Journal of Sport and Exercise Psychology, 2009, 31, 554-565

Decision Making in Elite White-Water Athletes Paddling on a Kayak Ergometer

Karen Davranche,[1,2] Danny Paleresompoulle,[1] Rémy Pernaud,[1] Julie Labarelle,[1,3] and Thierry Hasbroucq[1]

[1]Université de Provence & CNRS; [2]University of Chichester; [3]Pôle Espoir de Canoë-Kayak de Marseille and Fédération Française de Canoë-Kayak

The present study investigated the effects of acute paddling on performance in a typical decision-making task. It was aimed at assessing whether the effects of moderate exercise can be replicated using the feet as response effectors when physical exercise essentially solicits upper-body muscles. Twelve national-level paddling athletes performed a Simon task while paddling at a moderate (75% of maximal heart rate, HR_{max}) and at very light (40% of HR_{max}) intensities. The results showed that the effects of moderate exercise can be generalized to exercises involving different response effectors and upper-body muscle groups. They suggest (1) that the activation-suppression hypothesis (Ridderinkhof, 2002) holds when the task is performed with the feet, and (2) that moderate exercise speeds up reaction time and impairs the suppression of direct response activation.

Keywords: reaction time distribution, moderate exercise, activation-suppression hypothesis, response effectors, upper-body muscles

In sporting activities, successful performance requires filtering relevant information and selecting actions consistent with current goals. Performance is thus linked to the athlete's ability to simultaneously deal with cognitive and physical requirements. The effects of acute exercise on information processing have been studied in a wide range of reaction time (RT) tasks performed either simultaneously or following exercise (for a detailed review, see Tomporowski, 2003).

Choice RT is on average shorter when the task is performed concomitantly with a moderate exercise than when it is performed at rest (e.g., Davranche, Burle,

Davranche is with the Laboratoire de Neurobiologie de la Cognition, Université de Provence & CNRS, Marseille, France, and the Sport, Exercise, and Health Sciences Department, University of Chichester, Chichester, West Sussex, U.K. Paleresompoulle, Pernaud, and Hasbroucq are with the Laboratoire de Neurobiologie de la Cognition, Université de Provence & CNRS, Marseille, France. Labarelle is with the Laboratoire de Neurobiologie de la Cognition, Université de Provence & CNRS, Marseille, France, and Pôle Espoir de Canoë-Kayak de Marseille, Fédération Française de Canoë-Kayak, Marseille, France.

Audiffren, & Hasbroucq, 2005). Higher level of nervous system activation (McMorris & Graydon, 2000) or greater efficiency of the peripheral motor processes at exercise than at rest (Davranche et al., 2005) could account for these results. Although mean RT and average error rate do provide valuable information relative to cognitive processes, more-detailed data analyses uncover modulations that the sole consideration of central tendency indices cannot reveal. Reaction time distribution analyses have proved to be powerful for assessing the processes implemented during decision-making tasks and in the Simon task in particular. The Simon task is a classical paradigm used to study how irrelevant spatial relationships between stimuli and responses affect human decisions (for a review, see Simon, 1990). In the most common version of this task, the participants have to choose between a left- and a right-hand button press according to the color of a visual stimulus presented either to the left or the right of a fixation point. Mean RT is shorter for same-side (congruent, CO) stimulus-response associations than for different-side (incongruent, IN) stimulus-response associations (Craft & Simon, 1970). This phenomenon is known as the *Simon effect* and is interpreted as resulting from a conflict between alternative responses. It is currently considered that the information conveyed by the stimulus is processed via two parallel routes, one indirect and relatively slow, and one direct and fast. The irrelevant stimulus location is thought to activate its spatially corresponding response via the direct route whereas the relevant stimulus feature (e.g., the color) activates the correct response via the indirect route (De Jong, Liang, & Lauber, 1994; Kornblum, Hasbroucq, & Osman, 1990; Proctor, Lu, Wang, & Dutta, 1995). When the stimulus-response association is CO, the direct route activates the correct response, thereby facilitating its implementation. In contrast, when the stimulus-response association is IN, the direct route activates the incorrect response and this response competes with the correct one, thereby impairing its implementation.

