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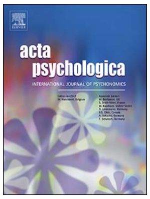

Motor skill experience modulates executive control for task switching

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ABSTRACT

This study aimed to investigate the effect of types of motor skills, including open and closed skills on enhancing proactive and reactive controls for task switching. Thirty-six athletes in open (n = 18) or closed (n = 18) sports and a control group (n = 18) completed the task-switching paradigm and the simple reaction task. The task-switching paradigm drew on the proactive and reactive control of executive functions, whereas the simple reaction task assessed the processing speed. Significant Validity × Group effect revealed that the participants with open skills had a lower switch cost of response time compared to the other two groups when the task cue was 100% valid; whereas the participants regardless of motor skills had a lower switch cost of response time compared to the control group when the task cue was 50% valid. Hierarchical stepwise regression analysis further confirmed these findings. For the simple reaction task, there were no differences found among the three groups. These findings suggest that experience in open skills has benefits of promoting both proactive and reactive controls for task switching, which corresponds to the activity context exposed by the participants. In contrast, experience in closed skills appears to only benefit development of reactive control for task switching. The neural mechanisms for the proactive and reactive controls of executive functions between experts with open and closed skills call for future study.

1. Introduction

Previous studies found that the experts in motor skills outperformed in executive control relative to non-experts in motor skills (Chan, Wong, Liu, Yu, & Yan, 2011; Kida, Oda, & Matsumura, 2005; Verburgh, Scherder, van Lange, & Oosterlaan, 2014). For instance, Chan et al. (2011) reported that in a Go/Nogo task high-fit fencing experts showed fewer errors on the Nogo condition than the high-fit non-experts, suggesting that fencing expertise led to better action inhibition. The motor skills that are potentially beneficial to executive function in young adults include fencing (Chan et al., 2011), baseball (Kida et al., 2005), basketball (Nakamoto & Mori, 2008b) and soccer (Verburgh et al., 2014).In general, motor skills can be briefly divided into open skills, which require players to react in a dynamically changing and externally paced environment (e.g., badminton, tennis, and football; Allard & Starkes, 1991; Wang et al., 2013), and closed skills, which require players to perform in a highly consistent, stationary, and self-paced environment (e.g., swimming or track and field; Allard & Starkes, 1991; Wang et al., 2013). The main difference between open and closed skills was suggested to be in the activity context, particularly the environment within which the activity is performed. The environment for closed skills is relatively more stable and consistent, while that for open skills is more changeable and demands rapid changes in response to the actions of an opponent (Di Russo et al., 2010; Eidson & Stadulis, 1991; Voss, Kramer, Basak, Prakash, & Roberts, 2010; Yu et al., 2016).

The more changing external environment such as what the open-skilled experts exposed to would have at least two characteristics when compared with the relatively stable external environment such as what the closed-skilled experts exposed to. First, the variability of changes in the environment in the former would be much wider than that of the latter. For example, a football player (defender) would need to immediately respond to how the opponent football players move and maneuver the ball, of which the defender's responsiveness to the changes in the environment would have impact on his performance (Verburgh et al., 2014). In contrast, a 1500-meter indoor swimmer is less likely to need to respond to the ways that other swimmers circle their arms and kick their feet, and hence the relatively more stable environment would have less impact on the swimmer's performance (Wang et al., 2013). Second, the sets of motor responses to be made by the open-skilled experts would be more diverse than those by the closed-skilled experts. Di Russo et al. (2010) explained that the motor responses made by closed-skilled experts tend to follow set patterns, and hence more consistent than open-skilled experts. In contrast, the motor responses made by open-skilled experts tend to vary contingent

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upon the environment in that particular instance.

The changing environment and hence diversity of the responses under high time pressure would demand open-skilled experts on having higher level of executive control in advance anticipation (Aglioti, Cesari, Romani, & Urgesi, 2008; Müller & Abernethy, 2012) and imperative responses (Di Russo et al., 2010, Wang et al., 2013) than closed-skilled experts. Advance anticipation is online updating of the external changes (McRobert, Ward, Eccles, & Williams, 2011) and predicting the outcomes due to these changes such as kinematic information of the other players (Aglioti et al., 2008; Müller & Abernethy, 2012). Imperative response involves initiating in-time actions in response to the external changes, which has been reported to tap on executive processes of cognitive flexibility (Taddei, Bultrini, Spinelli, & Di Russo, 2012), initiation of appropriate actions (Di Russo et al., 2010), and inhibition of inappropriate actions (Chan et al., 2011; Taddei et al., 2012).

