updating the new task set without the predictive cue (Hillman et al., 2006; Scisco et al., 2008). Smaller switch-related negativity of stimulus-locked P3 was related to a smaller switch cost of response time when the cue was fully predictive (Jamadar et al., 2010a; Li et al., 2012). The reason for switch-related negativity of stimulus-locked P3 with the predictive cue is that the implementation of new stimulus-response set required a higher level of attentional resources to overcome the conflicts elicited by two alternative action rules (Jamadar et al., 2010a; Tarantino et al., 2016). In addition, when there was not a predictive cue, stimulus-locked P3 was related to the attentional resources required for updating the new task set in the reactive control (Hillman et al., 2006; Scisco et al., 2008). However, P3 in the reactive control for inhibition is related to stimulus categorization and the response inhibition process (Taddei et al., 2012; Zhang et al., 2015), which is different from that in the reactive control for task switching. Thus, the amplitudes of stimulus-locked P3 in the present study employing the cued task-switching paradigm is related to attentional resources in stimulus-response set implementation with the predictive cue and updating the action rule with the non-predictive cue.

When the cue was 100% valid, the mean amplitude of stimulus-locked P3 in the parietal region was less positive-going in the switch than that of the repeat trials across all the three groups (Figure 5c, left panel), which replicated the findings in previous studies (Gajewski & Falkenstein, 2011; Rushworth et al., 2005). Less positive stimulus-locked P3 in switch trials compared to repeat trials for the three groups was due to progressively increased amplitudes of the stimulus-locked P3 in repeat trials following the switch trial. The representation of stimulus-response mapping reflected by stimulus-locked P3 was weak at the beginning of the switch trial and was strengthened by successive repeat trials (Barcelo et al., 2000; Swainson et al., 2006). Another explanation was that stimulus-locked P3 was a response-related process, which was more variable in switch trials relative to repeat trials, so that the stimulus-locked P3 in switch trials was broader and smaller on the trial level.

When the cue was 50% valid, our ERP results also showed the open- and closed-skilled participants had less positive-going stimulus-locked P3 in the parietal region in the switch than those in the repeat trials, whereas no between-trial difference was found in the control group. Thus, these findings suggested that when the cue was non-predictive, the open- and closed-skilled groups would have deployed less attentional resources in updating the alternate action rule in the reactive control process; however, they performed better in the reactive control for task switching when the cue was non-predictive. These findings suggested that both of the open- and closed-skilled groups would have higher efficiency of updating in reactive control. These findings are inconsistent with those reported in previous studies. Previous studies found that participants with intensive experience of physical training, regardless of the type of sports, employed more attentional resources for updating a new task goal or action rule than the control participants (Kamijo & Takeda, 2010; Scisco et al., 2008). The tasks employed in these two studies were noncued-task-switching paradigms. One plausible reason for explaining the discrepancies of findings between our study and theirs is that the participants recruited in Kamijo et al.'s (2010) and Scisco et al.'s (2008) studies were people with regular physical training but not experts in sports. The experts in sport, who had been used to the high physical and cognitive demands during sport training and in competitions, could deploy cognitive resources more efficiently in the task, tapping on the cognitive functions usually required in the sport training (Zhang et al., 2015).

However, higher efficiency in updating the new action rule in reactive control for task switching in open- and closed-skilled experts was supported by the previous finding that fencers were found to deploy less cognitive efforts than their novice counterpart in stimulus evaluation and inhibition of a planned response in the reaction control (Zhang et al., 2015). The less cognitive efforts were reflected from the less positive-going P3 amplitude elicited in a Nogo task (Note: P3 reflects cognitive efforts instead of attentional resources in a Nogo task). This enhanced neural efficiency in the reactive control for inhibition was due to more experience of inhibiting inappropriate actions in the long-term fencing training (Zhang et al., 2015). Even though this efficient manner seemed a little unexpected, but it could be found not only in the sport experts (Babiloni et al., 2010; Zhang et al., 2015), but also in other experts (Andreasen et al., 1995; Graham et al., 2010; Herzmann & Curran, 2011; Motes, Malach, & Kozhevnikov, 2008; Neubauer & Fink, 2009). The fine-tuned neural process is due to the expertise-related training (Herzmann & Curran, 2011). In the present study, the reactive responses to the unpredictable environment changes in the sport training and competition required the experts in open and closed-skilled sports to have more experience in immediate updating the unpredictable environment changes and the new stimulus-response set and hence have higher efficiency in updating the new action rule in reactive control than control participants.

The Correlations of P3 to Task Switching

When the cue was 100% valid, the between-trial difference in the amplitudes of cue- rather than stimulus-locked P3 was positively correlated with the switch cost of response time in the open-skilled participants. No significant correlations were revealed in the closed-skilled and control counterparts. The significant correlation with the cue- rather than stimulus-locked P3 for the open-skilled group suggested that they could have engaged more intensively in the proactive than they had in the reactive control processes when the cue was predictive of the subsequent stimulus with which the updating of alternate task goal and rules processes would have begun at the early sage in preparation for the stimulus. These processes would be comparable to the anticipation process, which is of great importance for open motor skill experts to prepare a response to predictable environment changes under time constraints (Aglioti et al., 2008; Müller & Abernethy, 2012; Rosalie & Müller, 2013)