In this framework, Ridderinkhof (2002) proposed that after being activated via the direct route, the response is later on actively inhibited. This proposal is referred to as the *activation-suppression hypothesis*. Arguments in favor of this notion rely on the analysis of delta plots, which represent the differences between the distribution curves of two experimental conditions (see Methods for details). This analysis revealed that the size of the Simon effect decreases as RT increases; that is, the later the response, the less the irrelevant stimulus location affects RT. According to Ridderinkhof, such a decrease reflects the implementation of within-trial inhibitory processes. So far, negative-going delta plots have been observed only when the participants were to make manual responses to visually presented stimuli. In particular, Wascher, Schatz, Kuder, and Verleger (2001) and Wiegand and Wascher (2005) could not observe this with auditory stimuli and proposed that the suppression of the direct activation in the visuo-manual version of the Simon task is tied to the special ecological status of primates' reaching behavior, which would rely on a natural, direct integration of visual and motor systems. Other task conditions would preclude the direct route access to the motor system, alleviating the need to implement the within-trial inhibitory control formalized by Ridderinkhof (2002).

Recently, delta-plot analysis has been applied to assess the effects of a moderate physical exercise on inhibitory control (Davranche & McMorris, 2009). Participants with a high or very high fitness level performed a Simon task during a

20-min steady-state cycling exercise at ventilatory threshold intensity (corresponding on average to 77% ± 4 of maximal heart rate, HR_{max}). Davranche and McMorris observed faster mean RTs without change in accuracy when the Simon task was performed simultaneously with the exercise compared with rest. The authors further reported a more pronounced Simon effect on mean RT during exercise (+39 ms) than at rest (+31 ms), which was interpreted as a deterioration of inhibitory control during moderate exercise. More importantly, the delta plot turned less negative during exercise than during rest, which suggests that the inhibitory control of direct response activation was impaired by physical exercise. Since the task required manual response to lateralized visual stimuli, this result is compatible with Wascher and colleagues' view and its generalization to task performed with other response effectors is unwarranted.

The aim of the current study was to decipher whether the effects of moderate exercise on the Simon task can be replicated with other response effectors. To this end, the participants were asked to respond to lateralized visual stimuli with the feet while performing a physical exercise close to the requirements of paddling activities and involving upper-body muscles. We hypothesized that the suppression of the direct activation could be generalized across task conditions and expected to replicate the results of Davranche and McMorris. More precisely, we expected (i) a decrease of the size of the Simon effect as RT increases; (ii) faster mean RT when the Simon task is performed concurrently with a moderate compared with a light exercise; (iii) a larger Simon effect during moderate compared with a light exercise; and (iv) a divergence in the dynamics of the delta plot curves across exercise conditions, with the delta plots turning to negative later for moderate than for light exercise.

Method

Participants

Participants (N = 12) were cadet (between 14 and 16 years of age), junior (under 18 years of age), and senior (between 18 and 35 years of age) national-level whitewater paddling athletes with a very high level of activity (8 ± 2 trainings per week). Volunteers signed written consent forms and were fully informed about the protocol. Participants' anthropometrical and physiological characteristics are presented in Table 1.

