Original Article

The relationship between action inhibition and athletic performance in elite badminton players and non-athletes

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ABSTRACT

Racket sports are among the most popular sports in the world. They require higher-order cognitive processes to execute complex actions to achieve successful performance on the court. Action inhibition is the ability to suppress ongoing actions; it is crucial to achieving higher levels of sports performance. The aim of the present study was to investigate the effect of expertise on action inhibition in badminton players and non-athletes. Current study recruited forty-two professional badminton players and matched fifteen non-athlete controls to participate in the study. Badminton player was asked to fill out the questionnaire for collect their information of training background. Matched participants then performed the stop signal task for evaluation of their action inhibition ability. We compare the difference in cognitive performance between badminton player and non-athlete controls group. The results showed that badminton players had a greater likelihood than non-athletes of successfully inhibiting their responses during stop trials. Furthermore, a strong positive correlation indicated that badminton players who participated in higher levels of competition had better performance on response inhibition. To concluded, the present study links the relationship between cognitive ability and athletic performance in badminton player. Moreover, the results of the present study on action inhibition in sports expertise may provide information for future sports training and benefits for those who suffer from cognitive difficulties. **Key words:** RACKET SPORTS, COGNITIVE ABILITY, ACTION CONTROL, SPORTS PERFORMANCE.

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INTRODUCTION

Inhibitory control is a critical cognitive function in daily life and is widely applied in real-life scenarios. For example, when a pedestrian crosses the street, the pedestrian needs to pay attention to traffic signals. This ability is well documented in the scientific literature. Several studies have suggested that inhibition ability is related to academic achievement (Visu-Petra et al., 2011), verbal intelligence (Lee et al, 2015), and even driving performance (Jongen et al., 2011; Mäntylä et al., 2009). This ability also plays an important role in survival in society and in life achievement.

However, the ability of action inhibition is not crucial only for the normal population or patients with cognitive difficulties; it is also important for elite athletes. To push the limits of human performance, elite athletes need to respond quickly and adapt to dynamic changes in their external environments. Specifically, elite athletes need to adjust or withhold their intended actions to respond to their opponents within a given period. Recent studies have reported the superior performance on action inhibition of athletes who experience high-intensity physical training, including elite fencers (Chan et al., 2011), tennis players (Wang et al., 2013), ultramarathon runners (Cona et al., 2015), soccer players (Verburgh et al., 2014; Vestberg et al., 2012), and volleyball players (Alves et al., 2013). For example, Wang et al. (2013) compared open skilled athletes (i.e., tennis players), closed skilled athletes (i.e., swimmers), and non-athletes to examine the psychological process of action inhibition by using a stop signal task. The stop signal reaction-time (SSRT) is an index for measuring inhibition of a motor response that has already been executed (Logan, 1994). The primary finding of their study was that the stop signal reaction times (SSRTs) of open skilled athletes were shorter than those of closed skilled athletes and non-athletes. Although they found that open skilled athletes have a better ability to inhibit motor responses, it is still unclear whether the effect on action inhibition exists generally or is specific to certain type of sports expertise. For example, Cona et al. (2015) investigated the influence of cognitive processes in closed skilled athletes (i.e., ultra-marathon runners) by performing a battery of computerized tests before their participation in an ultra-marathon. The results suggested that the ability to inhibit motor responses is greater in faster runners than in slower runners. This finding implies that the ability to inhibit motor responses may be affected by other potential factors, such as the level of expertise of the athletes, rather than the type of sports activity.

While the above studies provide some empirical evidence regarding how competitive sporting experience may improve an athlete's ability to inhibit actions, it remains unknown whether action inhibition ability affects sports performance. The present study also examined whether the effects of action inhibition exist in a different levels of racket sports expertise (i.e., badminton players). Hence, the purpose of the current study was to elucidate the underlying psychological process of action inhibition and the effects of the ability of action inhibition on sports performance. We hypothesized that that racket sports players (i.e., badminton players) would have superior performance on a motor inhibition task (i.e., the stop signal task) as compared to non-athletes. Furthermore, we expected that performance on inhibitory ability would be related to sports performance.