When the cue was 50% valid, the between-trial difference in the amplitudes of the stimulus-locked P3 was negatively correlated with the switch cost of response time among the control participants. Such relationships were not observed among the open- and closed-skilled participants. This finding suggested that more attentional resources employed for updating the alternative action rule in the reactive control for task switching would have been related to better performance in the task switching for the control participants. These findings are consistent with those reported by Li et al. (2012) showing that between-trial difference in the amplitudes of stimulus-locked P3 was negatively correlated with the switch cost of response time in task switching. The significant correlation in the stimulus-locked rather than cue-locked P3 also supported the notion that the reactive control process would have been the predominant processes when the cue is non-predictive of the subsequent stimulus. The plausible reason for explaining the nil findings for the open- and closed-skilled groups could have been due to the heterogeneity of the strategies employed by the open- and closed-skilled groups. For example, some experts employed more attentional resources to achieve better performance in the reactive control, whereas some other experts employed less attentional resources for updating but could achieve better performances in a reactive control. The strategy for the latter subgroup experts could be supported by the findings in Pang et al. (2013), which showed that higher skill level art experts displayed less positive-going P3 amplitude reflecting the memory process when free viewing the art and nonartistic stimuli. In addition, based on the scatter plot, we observed that the relationships between the amplitudes of stimulus-locked P3 and switch cost of response times were not linear for open- and closed-skilled groups. In open- and closed-skilled groups, the relationships of the subgroups split by the median of switch cost of response time or $sP3_{S\_}sP3_{R}$ seemed quite different. As a result, A median-split method was employed to show evidence on the proposition of heterogeneity of strategies among the open- and closed-skilled groups in this study (Tamura, Kitamura, Endo, Hasegawa, & Someya, 2010; Themanson, Hillman, & Curtin, 2006). With a median-split of switch cost of response time (64.44 ms) for the open-skilled participants, the correlation between $sP3_{S\_}sP3_{R}$ and switch cost of response time was positive and significant (r = 0.722, *P* = 0.028) when the switch cost of response time was higher than 64.44 ms; whereas the correlation was not significant (r = -0.348, P = 0.358) when the switch cost of response time was lower than 64.44 ms. Similarly, with a median-split the median of $sP3_S\_sP3_R$ (-1.06 µv) for the closed-skilled participants, the correlations between $sP3_S\_sP3_R$ and switch cost of response time for two subgroups were significant but of opposite directions ($sP3_S\_sP3_R$ higher than -1.06 µv: r = 0.662, P = 0.052; $sP3_S\_sP3_R$ lower than -1.06 µv: r = -0.791, P = 0.011). These findings supported the proposition that the open- and closed-skilled groups could have employed different strategies when approaching the task switching. For example, the closed-skilled participants with higher amount utilization of attentional resources in updating could have deployed less attentional resources for achieving better performances in their reactive control for task switching. In contrast, the closed-skilled participants with lower amount utilization of attentional resources in updating, could have deployed more attentional resources for achieving better performance in reactive control. Nevertheless, the sample size for each subgroup's correlations was small (n = 9). Further studies should explore the effects of the strategies used by the open- and closed-skilled participants on proactive and reactive controls.

P3 Under 75% Validity Condition

Even though no group differences in the mean amplitudes cue-locked P3 and stimulus-locked P3 between switch and repeat trials when the cue was 75% valid, the results of regression analysis showed that the magnitude differences of both cue-locked P3 and stimulus-locked P3 could predict the performance in task switching for three groups when the cue was uncertain. This finding supported the notion that the trials with 75% validity required both proactive and reactive controls to give a response. In addition, this finding could be supported by the findings in Scheibe et al.'s study (2009), which showed that the level of proactive preparation was lower and the demand of reactive control was higher under the uncertain cue with 75% validity compared to the certain cue with 100% validity.

Chapter VI

Conclusion

This study investigated the effects of experiences in open and closed skills on modulating proactive and reactive controls of executive functions by using a cued-task-switching paradigm. At the theory level, we attempted to address how proactive and reactive control processes can be dissociable. At the application level, we explored the potential benefits of open- and closed-skilled motor skills on the development of different aspects of executive functions (proactive vs. reactive) among young individuals. The cued-task-switching paradigm was custom-designed for this study in which the participants engaged in proactive or reactive control for task switching. The open-skilled participants exposed to a changeable and externally-paced environment were the members in the badminton team; whereas the closed-skilled participants exposed to a stable and self-paced environment were the members in the athletics team. The task required the participants to switch between two types of response rules. The cue presented prior to the target stimulus can be fully, partially, or not predictive of the response sets contained in the subsequent stimulus. The cue-then-stimulus was meant to manipulate the demands for the proactive and reactive control for task-switching processes.

The behavioral findings in this study showed that participants with experience in open skills showed a significantly higher level of performance in both the proactive and reactive control for task switching than that of those in the control group. In contrast, the participants with experience in closed skills appeared to only have a significantly higher level of performance in the reactive control for task switching rather than the control counterpart. It is noteworthy that the open-skilled participants had a significantly higher level of performance than that of the closed-skilled participants in the proactive control condition. The results pointed to the direction that the open skills were associated with proactive and reactive controls, whereas closed skills were associated with a reactive control only. More importantly, experience in the sport-related-skill training would modulate executive functions, which in this study were the proactive and reactive controls of task switching.

The electrophysiological results further offered insight into understanding the mechanisms behind the experience-based modulation of the execution functions. The markers consistently showing between-group differences in this study were the cue-locked P3 for the proactive control process and stimulus-locked P3 for the reactive control process. These two markers have been commonly related to the attentional processes associated with updating task goals and underlying action rules achieving the goal. Firstly, the open-skilled participants were found to demonstrate a higher level of efficiency in updating the task goal and action rule in the proactive control of task switching compared with the closed-skilled and control participants. This was reflected by the lower switch cost of response time in the task-switching paradigm and the significantly less positive-going differences in the cue-locked P3 elicited primarily over the parietal region between switch and repeat trials when the cue was fully predictive (100% validity condition). The less positive-going cue-locked P3 in the parietal region (switch verse repeat trials) reflected the open-skilled participants tended to deploy less attentional resources when engaging in the proactive control for the task-switching process. Secondly, the open- and closed-skilled participants also showed a significantly higher level of efficiency in updating the task goal and action rule in the reactive control for task switching when compared with the control participants. This was reflected by the lower switch cost of response time in the task-switching paradigm and the significantly less positive-going difference in the stimulus-locked P3 elicited in the parietal region between the switch and repeat trials when the cue was not predictive (50% validity condition). The less positive-going stimulus-locked P3 in the parietal region (switch vs. repeat) reflected the open- and closed-skilled participants tended to deploy less attentional resources when engaging in the reactive control for the task-switching process. The regression analyses showed that the proactive control for task switching was associated with the differences in the amplitudes of the cue-locked P3 in the parietal region between the switch and repeat trials among the open-skilled participants rather than closed-skilled and control participants; whereas the reactive control for task switching was associated with the differences in the amplitudes of the stimulus-locked P3 in the parietal region between switch and repeat trials disregard memberships of the participants. A higher efficiency in updating the task goal and action rule in the proactive control of task switching for the open-skilled rather than closed-skilled participants was the new finding, which suggested that the dissociated effects of different motor-skill experiences on the executive control process were in proactive rather than reactive controls.