Design and Task

Participants sat on a kayak ergometer (Dansprint, Denmark) fully adjustable for a perfect fit. Two green/red light-emitting diodes (LEDs), separated by 10 cm, were positioned at both sides of a black panel placed 1.6 m in front of the participant. Two force sensors, separated by 8 cm, were fixed on the right and the left sides of the footrest. Participants were asked to exert a press with the big toe, as quickly and accurately as possible, on the right or on the left force sensor as soon as one of a LEDs lit up. The light could be green or red and could be delivered either to the left or to the right side. Participants were asked to respond according to the color of the LED (task-relevant attribute), and to ignore the location of the LED (the task-irrelevant attribute). Six participants had to exert a press with the left big

Table 1 Participants' Anthropometrical and Physiological Characteristics

Variable	Mean ± *SD*		
	All	Female	Male
Sample size	12	4	8
Age (years)	18 ± 4	20 ± 6	17 ± 2
Height (cm)	176 ± 6	169 ± 4	179 ± 4
Weight (kg)	68 ± 9	58 ± 4	73 ± 5
HR rest (bpm)	70 ± 8	66 ± 11	72 ± 5
HR max (bpm)	192 ± 7	195 ± 7	190 ± 7
Light session (bpm)	77 ± 9	72 ± 12	79 ± 6
% HR_{max}	40 ± 4	37 ± 5	42 ± 3
Moderate session (bpm)	143 ± 6	143 ± 9	143 ± 5
% HR_{max}	75 ± 2	73 ± 2	75 ± 1

toe when the LED was red and a press with the right big toe when the LED was green, the six other participants were to perform the reverse stimulus-response mapping. Each block was self-initiated by a press exerted on one of the two sensors. At the end of each trial, an auditory signal was delivered (1600 Hz, 75 dB, 200 ms) to inform the participant of the recording of the response. The delivery of a response turned off the stimulus and the next trial began. The intertrial interval was 1 s. There were two types of trials in each block: congruent trials (50%) and incongruent trials (50%). In congruent trials (CO), the lateral locations of the stimulus and response corresponded (e.g., left stimulus/left response). In contrast, in incongruent trials (IN), the lateral locations of the stimulus and response counter-corresponded (e.g., left stimulus/right response). For a video illustration, see http://karen.davranche.free.fr/Videoprotocol.avi

Experimental Procedure

Participants took part in two separate sessions run on different days: a pretest session and an experimental session. The resistance of the rotating fan, chosen to allow an uncontrived paddling movement at a reasonable stroke rate, was maintained constant throughout the experiment (male: 6/10 and female: 4/10). During the pretest session, participants undertook a habituation session on the Simon conflict task, consisting of two blocks of 64 trials each performed at rest and while paddling. This was followed by a continuous incremental protocol until exhaustion on a kayak ergometer to determine the exercise workload of the experimental session. The maximal test began by a 5-min warm-up at 50 W, and then the workload progressively increased until exhaustion (male: 20 W/min and female: 15 W/min). The baseline heart rate (HR_{rest}) and HR_{max} recorded during the pretest session are reported in Table 1. During the experimental session, participants were required to perform the cognitive task simultaneously with paddling. A first set of five blocks of 64 trials each was performed while paddling at a very light intensity fixed at 10% (± 2.5%) above HR_{rest} and a second set of 5 blocks of 64 trials each was performed at a moderate intensity. The moderate exercise intensity was obtained using the Karvonen formula (Brooks, Fahey, & White, 1996) for calculating a target heart rate (THR) corresponding to a 60% (±2.5%) intensity (see Table 1 for equivalence in beat per minute and percentage of HR_{max}).

$$THR = [(HR_{max} - HR_{rest}) \times \%\ intensity + HR_{rest}]$$

The order of the sets was counterbalanced across participants and the two sets were separated by a resting period about 15 min. Each set began with a 10-min warm-up, which allowed participants, first and foremost, to individually adjust his or her stroke rate and stroke power to reach the required intensity (% HR_{max}). Then the five blocks were successively administrated and participants were asked to keep paddling during the transition between blocks (30 s). These "cognitive breaks," at the end of each block, have been used to adjust the intensity of the effort by keeping the HR close to the THR. The exercise duration of each set, including the warm-up period, was about 24 min.