MATERIALS AND METHOS

Participants

All participants were provided consent forms and were informed of their rights and obligations before participating in the experiment. The study was reviewed and approved by the Institutional Review Board of University. Forty-two right-handed badminton players (male= 28, female = 14) aged 19 to 26 and fifteen non-athletes (male = 7, female = 8) aged 23 to 27 participated in the study. All 42 badminton players were members of national sports delegations and national intercollegiate competitors. All were also first-division elite athletes in our country. Nine were also ranked in the top 100 badminton players in the Badminton World Federation World Ranking. All participants had normal or corrected-to-normal visual accuracy and were right-handed. Prior to performing the psychological task, all participants completed a questionnaire that established their amount of training (training times per week), their age of commencement (starting training age), and their athletic achievements (level of competition). The purpose of the pre-test questionnaire was to understand the athletes' backgrounds of sports experience in order to determine which factor(s) contributed to their cognitive performance. The demographic information of all participants is reported in Table 1.

Table 1. Demographic Information of Participants.

Type	Badminton Player	Control	F	p
Total	42(F=14)	15(F=8)	N/A	
Age	22.7(±3.6)	26.1(±2.6)	10.71	0.002**
Education	15.6(±2.0)	17.1(±1.0)	6.606	0.013**
Level of competition	3.5(±1.8)	N/A	0.412	0.312
Starting Age	10.1(±1.6)		0.008	0.931
Duration of Training (Years)	11.2(±2.9)		1.256	0.275
Training Times per Week	5.7(±0.5)		17.091	0.001**
Practice Time per Day	5.5(±0.9)		0.003	0.955

*Values are given as mean (± standard deviation), **p<0.001.*

Apparatus
All experiments were conducted on ASUS A40JE Intel® Core™ i3 laptop computers with 14" displays, and the participants provided responses via the keyboard. The tasks were presented with custom software on the Windows system (i.e., STOP-IT) (Verbruggen, Logan, & Stevens, 2008).

Demographic information
We adopted the independent sample Student's t-test to compare the variables of age and years of education. The results of the between-group comparisons showed significant differences in demographic variables, including age ($F(1,55)$ = 10.7, p = .002, η_p^2 = .163) and years of education ($F(1,55)$ = 6.6, p= .013, η_p^2= .107).

Procedures
All participants were tested in a standard laboratory space. Participants were informed that they would be performing cognitive tests for a study about the intensity of physical activities and cognition and that their participation would take approximately 30 minutes. Behavioral tests were carried out with the stop signal task for all participants. The task consisted two phases: a practice phase of 32 trials and an experimental phase

of three blocks of 64 trials. The participants were given 1-minute breaks between blocks to mitigate the potential fatigue effect.

Action inhibition: Stop Signal Task

The stop signal paradigm was designed to investigate motor inhibition in a lab-based task (Logan, 1994). In the current study, we followed the procedures described in Verbruggen et al., (2008). The task consisted of visual and auditory stimuli. The parameter of visual stimuli included a fixation cross, a square (1.5 × 1.5 cm; each frame subtended a visual angle of approximately 1.43° × 1.43°, assuming a 60-cm viewing distance), and a circle (1.5 cm in diameter; each frame subtended a visual angle of approximately 1.43° × 1.43°, assuming a 60-cm viewing distance), and the auditory stimulus was a 750-Hz tone with a duration of 75 ms. The paradigm consisted of a practice block of 32 trials and three experimental blocks of 64 trials each. Each block consisted of 75% go trials and 25% stop trials, presented in random order. On a go trial, a fixation cross stimuli presented in the middle of the screen for 250 ms, followed immediately by a square or a circle in the same location. The participants were instructed to press the “slash” key when they saw a circle or the “Z” key when a square presented on the screen. The stimuli remained on the screen for a maximum of 1,250 ms or until the participant responded. The stop trials had the same parameters, except that a tone was presented briefly at designated intervals after the offset of the square or circle. Participants were asked to withhold their response when they perceived the stop signal. The time interval between the offset of the go targets and the onset of the tone (the stop signal delay) was set to 250 ms by default. When the participant successfully inhibited their response on a stop trial, the delay in the next stop trial was increased by 50 ms to increase the difficulty of withholding a response. Conversely, when the participant failed to withhold a response on a given stop trial, the delay was decreased by 50 ms to decrease the difficulty.