Intensive experience of open-skilled training, such as those in professional badminton players, was related to better proactive control of executive functions. The plausible reason is that the participants with intensive of open-skilled experience had higher efficiency in update the environment changes in advance anticipation than closed-skilled and control participants. Secondly, both intensive experiences of open- and closed-skilled trainings were related to better reactive control of executive functions. The plausible reason is that the participants with intensive open- and closed-skilled experiences had a higher level of efficiency in updating the unpredictable environment changes in the imperative response than that of the control participants.

Limitations

This study employed the cued-task-switching paradigm for inducing the proactive and reactive control of executive functions. The nature of the task and the task processes involved would have limited generalizations of the results obtained from this study. Firstly, the proactive and reactive control processes manipulated were restricted to the attention switching between different action rules. The results may not be generalized to other executive functions such as inhibition or self-regulation. Future studies should explore the effects of motor-skill experiences on other executive functions by adopting the model of proactive and reactive controls. Secondly, the relatively small sample sizes of the three groups of participants (n = 18 for each group), which could have weakened the power of the analyses. Future studies should recruit more participants to increase the power of the analyses.

Thirdly, the CTT is a measure of executive function which should have covered proactive and reactive controls. However, the results of participants' scores on the CTT did not reveal significant differences in the relationships with the performance of proactive and reactive controls across the three participant groups. This leads to the notion that the CTT may not have the sensitivity and specificity for measuring proactive and reactive controls. Future studies should explore the relevant psychological or neuropsychological tests, which are sensitive for detecting proactive and reactive controls as well as their differences. Fourthly, this study didn't consider the effects of levels of expertise. Because the levels of expertise in sports showed different effects on cognitive functions, future study should consider the effect of the levels of expertise. Fifthly, the present study didn't assess the detail log of participants’ training, which couldn’t help us differentiate the activity context between badminton and athletics. Future study should involve the details log of participants’ training. Sixthly, the findings of subgroup correlations between sP3S-sP3R and the switch cost of response time were likely to suggest that the heterogeneity of strategy employed by the open- and closed-skilled groups had different effects on proactive and reactive controls. For example, closed-skilled participants with a higher amount of utilization of attentional resources in updating, deployed less attentional resources but could achieve a better performance in the reactive control for task switching. In contrast, closed-skilled participants with a lower amount of utilization of attentional resources in updating, deployed more attentional resources to achieve better performance in reactive control. Future study should consider the effects of different strategies employed by open- and closed-skilled experts and also different motor-skill levels on the proactive and reactive controls.

Suggestions for Future Study

Firstly, this study offers some initial findings on the neural processes associated with the effects of focused attention and imagery on modulating pain perception. Further studies need to be conducted to enrich further the knowledge in the area. A study using randomized controlled trial design could be conducted to explore the effectiveness of different motor skills on proactive and reactive control. Secondly, the results of 75% validity condition couldn’t show significant difference between open- and closed-skilled groups. In the future study, the experimental design could only compare 100% and 50% validity conditions, which may elicit larger differences between open and closed skills, especially in the between-trial difference of the amplitude of cue-locked P3. Thirdly, the uncertain cue (75% cue validity) is very common in our daily life. The potential reason for the nil findings in 75% validity condition was that the different strategies employed by open- and closed-skilled groups when the cue was uncertain. The plausible explanation was the "expect the unexpected" strategy adopted by open-skilled experts in the uncertain environment (Pesce & Audiffren, 2011). Thus, the contrast of valid (75%) and invalid (25%) conditions could help us understand the different strategies employed in proactive and reactive controls between open- and closed-skilled groups when the cue is uncertain. Fourthly, future studies should adopt the model of proactive and reactive controls to explore the effects of motor-skilled experiences on other executive functions (e.g., inhibition function). For example, cue validity could be employed to monitor the levels of proactive and reactive controls of inhibition function in the stop-signal task,(Zandbelt, van Buuren, Kahn, & Vink, 2011). Fifthly, more advanced methods (e.g., time-frequency analysis) could be used to further substantiate the findings in the present study.

Clinical Implications

Physical activities, including open and closed motor skills, have been reported to be able to enhance the ability of executive control (Hillman, Snook, & Jerome, 2003; Kamijo & Takeda, 2010; Themanson et al., 2006). However, the improvements in executive functions in terms of proactive and reactive control abilities resulting from open- or closed-motor-skill training were largely unclear in these previous studies. Our behavioral and ERP findings suggested that open-skilled training (badminton) has benefits of promoting proactive control, whereas both open- (badminton) and closed-skilled (athletics) trainings benefit of promoting reactive control. These findings substantiated the performance differences in the proactive and reactive controls of executive functions between open- and closed-skilled participants and underlying neural mechanism. Previous studies also showed that other open and closed skills without physical training had different effects on proactive and reactive controls. For example, music video game (open skills without physical training) showed a larger benefit on the proactive control compared to the control group and no-music video game group(Fu & Zhang, 2017). However, open-skilled participants showed better proactive and reactive controls for inhibiting a response reflected by more negative prefrontal negativity in proactive control and more positive P3 in reactive control than the musicians (closed skills without physical training) (Bianco, Berchicci, Perri, Quinzi, & Di Russo, 2017).