Data Processing

In each exercise condition, RT-distributions (for CO and IN trials separately) were obtained using individual RT-distributions "Vincentized" (Ratcliff, 1979) into five equal-size speed bins (quintiles). Delta plots were then constructed by plotting the congruence effect size (IN minus CO) as function of response speed (average of means RTs in the CO and IN conditions per quintile). The point of divergence in the dynamics of the delta plot curves is a relevant variable because it indexes the level of inhibitory and the strength of inhibitory processes (for details, see Ridderinkhof, 2002). Slopes were computed for the delta plot segments by connecting the data points of Quintiles 1 and 2, Quintiles 2 and 3, Quintiles 3 and 4, and Quintiles 4 and 5.

Data Analysis

The arcsine transforms of the error rate, the mean RT, and the delta plot analysis were submitted to repeated-measures ANOVAs with exercise conditions and congruency as within-participant factors. Greenhouse–Geisser degree-of-freedom correction was applied when necessary. Significance was set at $p < .05$ for all analyses. Effect sizes were calculated using partial eta square (η_p^2). Repeated-measures ANOVAs involving exercise condition, congruency, and quintiles as within-participant factors were performed on RT distributions to determine point of divergence in the dynamics of the delta plot curves. A set of ANOVAs involving exercise and quintile as within-participant factors was conducted on the delta plot segments.

Results

Response Accuracy

The arcsine transforms of decision error rate were submitted to an ANOVA involving exercise condition (moderate vs. light) and congruence (CO vs. IN) as within-participant factors. This analysis did not reveal any significant effect of exercise condition and congruence, neither as main effects nor as interaction (*F*s < 1). Thus, the RT changes observed through the manipulation of these two factors could not be explained by a speed–accuracy trade-off (Pachella, 1974).

Reaction Time

An ANOVA involving exercise condition and congruence as within-participant factors was performed on mean RT. Results showed shorter RT during moderate compared with light exercise, $F(1, 11) = 7.44$, $p = .02$, $\eta_p^2 = .40$, and, as typically observed in the Simon task, congruent trials were faster than incongruent trials, $F(1, 11) = 19.46$, $p = .001$, $\eta_p^2 = .64$. There was no interaction between exercise condition and congruence ($F < 1$). Table 2 shows percentages of decision error, mean RT, standard deviations, and effects size for congruent and incongruent trials during moderate and light exercises.

Delta Plot Analysis of Reaction Time

A first ANOVA involving exercise condition, congruence, and quintile was conducted on Vincentized RT data. The analysis confirmed a main effect of exercise, $F(1, 11) = 6.47$, $p = .03$, $\eta_p^2 = .37$, and a main effect of congruence, $F(1, 11) = 10.47$, $p = .01$, $\eta_p^2 = .49$. In addition, results showed a main effect of quintile, $F(1, 12) = 285.09$, $p < .001$, $\eta_p^2 = .96$; an interaction between exercise condition and quintile, $F(1, 14) = 5.30$, $p = .03$, $\eta_p^2 = .32$; and an interaction between congruence and quintile, $F(2, 23) = 3.69$, $p = .04$, $\eta_p^2 = .25$. The three-term interaction between exercise condition, congruence, and quintile was not significant ($F < 1$). Post hoc Newman–Keuls analyses were conducted to better characterize the two significant interactions.

First, irrespective of exercise condition, the Simon effect was less pronounced for slow RT than for the fast RT (see Figure 1, left). The Simon effect was significant for the early quintiles (q1, $p < .001$; q2, $p < .001$; q3, $p = .01$) but was not significant after the third quintile (q4, $p = .24$; q5, $p = .69$). A second ANOVA was conducted on the delta plots curve to assess the magnitude of the Simon effect as a function of the response speed. This analysis revealed that compared with the first quintile (24 ms) the interference was smaller for the fourth (6 ms; $p = .04$) and the fifth (2 ms; $p = .01$) quintiles (see Figure 1, right).