Data processing

We compared the cognitive performances of badminton players and non-athletes by analyzing the mean accuracies and RTs for the stop signal task and used the independent sample T-test. For the current study, we calculated the following variables: no-signal reaction time, stop signal reaction time, no-signal accuracy, and stop probability. We then entered the data into the independent t-test with the group to determine the effects of sports expertise on action inhibition. The primary index for the stop signal task is SSRT, an estimate of the participant’s capacity for inhibiting prepotent motor responses. SSRT was calculated by subtracting the mean stop signal delay from the mean RT to go stimuli (go RT). In addition, another index of interest was stopping probability, an estimate of the proportion of preponent motor responses successfully inhibited by the participant. We estimated the effect sizes using partial eta squared (η_p^2) for the means of group comparisons. Analyses were conducted using SPSS/PASW Statistics (Version 18.0. Chicago: SPSS Inc.)[1]. In our hypothesis testing, we set the alpha levels at .05 for all tests.

RESULTS

Results of Stop Signal Task

The results of the stop signal task are summarized in Table 2. Between-group comparisons were conducted to analyze the no-signal reaction time, stop signal reaction time, no-signal accuracy, and stop probability by using the independent sample t-test.

[1] *Note. Because of a dispute over ownership of the name "SPSS", between 2009 and 2010, the product was referred to as PASW (Predictive Analytics SoftWare).*

For the no-signal RT variable, the results of the independent t-test did not reveal significant expertise effects on no-signal reaction time (i.e., response time without a stop signal occurring) (F(1,55) = 1.872, p = 0.177, *MSE* = 26.8 η_p^2 = 0.03) and thus no difference in basic sensorimotor speed between badminton players and non-athletes. For the stop signal RT (SSRT), no group effect of SSRT (i.e., the time taken after a stop signal is presented for inhibition to be completed) (F(1,55) = 2.520, p = 0.118, *MSE* = 6.8 η_p^2 = 0.044) was observed, possibly indicating no difference in stopping efficacy between badminton players and non-athletes. In addition, we also observed no difference in accuracy for the no-signal condition (F(1,55) = 0.556, p = 0.647, *MSE* = 24.3 η_p^2 = 0.03). However, a significant difference on stop possibility (i.e., the likelihood of stopping a prepotent response, see Figure 1) was found between badminton players and non-athletes (F(1,55) = 0.002, p = 0.963, *MSE* = 0.52 η_p^2 = 0.00), which reflects that badminton players had greater likelihood of successfully stopping prepotent responses. Specifically, the correlation analysis showed that badminton players who participated in higher levels of sports competition had greater likelihood of successfully stopping prepotent responses (r=.442, p=.003) (Table 3).

Table 2. Summary of results of the stop signal task.

Group	Badminton Players	Non-Athletes
SP	37.3(±13.8)	45.8(±13.1)
SSRT	304.1(±51.7)	279.8(±48.4)
NSRT	729.9(±194.0)	647.3(±219.5)
NSACC	96.9(±4.03)	97.0(±3.83)

Values are given as mean (± standard deviation).
SP: stop possibility; SSRT: stop signal reaction time; NSRT: no signal reaction time; NSACC: no-signal accuracy.

Table 3. Correlations between task performance and sports experience.

	SP	SSRT	NS_RT	NS_ACC
EDU	0.254	-0.088	-.276*	.401**
LC	.442**	.309*	-.328*	.432**
SA	0.165	0.081	-0.267	.460**
DTY	0.265	0.17	-0.202	.335*
TTPW	-0.042	0.076	0.136	-.320*
PTPD	0.145	-0.002	-0.114	0.258

***Correlation is significant at the 0.01 level (2-tailed); *Correlation is significant at the 0.05 level (2-tailed). EDU: years of education; LC: levels of competition; SA: starting age for sports training; DTY: duration of training years ; TTPW: training times per week; PTPD: practice time per day.*