Proactive control of executive functions plays an important role in our daily life, because proactive control could selectively allocate the preparatory attention before the response tendency is triggered, which was important for the self-regulated behaviors (Aron, 2011). Firstly, Previous study showed that 3-year-olds children show greater mental effort after the onset of target stimulus, which suggested they had no proactive control for the target stimulus. And around the age of 6 years young children begin to employ proactive control (Chevalier, James, Wiebe, Nelson, & Espy, 2014; Lucenet & Blaye, 2014). However, young children prefer to engaging reactive control and may engage proactive control only when reactive control is hard to implement. Thus, enhancing the children’s engagement in proactive control is very important for their self-regulated behaviors, especially those with learning difficulties (Danielsson, Henry, Ronnberg, & Nilsson, 2010). Secondly, proactive control plays an important role in maintaining health for adult people. For example, alcohol addicts having an advance goal of abstaining from taking drinks in proactive control could effectively help them stopping taking drinks (Aron, 2011). Thirdly, proactive control was also very important to the elderly people. For example, previous studies showed that elderly people tended to employ reactive control, but less depended on proactive control (Jimura & Braver, 2010; Kopp, Lange, Howe, & Wessel, 2014). Besides our daily life, proactive control was important for some clinical cases. For example, proactive control is severely impaired in schizophrenia (Lesh et al., 2013; Zandbelt et al., 2011), attention deficit hyperactivity disorder (ADHD, Banich, et al., 2009). The impairment in proactive control of executive functions for these patients could be related to lateral prefrontal cortex dysfunctions (Banich et al., 2009; Lesh et al., 2013). In addition, the patients with Parkinson disease showed impaired proactive control due to basal ganglia dysfunction, so that they tended to employ reactive control to resolve the response conflict (Wylie, Ridderinkhof, Bashore, & van den Wildenberg, 2010). The findings in the present study shed light on designing simulated open-skilled training programs, closed-skilled training with the insertion of some ball games (e.g., swimming with water polo) , or the music video games to improve the performances in the proactive control of the executive functions, especially for some clinical cases with proactive control impairment.

Appendix 3.1. Information Sheet for Participants (English Version)

Information Sheet for Participants

<u>Project title:</u> Expert Athletes' Task Switching Processes in Motor Planning: An ERP study

<u>Project information:</u>

Aim of Study: to investigate the experts' task switching processes. The experimental task employs cue validity and two-pattern response-set switching design.

Everyday life requires frequent shift between different tasks. Task switching ability is very important for athletes, especially in the open sports. Less evidence suggested that expert athletes would have different ability during task switching compared with the non-expert subjects. This study would use the electroencephalogram (EEG) to explore the difference of neural processing during task switching between expert athletes and non-expert subjects.

Before the task begins, it takes about 1.5 hour EEG preparation and 2 hours for completing 10 blocks of the response switching task, during which the brain activity will be recorded. There is a training and introduction of the study for 25 minutes before the experiment. After the EEG data collection, there are another neuropsychological task (Color Trails Test*)*, two sport psychological questionnaires (Sport Competition Anxiety Test and Global Physical Activity Questionnaire—Chinese Version) and one physical fitness test. Time for psychological tasks and physical fitness test *(*Queen's College Step Test) will take around 1 hour. There is no risk to your body during the whole experiment.

You could contact the co-investigator Miss Yu at 2766 6764 or e-mail: <u>qiuhua.yu@</u> . And you can also contact the chief investigator, Prof Chetwyn Chan at 2766 6727 for any questions about this study.

Appendix 3.2. Information Sheet for Participants (Chinese Version)

參加者的信息手冊

研究項目：運動專家在運動計劃中的任務轉換過程：事件相關電位研究

項目內容：

研究目的是探索運動專家的任務轉換過程。研究的測試任務應用了不同有效性的提示和不同接聽模式的轉換的設計。

每天的生活都需要經常在不同的任務之間轉換。任務轉換對於運動員是非常重要的，尤其是開放性運動。目前還缺乏研究證據證明專業的運動員是否有異于非運動員的任務轉換能力。本研究將使用腦電波（EEG）來探索運動員和非運動員在任務轉換的神經加工過程的差異。

然後需要大約1.5個小時來準備腦電波實驗和2個小時來完成10組的任務轉換測試（轉換兩組不同模式的應答任務）。期間腦電波的活動情況將同時記錄下來。實驗開始前有25分鐘介紹本實驗和練習。在收集完腦電波後，參加者還需要完成一個心理測試（威斯康星卡片分類試驗和顏色連線測試）、兩個運動心理問卷（運動競賽焦慮測驗和国际体力活动问卷——中文版）和一個體能測試（臺階測試），時間約1個小時。整個研究過程對您的身體都沒有任何危害。

如您有任何疑問，您可以致電2766 6764或電郵qiuhua.yu@ 來聯繫此次研究課題的研究人員余小姐或2766 6727，或來聯繫此次研究課題負責人陳智軒教授。

Appendix 3.3. Informed Consent for Participants (English Version)

The Hong Kong Polytechnic University

Department of Rehabilitation Sciences

Research Project Informed Consent Form

Project title: **Expert Athletes' Task Switching Processes in Motor Planning: An ERP study**

Investigator(s): Professor Chetwyn Chan (supervisor), Dr. Amy Fu, Yu Qiuhua

Project information:

Cognitive flexibility is very important in our daily life, especially in the development of sport expertise. The aim of this research is to investigate the expert athletes' (especially in open sports) task switching processes in motor planning. The experimental task employs cue validity and response-set switching design.

Project content:

At the beginning you will be asked to provide some personal information and read the information sheet. Then it will take about one and a half hours for the ERP preparation and after that you will spend two hours for the ERP data collection. After the ERP data collection, you need to complete another psychological test (Color Trails Test), two sport psychological questionnaires (Sport Competition Anxiety Test and Global Physical Activity Questionnaire—Chinese Version) and one physical fitness test (Queen's College Step Test). Time for psychological tasks and physical fitness test will take around one hour. Participation of you is on a voluntary basis.