Second, irrespective of congruence, the effect of exercise was more pronounced for slow RTs than for fast RTs (see Figure 2, left). The effect of exercise was significant for all quintiles (q2, $p = .02$; q3, $p < .002$; q4, $p < .001$; q5, $p < .001$), except the first quintile ($p = .21$). A second ANOVA was conducted on the delta plots curve to assess the magnitude of this effect as a function of the response speed. As depicted in Figure 2 (right), the magnitude of the effect significantly increased between the first and the fifth quintiles ($p = .02$) and tended to increase between the first and the fourth quintiles ($p = .09$).

A second set of ANOVAs, focused on the Simon effect on the delta plot slopes, was conducted to examine whether it was possible to identify a point in time for which the delta plot curves diverge between moderate and light exercise. Because a point of divergence in the dynamics of the delta plot curves, with a turn

Table 2 Percentages of Decision Errors, Mean Reaction Time (RT), and *SD* per Exercise Condition and Congruence in the Simon Task

	Signal-Response Congruence				
	Congruent		Incongruent		
Exercise Condition	% Error	RT	% Error	RT	Simon Effect Size (ms)
Light exercise	1.31 (1.08)	607 (86)	1.41 (1.04)	622 (76)	15
Moderate exercise	1.57 (0.94)	549 (67)	2.45 (3.26)	565 (72)	16
Exercise effect size (ms)	—	58	—	57	—

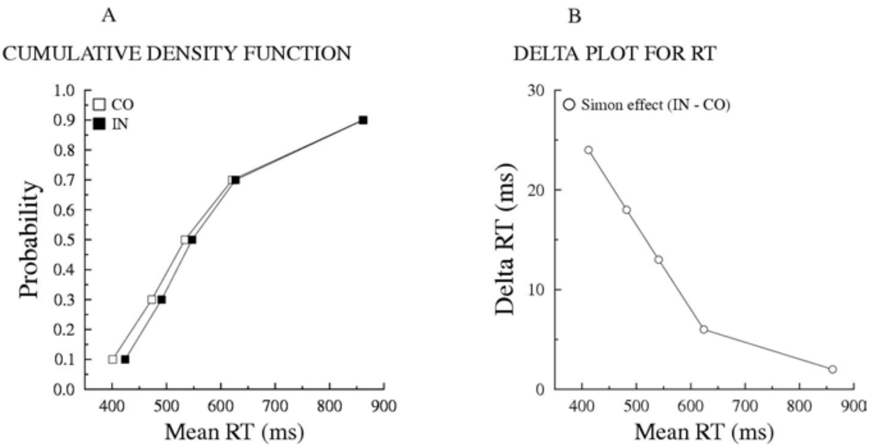

Figure 1 — Left: cumulative density functions for congruent (empty circles) and incongruent (full circles) trials. Right: delta plots for the effect of congruence during the Simon task as a function of increasing RT.

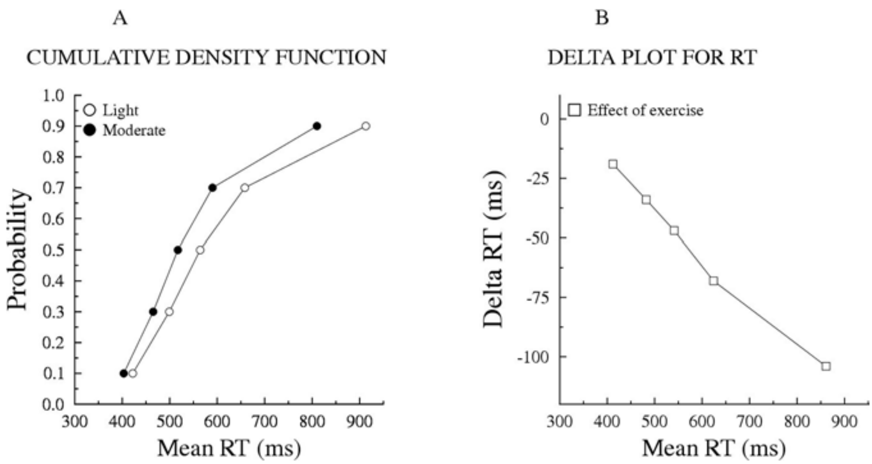

Figure 2 — Left: cumulative density functions during light intensity (empty circles) and moderate intensity (full circles) conditions. Right: delta plots for the effect of exercise as a function of increasing RT.