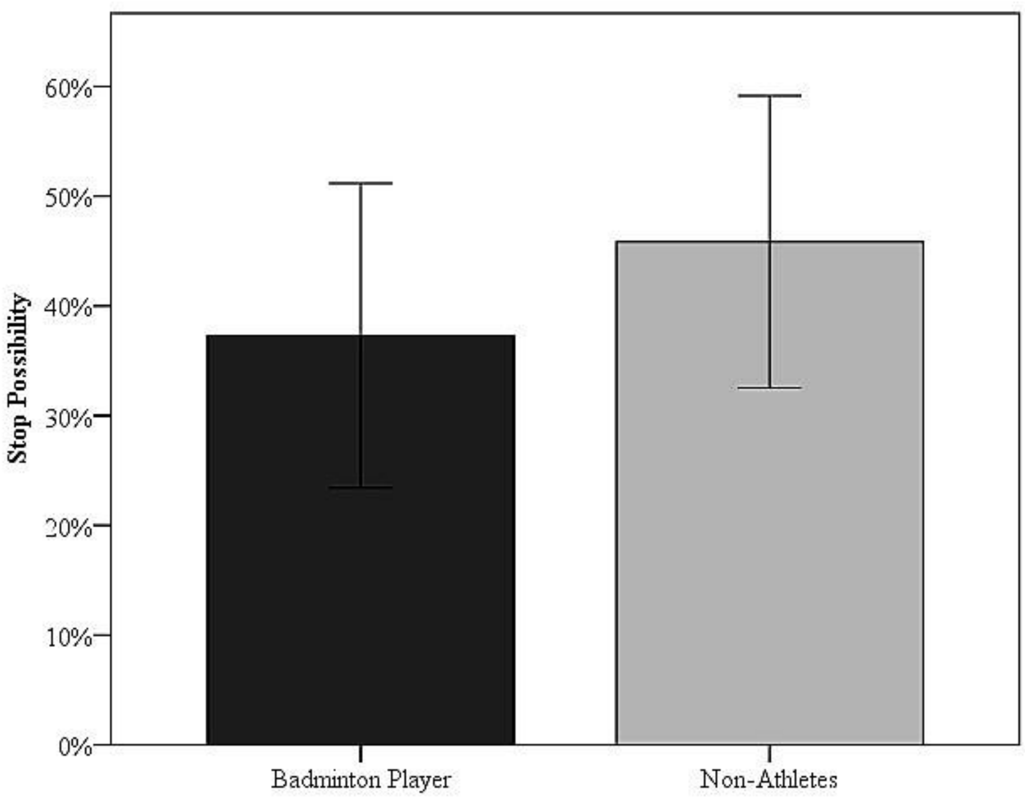

Figure 1. Stop possibility of the stop signal task.
Error bar indicated as ± standard deviation.

DISCUSSION

This study investigated the expertise effects of action inhibition in elite badminton players and non-athletes and whether that ability is related to sports performance in elite badminton players. As predicted, our primary findings demonstrated that badminton players had greater likelihood than non-athletes of successfully inhibiting motor responses. More specifically, a strong positive correlation was found between sports achievements and motor inhibition; the elite badminton players who participated in higher-level competitions had greater likelihood of successfully withholding a response. In other words, the ability to inhibit an ongoing action is crucial for participants in higher-level competition. Among the racket sports, the shuttlecock of badminton has been recorded as the fastest moving object (i.e., 408 km/h (253.55 mph)); thus, it is reasonable to infer that elite badminton players need to adjust their actions in response to ultra-fast changes in their environment quite rapidly (Ooi et al., 2009).

While we observed the expertise effect of motor inhibition in badminton players, the primary index of the stop signal task (i.e., SSRT) showed no difference between athletes and non-athletes, even though SSRT reflects the ability to stop an ongoing motor response. Previous sports expertise studies on inhibition have suggested that the difference between athletes and inactive people can be observed from the stop signal reaction time in the stop signal paradigm (Verburgh et al., 2014; Wang et al., 2013). For instance, Verburgh et al. (2014) examined executive function by using the stop signal paradigm for motor inhibition in highly talented soccer players. Their results showed that the highly talented group had superior motor inhibition as measured by SSRT on the stop signal task, indicating that talented soccer players had a better ability to inhibit intended actions, which may be an important factor for success in soccer. One explanation for why our results revealed no difference may be the years of education variable in the control groups. This factor has been reported to influence cognitive function (Fichman et al., 2009; S Lee et al., 2003). For example, de Azeredo Passos et al. (2015) investigated the influences of sex, age, and education on cognitive tests in a large sample-size cohort study. Their results revealed that poor performance on cognitive tests was observed with increasing age and, notably, with decreasing level of education (de Passos et al., 2015). Considering this design flaw, we hereby suggest that future studies more cautiously control the participants' demographic factors to avoid type I errors.

Moreover, we also captured no group difference between badminton players and non-athletes on no-signal reaction time or no-signal accuracy, suggesting that fundamental sensorimotor speed did not influence performance on the inhibition task.

CONCLUSIONS

To summarize, the present study found that elite badminton players had greater likelihood to successfully inhibit their motor responses during stop signal trials. Specifically, we also demonstrated that elite badminton players who participated in higher-level competition were more likely to inhibit their responses successfully. However, the results of this study should be interpreted cautiously due to the unbalanced sample sizes of the athletes and the non-athletes in the control group.

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