Consent:

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

I can contact the co-investigator Miss Yu at 2766 6764 or e-mail: qiuhua.yu@ . And you can also contact the chief investigator, Prof Chetwyn Chan at 2766 6727 for any questions about this study. If I have complaints related to the investigator(s), I can contact Ms Michelle Leung, secretary of Departmental Research Committee, at 2766 5397. I know I will be given a signed copy of this consent form.

Signature (subject): _________________________ Date: ___________________

Signature (witness): _________________________ Date: ___________________

Appendix 3.4. Informed Consent for Participants (Chinese Version)

香港理工大學康復治療科學系科研同意書

研究題目

運動專家在運動計劃中的任務轉換過程：事件相關電位研究

研究員

主要科研人員：陳智軒教授，符少娥博士，余秋華

研究目的

思維的靈活性在日常生活任務中是非常重要的，尤其對於運動技能的發展。本研究主要目的是探索運動專家(尤其是開放性運動的運動員)在運動計劃中的任務轉換過程。 研究任務將使用多種提示的有效性和回答任務轉換來設計的。

研究內容

比賽前所有被試都要填寫個人資料表和閱讀資訊小冊。 然後你將接受需要大約 1.5 個小時來準備 ERP 實驗裝置和 2 個小時來收集 ERP 的資料。在收集完 ERP 的資料後，你再需要完成一個心理測試（顏色連線測試）、兩個運動心理問卷（運動競賽焦慮測驗和国际体力活动问卷——中文版）和一個體能測試（臺階測試），時間約 1 個小時。您是自願參加這個測試。

同意書

本人______________________已瞭解此項研究的具體情況。本人自願參與這項研究，本人有權在任何時候、毫無理由地退出這項研究，而此舉不需要我承擔任何後果。本人明白參加此項研究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，名字或相片不會出現在任何出版物上。

本人可以用電話 2766 6764 或電郵 qiuhua.yu@ 來聯繫此次研究課題的研究人員余秋華小姐或 2766 6727 來聯繫此次研究課題負責人陳智軒教授。若本人對此研究人員有任何投訴，可以聯繫梁女士（部門科研委員會秘書），電話：2766 5397。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（參與者的名字）：____________________ 日期：__________________

簽名（證人） ：__________________________ 日期：____________________

Appendix 3.5. Letter of Ethics Approval

THE HONG KONG POLYTECHNIC UNIVERSITY
香港理工大學

To	Chan Che Hin (Department of Rehabilitation Sciences)		
From	TSANG Wing Hong Hector, Chair, Departmental Research Committee		
Email	rshtsang@	Date	26-May-2013

Application for Ethical Review for Teaching/Research Involving Human Subjects

I write to inform you that approval has been given to your application for human subjects ethics review of the following project for a period from 01-May-2013 to 01-May-2015:

Project Title:	Expert Athletes' Task Switching Processes in Motor Planning: An ERP Study
Department:	Department of Rehabilitation Sciences
Principal Investigator:	Chan Che Hin

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

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

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

TSANG Wing Hong Hector

Chair

Departmental Research Committee

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Appendix 3.6. Global Physical Activity Questionnaire—Chinese Version (GPAQ-C)

Subject NO. Name: Date:

國際體力活動問卷

核心內容：體力活動			
下面我要詢問你通常每週做各類體力活動所花費的時間。請回答下列問題（即使你認為自己不經常參加體力活動）。首先談到工作中的體力活動。工作是指你必須完成的有酬或無酬工作，學習/培訓，家務，收割食物/糧食，漁業或獵捕食物，以及找工作。*[根據需要添加其他例子]* 關於劇烈活動，是指高負荷的體力活動並引起呼吸心跳顯著增加。中等強度的活動是指一定負荷的體力活動並引起呼吸心跳輕度增加。			
問題		**回答**	**代碼**
工作時的體力活動			
54	你的工作需要做劇烈活動以致引起呼吸和心跳顯著增加［如搬運或舉重物、挖掘或建築工作］時間至少持續 10 分鐘嗎？ *[插入例子]（使用圖示卡片）*	是 1 否 2 *若為否，跳轉至 P 4*	P1
55	你的工作中通常每週有多少天會做劇烈活動？	天數 └─┘	P2
56	你通常每天工作中做多長時間的劇烈活動？	小時：分鐘 └─┴─┘：└─┴─┘ 小 時 分	P3 (a-b)
57	你的工作需要做引起呼吸和心跳輕度增加的中等強度活動，如快步走［搬運較輕的物品］時間至少持續 10 分鐘嗎？ *［插入例子］（使用圖示卡片）*	是 1 否 2 *若為否，跳轉至 P 7*	P4
58	你通常每週有多少天工作時做中等強度的活動？	天數 └─┘	P5
59	你通常每天工作時做多長時間中等強度的活動？	小時：分鐘 └─┴─┘：└─┴─┘ 小時 分	P6 (a-b)
交通時的體力活動			
以下問題不包括上述工作時的體力活動。 現在我要詢問你通常的交通方式。例如，去上班、去購物、去市場等 *［根據需要添加其他例子］*			
60	你去某個地方時步行或騎自行車至少持續 10 分鐘以上嗎？	是 1 否 2 *若為否，跳轉至 P 10*	P7
61	你通常每週有多少天從一個地點到另一地點步行或騎自行車至少持續 10 分鐘以上?	天數 └─┘	P8
62	你通常每天在交通方面花多少時間步行或騎自行車？	小時：分鐘 └─┴─┘：└─┴─┘ 小時 分	P9 (a-b)