from positive to negative later during moderate compared with light exercise, was predicted on the basis of previous results (Davranche & McMorris, 2009), we used a one-tailed F test. Results showed that the slopes between quintile points turn from positive to more negative later during moderate compared with light exercise. The difference was significant for q1–2 level, $F(1, 11) = 3.80$, $p = .04$; $\eta_p^2 = .26$, and not significant for other segments: q2–3: $F(1, 11) = 2.29$, $p = .08$; d3–4: $F < 1$; d4–5: $F < 1$. (See Figure 3.)

Discussion

The present study attempted to decipher whether the effects of a moderate exercise on the Simon task can be replicated with the big toes as response effectors. The exercise, which essentially involved upper-body muscles, consisted in paddling on a kayak ergometer and was performed by elite white-water athletes. Most of the results replicated those obtained by Davranche and McMorris (2009) in high-fitness-level participants performing a visuo-manual Simon task while cycling. Such a replication indicates that the previous results cannot be attributed to the strong coupling between vision and hand movements. In addition, the effect of exercise on RT had so far been studied with cycle-ergometer or treadmill exercises that solicit lower-body muscles. The present results thus show that effects of moderate exercise can be replicated with physical exercises essentially involving upper-body muscles.

Mean Reaction Time

Mean RT performance was better (faster without change in accuracy) when the Simon task was performed with the feet concurrently with a moderate paddling exercise compared with a light paddling exercise. This beneficial effect is consistent with previous RT results obtained with manual responses during moderate exercise involving lower-body muscle activation (e.g., Davranche et al., 2005; Davranche & McMorris, 2009; Pesce, Tessitore, Cassella, Pirritano, & Capranica, 2007). This supports the view that the effect of exercise on mean RT is not restricted to the activation of lower-body muscles. As expected on the basis of numerous previous studies, IN associations lead to longer mean RT than CO associations. This effect, classically observed with the hands as response effectors, has already been obtained with the feet as response effectors (Leuthold & Schröter, 2006; Rubichi, Nicoletti, Pelosi, & Umiltà, 2004). There was no difference in the magnitude of the Simon effect between the two exercise conditions (moderate

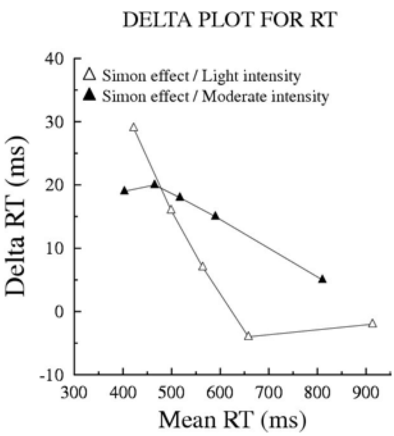

Figure 3 — Delta plots for congruence effect during the Simon task as a function of increasing RT during light-intensity (empty circles) and moderate-intensity (full circles) conditions.

intensity: +16 ms; light intensity: +15 ms). This pattern is at variance with that reported by Davranche and McMorris (2009). In this previous study, the Simon effect was larger during a moderate cycling exercise than at rest. However, unlike the cutting-edge cycle ergometer used by Davranche and McMorris, the present kayak ergometer did not automatically adjust the resistance of the fan as a function of paddling rate. Thus, participants self-adjusted their HR to reach the target intensity between blocks to maintain constant exercise intensity. The information provided by a HR monitor fixed on the footrest allowed them to adjust the power output by modifying their stroke rate, stroke power, and technical movement. In addition to the difficulty of responding with the feet while paddling, the monitoring of HR fluctuations made the present task more complex than that of Davranche and McMorris. To match the difficulty of the two task conditions, we contrasted the moderate exercise condition to a very light exercise condition rather than to a rest condition (i.e., a task performed while the participants would have simply sat on the ergometer without paddling). A negative counterpart of this methodological choice is that the effect of exercise may have been underestimated, which increases the risk of committing a type II error.