Participation in open or closed-skilled sports provides a good basis for studying the effect of open and closed motor skills on executive functions of individuals. The reason is that players of sports particularly those who are ranked at the expert level would have engaged in high intensity, repetitive, and long term training for accomplishing the motor-related expertise. Recent studies on the effects of experts with open and closed motor skills on enhancing executive functions have revealed inconsistent results. For instance, Wang et al. (2013) reported that experts in open-skill sports exhibited stronger inhibitory function in a stop-signal task compared with those in closed-skill sports. Their results are inconsistent to those reported in Nakamoto and Mori's study (2008a) which employed both sport- and non-sport-specific Go/Nogo tasks. In the non-sport-specific Go/Nogo task, no significant differences in the behavioral and EEG results were revealed between the open- and closed-skilled experts. However, in the sport-specific Go/Nogo task, the open-skilled experts had shorter response time on the Go condition and more positive-going frontally distributed P300 on the Nogo condition than the closed-skilled experts. The results suggested that the open-skilled experts showed better inhibitory function than the closed-skilled experts only in sport-specific content. There are two shortfalls comparing the results reported in these two studies. First, the stop-signal task used by Wang et al. was non-sport-specific, while the Go/Nogo task used by Nakamoto and Mori had both sport- and non-sport-specific contents. Comparisons of the results between the two studies can only be those obtained from the non-sport-specific content, because the sport-specific content could be confounded by the sport experts' superior sport-related declarative and procedural knowledge which they had been familiar with. Second, previous studies revealed that stop-signal task required higher level of response inhibition ability than Go/Nogo task (Enriquez-Geppert, Konrad, Pantev, & Huster, 2010). What it means is that the task employed by Wang et al. could have been more sensitive on differentiating the inhibitory function between the open- and closed-skilled experts than those employed by Nakamoto and Mori. This study aimed to revisit the enhancement of executive functions among open- and closed-skilled experts using a cued task-switching paradigm based on the proactive and reactive controls model. The reason is that the cued task-switching paradigm, in which cue validity could manipulate the level of demands for proactive and reactive controls, is deemed more sensitive to detect the between-group differences on executive control than the stop signal task (Wang et al., 2013) or the Go/Nogo task (Nakamoto & Mori, 2008a).

A dual mechanisms of cognitive control model that demonstrated proactive and reactive controls (Braver, 2012; Braver, Gray, & Burgess, 2007) could potentially provide a more fine-grained understanding of the executive functions (e.g., switching function) related to open and closed skills. It is important to take proactive and reactive controls into account for understanding executive functions because executive control is a dynamic process, during which proactive control could reduce the cognitive demands for reactive control (Braver, 2012; Chikazoe et al., 2009; Karayanidis & Jamadar, 2014; Karayanidis et al., 2010). Proactive control is conceptualized as a form of early selection process. Goal-relevant information is actively maintained before cognitively demanding events occur. This early selection could optimally bias attention, perception, and action systems in a goal-driven manner (Braver, 2012). For example, badminton players would employed the opponent's body kinematics to anticipate the trajectory of a shuttle, which is a badminton equipment played by badminton players. This early anticipation could facilitate motor planning and enable a rapid and accurate response. On the other hand, reactive control is an imperative resolution of interference that occurs in a just-in-time manner after the target stimulus is presented (Braver, 2012). For example, a runner would exert a fine adjustment to his gait when running on a bumpy surface. Taking both proactive and reactive controls into account rather than treating executive control as a unity could provide a more comprehensive understanding of how different types of motor skills modulate executive functions.

Proactive and reactive controls can also be compared to motor feedforward and feedback controls which are common terms used for describing functionality of the motor system (Desmurget & Grafton, 2000; Seidler, Noll, & Thiers, 2004). Feedforward control is that a motor command is defined before the onset of movement. The motor command is pre-determined without taking into the account of online feedback and does not alter until a movement is completed. In contrast, feedback control is that plan and execution of a movement involve ongoing feedback from different systems based on which a movement is refined. With these in mind, proactive control involves early preparatory and selection process for a goal without considering responses from the prior event (Braver, 2012), of which the processes are similar to those in feedforward control. Reactive control occurs after the onset of external stimulus with just-in-time processes for resolving cognitive interference before making responses (Braver, 2012), of which the processes are similar to those in feedback control. Nevertheless, there are a few differences between proactive/reactive and feedforward/feedback controls. Proactive and reactive controls are higher-order cognitive processes relating to goal-directed regulation of thoughts or actions, and predominantly mediated by the fronto-parietal network (Braver, 2012; Braver et al., 2007). In contrast, feedforward and feedback controls are motor control processes relating to motor planning and execution of movement, and predominantly mediated by cortical (e.g. premotor cortex, posterior parietal cortex) and sub-cortical areas (e.g. putamen and cerebellum) (Desmurget & Grafton, 2000; Seidler et al., 2004). In the cued task-switching paradigm adopted in present study, the task preparation would occur before the onset of target stimulus and the response is required to be given after the target stimulus. Proactive and/or reactive control processes would be involved in different valid conditions (Swainson, Jackson, & Jackson, 2006). The 100% valid condition is likely to involve the strongest level of proactive control, whereby the set of responses is predictable and the action rule can be selected before the target stimulus. This would somehow involve feedforward control. In contrast, the 50% valid condition is likely to involve the strongest level of reactive control as set of responses is not predictable and action rule can only be selected after the target stimulus. This would predominantly involve feedback control. The cognitive control for task switching after target stimulus, which is to resolve the interference from the new stimulus-response implementation, is reactive control but predominantly involving feedback control (Tarantino, Mazzonetto, & Vallesi, 2016).

Proactive and reactive controls in terms of executive functions can be examined by using a task-switching paradigm, which involves a task cue that signifies whether an individual will repeat the previous task set or switch to a new task set before the appearance of the response-demanding stimulus (Kiesel et al., 2010; Meiran, 2010). Proactive control for task switching is individual switching to a corresponding task set before responding to a stimulus (Tarantino, et al., 2016). It requires feedforward control of updating the task set according to the task goal and maintaining it before the occurrence of a stimulus (Kiesel et al.,