娛樂性體力活動			
以下問題不包括上述的工作和交通過程中的體力活動。 現在我詢問你有關運動、健身和娛樂性體力活動（休閒）的問題*[插入相關的例子]*			
63	你進行引起你呼吸和心跳顯著增加的劇烈的運動、健身和娛樂性（休閒）體力活動並至少持續 10 分鐘以上嗎？ *[插入例子]（使用圖示卡片）？*	是 1 否 2 *若為否，轉跳至 P13*	P10
64	你通常每週有多少天進行劇烈的運動、健身和娛樂性（休閒）體力活動?	天數 └─┘	P11
65	你通常每天花多長時間進行劇烈的運動、健身和娛樂性體力活動？	小時：分鐘 └─┴─┘：└─┴─┘ 小時 分	P12 (a-b)
66	你進行引起你呼吸和心跳輕度增加的中等強度的運動、健身和娛樂性體力活動（休閒），如快步走（騎自行車、游泳、排球）至少持續 10 分鐘或以上嗎？ *[插入例子]（使用圖示卡片）*	是 1 否 2 *若為否，跳轉至 P 16*	P13
67	你通常每週有多少天進行中等強度的運動、健身和娛樂性（休閒）體力活動?	天數 └─┘	P14
68	你通常每天花多少時間進行中等強度的運動、健身和娛樂性（休閒）體力活動？	小時：分鐘 └─┴─┘：└─┴─┘ 小時 分	P15 (a-b)

擴展內容：體力活動				
久坐習慣				
以下問題是關於工作時、在家裡、交通過程中、會朋友時坐姿或靠著所花費的時間。 包括坐在桌前，與朋友一起坐著，乘坐轎車、公共汽車、火車，閱讀，打撲克或看電視，但不包括睡覺的時間。 *[插入例子)（使用圖示卡片）*				
69	你通常每天有多少時間坐著或靠著？	小時：分鐘	└─┴─┘：└─┴─┘ 小時 分	P16 (a-b)

Appendix 3.7. Demographic Information Sheet for Participants

個人信息情況

姓名（name）： ____________ 性別（gender）： ____________

年齡（age）： ____________ 常用手： 左 / 右

學歷： ____________

是否接受正規訓練：（yes/ no） 田徑項目(羽毛球免填)：

已經訓練多少年： ____________ 几歲開始： ____________

每周訓練羽毛球/田徑多長時間： ____________

以前有沒有獲得羽毛球/田徑比賽的獎項： ____________

平時除了羽毛球/田徑外，還參加其他哪些體育運動： ____________

多長時間訓練一次： ____________ 每次多長時間： ____________

是否有其他特長： ____________

是否練過鋼琴：（Yes / No）（ 级）

以下問題由工作人員填寫

Stepping test：脈搏_____ beats （男生：24 beats; 女生： 22 beats）

VO2max： ________

體重： ____________（kg） 身高： ____________（cm）

BMI（體重（kg）÷身高^2（m））： ____________

Appendix 4.1. Mean amplitudes (original and differences) of the cue-locked P3

			Mean Amplitudes					
			Open-skilled		Closed-skilled		Control	
Validity	Electrodes	Trial-type	Original	Diff	Original	Diff	Original	Diff
100%	Fz	repeat	-3.33 (2.63)	-0.53 (0.81)	-3.70 (3.28)	0.89 (1.39)	-3.42 (3.40)	-0.06(1.18)
		switch	-3.87 (2.67)		-2.83 (2.90)		-3.48 (2.74)	
	Cz	repeat	-1.72 (3.27)	-0.37 (0.65)	-1.92 (2.88)	-0.03 (1.111)	-1.97 (3.53)	0.16(1.07)
		switch	-2.09 (3.36)		-1.83 (3.24)		-1.81 (3.08)	
	Pz	repeat	1.28 (2.64)	-0.56 (0.78)	1.02 (2.67)	0.14 (1.10)	1.00 (3.52)	0.64 (0.80)
		switch	0.72 (2.73)		1.16 (3.15)		1.64 (3.08)	
75%	Fz	repeat	-2.07 (2.31)	-0.28 (1.38)	-1.65 (2.69)	0.04 (1.23)	-2.17 (3.01)	0.05 (0.98)
		switch	-2.36 (2.58)		-1.61(2.95)		-2.12 (2.71)	
	Cz	repeat	-0.83 (2.49)	-0.55 (0.99)	-0.69 (2.39)	0.28 (1.08)	-0.68 (3.02)	-0.05 (0.70)
		switch	-1.38 (2.63)		-0.41 (2.35)		-0.73 (2.89)	
	Pz	repeat	0.47 (2.01)	-0.27(0.84)	0.98 (2.10)	0.36 (1.10)	1.08 (2.66)	0.48 (0.77)
		switch	0.21 (2.17)		1.33 (2.21)		1.56 (2.54)	
50%	Fz	repeat	-2.26 (2.18)	-0.08(0.87)	-2.42 (3.45)	-0.47 (1.15)	-2.16 (3.11)	0.01 (2.00)
		switch	-2.34 (2.56)		-2.88 (3.38)		-2.15(3.18)	
	Cz	repeat	-0.78 (2.70)	-0.58 (1.26)	-0.85 (3.42)	-0.38 (1.32)	-0.52 (2.77)	-0.06 (1.90)
		switch	-1.36 (3.20)		-1.23 (3.31)		-0.57 (2.69)	
	Pz	repeat	1.35 (2.34)	-0.21(1.38)	2.04 (3.21)	-0.25 (1.27)	1.88 (2.43)	0.15 (1.48)
		switch	1.07 (2.40)		1.79 (2.94)		2.03(2.03)	

Note: Original denotes the original values of the mean amplitudes; Diff denotes the difference values of the mean amplitudes, which were the differences of mean amplitudes of Cue-locked P3 component between repeat and switch conditions.