Delta Plot Analysis

The results of the current study showed that the amplitude of the Simon effect decreased as RT increased, which indicates that the interference was less pronounced for slow RTs than for fast RTs. In line with the activation-suppression hypothesis (Ridderinkhof, 2002), the dynamics of the delta plots suggests that the ability to inhibit the response activated along the direct route response is less efficient during moderate than during light exercise. In addition, contrary to previous findings (Davranche et al., 2005, Davranche, Audiffren, & Denjean, 2006), the facilitating effect of exercise was not constant throughout the whole RT distribution but increased as RT increased.

A decrease in the Simon effect as RTs increase is usually reported in the literature when hands are used as response effectors (Ridderinkhof, 2002). However, according to Wascher and colleagues, such a direct integration would be “hard-wired” because of the special ecological status of humans’ reaching and grasping behaviors (Wascher et al., 2001, page 734). Other task conditions would prevent direct access of stimuli to the motor system, alleviating the need to inhibit the activation of the congruent response along the direct route. The results of present study are at odds with this proposal. Indeed, while foot reaching and grasping certainly do not belong to human natural action repertoire, the size of the Simon effect diminished as RT increased while the feet were used as response effectors. This shows that the activation-suppression hypothesis (Ridderinkhof, 2002) can be generalized to different task conditions. In this context, the present delta plot results support the view that moderate exercise impairs the ability to suppress the response activated by the direct route. This interpretation is in line with the Davranche and McMorris (2009) results obtained with high-fitness-level participants performing a visuo-manual Simon task while cycling. However, contrary to the Davranche and McMorris findings, in the current study the difference in inhibitory control across exercise conditions is likely not strong enough to cause a significant interaction on mean RT.

The finding that the effect of exercise increased with RT differs from previous results (Davranche et al., 2005, 2006) showing a shift of the distribution toward the left without modification of the form of the RT distribution. These previous studies indicate that the beneficial effect of cycling is small but constant throughout the whole RT distribution. The difference between these results and the present ones may be due to the response device. In former studies, Davranche and collaborators used low travel buttons or very sensitive levers and light muscle activations were sufficient to trigger the responses, ensuring little variability in movement times. In the current study, participants exerted a press with the big toe on force sensors and, as function of the paddler's position, the amplitude—and thus the timing—of the response movement was more variable than in the previous studies. Such an increase in variability can cause the delta plots to increase with the rank of the quintile (for a thoughtful explanation, see Zhang & Kornblum, 1997). Note that the expertise of the elite kayakers selected for this study was likely beneficial to performing the task. Their competence allowed them (i) to avoid pushing off the board with their toes, which were thus free for task completion, and (ii) to adapt the movement to conserve their balance without disturbing response speed. A population without kayaking experience would probably be unable to perform the present task especially at 75% of HR_{max}.

In summary, the current study shows that (i) that the activation-suppression hypothesis holds when the Simon task is performed with the feet and (ii) that moderate exercise enhances participants' ability to execute responses under time pressure, and impairs the suppression of the response activated along the direct route in the Simon task. Despite the specificity of the sample, the present findings suggest that the effects of moderate exercise can be generalized to tasks performed with different response effectors during exercises essentially soliciting muscles of the upper body.

References

Craft, J.L., & Simon, J.R. (1970). Processing symbolic information from a visual display: Interference from an irrelevant directional cue? *Journal of Experimental Psychology, 83,* 415–420.

Brooks, G.A., Fahey, T.D., & White, T.P. (1996). *Exercise physiology* (2nd ed.). Mountain View, CA: Mayfield Publishing Company.