Appendix 4.2. Summary of results of repeated measures ANOVAs using the central sites on mean amplitudes of the cue-locked P3

	Factors	df	*F*-value	*P*-value	*partial eta*^{2}
4-way repeated ANOVA	validity	2,102	13.00	<0.001***	0.203
	trial type	1.000,51	0.76	0.387	0.015
	site	1.486,75.773	174.66	<0.001***	0.774
	group	2,51	0.16	0.856	0.006
	validity×group	2,102	0.43	0.790	0.016
	trial type×group	2.000,51.000	4.75	0.013*	0.157
	site×group	2.971,75.773	0.47	0.702	0.018
	validity×trial type	1.968,100.349	1.87	0.160	0.035
	validity×site	2.796,142.618	27.04	<0.001***	0.346
	trial type×site	1.484,75.700	2.50	0.103	0.047
	validity×trial type ×group	3.935,100.394	0.49	0.743	0.019
	validity×site×group	5.593,142.618	0.56	0.752	0.021
	trial type×site×group	2.969,75.700	1.38	0.256	0.051
	validity×trial type×site	3.183,162.350	0.70	0.560	0.014
	validity×trial type ×site×group	6.367,162.350	2.28	0.035*	0.082
3-way repeated ANOVA	100% validity: trial type ×site×group	3.351,85.442	5.49	0.001**	0.177
	75% validity: trial type ×site×group	2.752,70.179	1.11	0.348	0.042
	50% validity: trial type ×site×group	3.249,82.856	0.13	0.952	0.005
2-way repeated ANOVA	Fz with 100% valid cue: trial type×group	2,51	6.82	0.002**	0.211
	Cz with 100% valid cue: trial type×group	2,51	1.32	0.277	0.049
	Pz with 100% valid cue: trial type×group	2,51	8.03	0.001**	0.239

Note: * denotes <0.050; ** denotes <0.010; *** denotes <0.001

Appendix 4.3. Mean amplitudes (original and differences) of the stimulus-locked P3

			Mean Amplitudes					
			Open-skilled		Closed-skilled		Control	
Validity	Electrodes	Trial-type	Original	Diff	Original	Diff	Original	Diff
100%	Fz	repeat	5.90 (4.38)	-0.73 (1.38)	4.01 (2.68)	0.17 (1.09)	1.68 (3.39)	0.01 (1.27)
		switch	5.17 (4.81)		4.18 (3.00)		1.69 (3.09)	
	Cz	repeat	9.03 (4.90)	-0.82 (1.13)	7.50 (4.12)	-0.36 (1.21)	3.64 (3.75)	-0.34 (0.98)
		switch	8.21 (4.97)		7.14 (4.43)		3.29 (3.73)	
	Pz	repeat	9.36 (3.63)	-0.76 (1.15)	8.16 (4.26)	-0.43 (1.13)	5.94 (2.65)	-0.69 (0.96)
		switch	8.60 (3.95)		7.74 (4.42)		5.25 (2.55)	
75%	Fz	repeat	4.58 (4.06)	-0.70 (1.34)	3.46 (3.14)	-0.41 (1.62)	1.11 (2.90)	0.03 (1.36)
		switch	3.88 (4.21)		3.05 (3.85)		1.15 (2.77)	
	Cz	repeat	7.37 (4.41)	-0.77 (1.51)	6.55 (3.65)	-0.31 (1.48)	2.99 (3.24)	-0.18 (0.96)
		switch	6.60 (4.77)		6.24 (4.18)		2.81 (3.30)	
	Pz	repeat	8.73 (4.21)	-0.48 (1.17)	8.29 (3.87)	0.01 (1.25)	5.90 (2.39)	-0.14 (0.86)
		switch	8.25 (4.52)		8.31(4.49)		5.76 (2.65)	
50%	Fz	repeat	5.19 (4.88)	-1.56 (1.44)	4.43 (3.86)	-0.72 (1.84)	1.35 (3.36)	-0.50 (1.68)
		switch	3.63 (4.00)		3.71 (3.27)		0.85 (3.21)	
	Cz	repeat	7.61 (5.18)	-1.42 (1.25)	7.16 (4.57)	-0.77(1.71)	3.10 (3.51)	-0.07 (1.58)
		switch	6.19 (4.60)		6.39 (3.75)		3.03 (3.57)	
	Pz	repeat	8.97 (4.87)	-0.98 (1.17)	8.92 (4.61)	-1.17 (1.69)	5.89 (2.63)	0.34 (1.35)
		switch	7.98 (4.68)		7.75 (4.22)		6.06 (3.24)	

Note: Original denotes the original values of the mean amplitudes; Diff denotes the difference values of the mean amplitudes, which were the differences of mean amplitudes of stimulus-locked P300 component between repeat and switch conditions.

Appendix 4.4. Summary of results of repeated measures ANOVAs using the central sites on mean amplitudes of the stimulus-locked P3

	Factors	df	F-value	*P*-value	*partial eta*^{2}
4-way repeated ANOVA	validity	2,102	5.11	0.008**	0.091
	trial type	1,51	28.29	<0.001***	0.357
	site	1.475,75.225	53.31	<0.001***	0.511
	group	2,51	5.91	0.005**	0.188
	validity ×group	4,102	1.49	0.216	0.055
	trial type ×group	2,51	4.79	0.012*	0.158
	site ×group	2.950,75.225	0.74	0.529	0.028
	validity ×trial type	2,102	2.00	0.144	0.038
	validity ×site	2.621,133.670	13.34	<0.001***	0.207
	trial type ×site	1.484,75.680	0.46	0.573	0.009
	validity ×trial type ×group	4,102	0.75	0.550	0.029
	validity ×site ×group	5.242,133.670	1.03	0.404	0.039
	trial type ×site ×group	2.968,75.680	1.60	0.197	0.059
	validity ×trial type ×site	2.846,145.128	4.64	0.003**	0.083
	validity ×trial type ×site ×group	5.691,145.128	2.37	0.035*	0.085
3-way repeated ANOVA	100% validity: trial type ×site ×group	2.819,71.888	2.05	0.118	0.075
	75% validity: trial type ×site ×group	2.903,74.022	0.80	0.495	0.030
	50% validity: trial type ×site ×group	3.234,82.479	3.30	0.022*	0.115
2-way repeated ANOVA	Fz with 50% valid cue: trial type ×group	2,51	2.02	0.143	0.073
	Cz with 50% valid cue: trial type ×group	2,51	3.52	0.037*	0.121
	PZ with 50% valid cue: trial type ×group	2,51	4.14	0.021*	0.140

Note: * denotes <0.050; ** denotes <0.010; *** denotes <0.001

Appendix 4.5. Summary of results of repeated measures ANOVAs using the left and right sites on mean amplitudes of the cue-locked P3

Factors	df	F-value	*P*-value	*partial eta*^{2}
validity	2,102	13.37	<0.001***	0.208
trial type	1,51	0.75	0.392	0.014
site	1.304,66.527	189.85	<0.001***	0.788
hemisphere	1,51	0.29	0.592	0.006
group	1,51	0.11	0.898	0.004
validity ×group	4,102	0.88	0.476	0.034
trial type ×group	2,51	4.82	0.012*	0.159
site ×group	2.609,66.527	0.87	0.447	0.033
hemisphere ×group	2,51	1.74	0.185	0.064
validity ×trial type	2,102	2.28	0.108	0.043
validity ×site	2.304,117.528	31.39	<0.001***	0.381
validity ×hemisphere	2,102	3.26	0.043*	0.060
trial type ×site	1.276,65.054	0.27	0.663	0.005
trial type ×hemisphere	1,51	0.76	0.387	0.015
site ×hemisphere	2,102	11.76	<0.001***	0.187
validity ×trial type ×group	4,102	0.45	0.774	0.017
validity ×site ×group	4.609,117.528	0.65	0.647	0.025
validity ×hemisphere ×group	4,102	0.85	0.494	0.032
trial type ×site ×group	2.551,65.054	1.06	0.365	0.040
trial type × hemisphere × group	2,51	0.35	0.707	0.014
site ×hemisphere ×group	4,102	0.92	0.457	0.035
validity ×trial type × site	3.072,156.682	0.54	0.659	0.011
validity ×trial type ×hemisphere	2,102	1.99	0.142	0.038
validity ×site ×hemisphere	2.952,150.566	1.85	0.142	0.035
trial type ×site ×hemisphere	2,102	0.86	0.425	0.017
validity ×trial type ×site ×group	6.144,156.682	1.05	0.396	0.040
validity ×trial type ×hemisphere ×group	4,102	1.20	0.316	0.045
validity ×site ×hemisphere ×group	5.905,150.566	0.64	0.698	0.024
trial type ×site ×hemisphere ×group	4,102	0.45	0.772	0.017
validity ×trial type ×site ×hemisphere	3.212,163.810	0.33	0.819	0.006
validity ×trial type ×site ×hemisphere ×group	6.424,163.810	0.65	0.705	0.025
group	1,51	0.11	0.898	0.004

Note: * denotes <0.05; *** denotes <0.001

Appendix 4.6. **Summary of results of repeated measures ANOVAs using the left and right sites on mean amplitudes of the stimulus-locked P3**

Factors	df	F-value	*P*-value	*partial eta*^{2}
validity	2,102	2.15	0.122	0.040
trial type	1,51	32.37	<0.001***	0.388
site	1.273,64.941	36.88	<0.001***	0.420
hemisphere	1,51	0.02	0.893	0.001
group	1,51	5.43	0.007**	0.176
validity ×group	4,102	0.72	0.578	0.028
trial type ×group	2,51	5.27	0.008**	0.171
site ×group	2.547,64.941	0.46	0.683	0.018
hemisphere ×group	2,51	2.39	0.102	0.086
validity ×trial type	2,102	2.93	0.058	0.054
validity ×site	2.265,115.533	12.39	<0.001***	0.195
validity ×hemisphere	2,102	1.83	0.165	0.035
trial type ×site	1.288,65.692	0.07	0.850	0.001
trial type ×hemisphere	1,51	1.13	0.293	0.022
site ×hemisphere	1.579,80.551	1.15	0.313	0.022
validity ×trial type ×group	4,102	1.13	0.348	0.042
validity ×site ×group	4.531,115.533	1.13	0.350	0.042
validity ×hemisphere ×group	4,102	0.48	0.750	0.019
trial type ×site ×group	2.576,65.692	1.89	0.148	0.069
trial type × hemisphere ×group	2,51	1.97	0.149	0.072
site ×hemisphere ×group	3.159,80.551	0.39	0.773	0.015
validity ×trial type × site	2.937,149.779	1.80	0.152	0.034
validity ×trial type ×hemisphere	2,102	0.60	0.553	0.012
validity ×site ×hemisphere	2.962,151.050	2.30	0.080	0.043
trial type ×site ×hemisphere	2,102	0.99	0.375	0.019
validity ×trial type ×site ×group	5.874,149.779	1.20	0.309	0.045
validity ×trial type ×hemisphere ×group	4,102	1.67	0.162	0.062
validity ×site ×hemisphere ×group	5.924,151.050	1.26	0.279	0.047
trial type ×site ×hemisphere ×group	4,102	1.50	0.211	0.055
validity ×trial type ×site ×hemisphere	3.292,167.914	0.93	0.433	0.018
validity ×trial type ×site ×hemisphere ×group	6.585,167.914	0.43	0.871	0.017

Note: ** denotes <0.01; *** denotes <0.001

Appendix 4.7. Summary of results of repeated measures ANOVAs using the central sites on mean amplitudes of CNV

Factors	df	F-value	Sig.	*partial eta*^{2}
validity	2,102	27.952	<0.001***	0.354
trial type	1,51	0.906	0.346	0.017
site	2,102	45.116	<0.001***	0.469
group	2,51	8.309	0.001**	0.246
validity ×group	4,102	0.336	0.853	0.013
trial type ×group	2,51	1.521	0.228	0.056
site ×group	4,102	1.57	0.188	0.058
validity ×trial type	2,102	1.298	0.278	0.025
validity ×site	3.254,165.974	7.855	<0.001***	0.133
trial type ×site	1.663,84.809	1.492	0.232	0.028
validity ×trial type ×group	4,102	1.054	0.206	0.056
validity ×site ×group	6.509,165.974	0.402	0.889	0.016
trial type ×site ×group	3.326,84.809	2.182	0.090	0.079
validity ×trial type ×site	4,102	3.335	0.011*	0.061
validity ×trial type ×site ×group	6.061,154.546	1.041	0.401	0.039

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