Davranche, K., Audiffren, M., & Denjean, A. (2006). A distributional analysis of the effect of physical exercise on choice reaction time task. *Journal of Sports Sciences, 24*(3), 323–329.

Davranche, K., Burle, B., Audiffren, M., & Hasbroucq, T. (2005). Information processing during physical exercise: a chronometric and electromyographic study. *Experimental Brain Research. Experimentelle Hirnforschung. Experimentation Cerebrale, 165*(4), 532–540.

Davranche, K., & McMorris, T. (2009). Specific effects of acute moderate exercise on cognitive control. *Brain and Cognition, 69*(3), 565–570.

De Jong, R., Liang, C-C., & Lauber, E. (1994). Conditional and unconditional automaticity: A dual-process model of effects of spatial stimulus-response correspondence. *Journal of Experimental Psychology. Human Perception and Performance, 20,* 731–750.

Kornblum, S., Hasbroucq, T., & Osman, A. (1990). Dimensional overlap: Cognitive basis for stimulus-response compatibility. A model and taxonomy. *Psychological Review, 97,* 253–270.

Leuthold, H., & Schröter, H. (2006). Electrophysiological evidence for response priming and conflict regulation in the auditory Simon task. *Brain Research, 1097,* 167–180.

McMorris, T., & Graydon, J. (2000). The effect of incremental exercise on cognitive performance. *International Journal of Sport Psychology, 31,* 66–81.

Pachella, R.G. (1974). The interpretation of reaction time in information-processing research. In B. Kantowitz (Ed.). *Human information processing: Tutorial in performance and cognition* (pp. 41–82). New York: Laurence Erlbaum Associates.

Pesce, C., Tessitore, A., Casella, R., Pirritano, M., & Capranica, L. (2007). Focusing of visual attention at rest and during physical exercise in soccer players. *Journal of Sports Sciences, 25*(11), 1259–1270.

Proctor, R.W., Lu, C-H., Wang, H., & Dutta, A. (1995). Activation of response codes by relevant and irrelevant stimulus information. *Acta Psychologica, 90,* 275–286.

Ratcliff, R. (1979). Group reaction time distributions and an analysis of distribution statistics. *Psychological Bulletin, 86,* 446–461.

Ridderinkhof, K.R. (2002). *Activation and suppression in conflict tasks: Empirical clarification through distributional analyses.* In W. Prinz & B. Hommel (Eds), Attention and Performance: Vol. 19. Common Mechanisms in Perception and Action (pp. 494–519). Oxford: Oxford University Press.

Rubichi, S., Nicoletti, C., Pelosi, A., & Umiltà, C. (2004). Right-left prevalence effect with horizontal and vertical effectors. *Perception & Psychophysics, 66*(2), 255–263.

Simon, J.R. (1990). The effects of a directional cue on human information processing. In R.W. Proctor & T.G. Reeve (Eds.), *Stimulus-response compatibility: An integrated perspective* (pp. 31–88). Amsterdam: North-Holland.

Tomporowski, P.D. (2003). Effects of acute bouts of exercise on cognition. *Acta Psychologica, 112*(3), 297–324.

Wascher, E., Schatz, U., Kuder, T., & Verleger, R. (2001). Validity and boundary conditions of automatic response activation in the Simon task. *Journal of Experimental Psychology. Human Perception and Performance, 27,* 731–751.

Wiegand, K., & Wascher, E. (2005). Dynamic aspects of stimulus-response correspondence; Evidence for two mechanisms involved in the Simon effect. *Journal of Experimental Psychology. Human Perception and Performance, 31,* 453–464.

Zhang, J., & Kornblum, S. (1997). Distributional analyses and De Jong, Liang, and Lauber's (1994) dual-process model of the Simon effect. *Journal of Experimental Psychology. Human Perception and Performance, 23,* 1543–1551.

Manuscript received: January 23, 2008
Revision accepted: April 5, 2009