Journal of Human Kinetics volume 51/2016, 27-35 DOI: 10.1515/hukin-2015-0167 27
Section I – Kinesiology

DE GRUYTER OPEN

The Effect of Exercise Intensity on Cognitive Performance During Short Duration Treadmill Running

by
Mike Smith[1], Jason Tallis[1], Amanda Miller[1], Neil D. Clarke[1], Lucas Guimarães-Ferreira[2], Michael J. Duncan[1]

This study examined the effect of short duration, moderate and high-intensity exercise on a Go/NoGo task. Fifteen, habitually active (9 females and 6 males aged 28 ± 5 years) agreed to participate in the study and cognitive performance was measured in three sessions lasting 10 min each, performed at three different exercise intensities: rest, moderate and high. Results indicated significant exercise intensity main effects for reaction time (RT) (p = 0.01), the omission error rate (p = 0.027) and the decision error rate (p = 0.011), with significantly longer RTs during high intensity exercise compared to moderate intensity exercise (p = 0.039) and rest (p = 0.023). Mean ± SE of RT (ms) was 395.8 ± 9.1, 396.3 ± 9.1 and 433.5 ± 16.1 for rest, moderate and high intensity exercise, respectively. This pattern was replicated for the error rate with a significantly higher omission error and decision error rate during high intensity exercise compared to moderate intensity exercise (p = 0.003) and rest (p = 0.001). Mean ± SE of omission errors (%) was 0.88 ± 0.23, 0.8 ± 0.23 and 1.8 ± 0.46% for rest, moderate and high intensity exercise, respectively. Likewise, mean ± SE of decision errors (%) was 0.73 ± 0.24, 0.73 ± 0.21 and 1.8 ± 0.31 for rest, moderate and high intensity exercise, respectively. The present study's results suggest that 10 min workout at high intensity impairs RT performances in habitually active adults compared to rest or moderate intensity exercise.

Key words: *Go/No-go task, Reaction Time, Response Inhibition.*

Introduction

The role of exercise on adult cognition has been extensively researched (Lambourne and Tomporowki, 2010; Tomporowski, 2003), with cognitive performance assessed during exercise (McMorris and Graydon, 1996), following an acute bout of exercise (Coles and Tomporowski, 2008; Hopkins et al., 2012; Tomporowski et al., 2005) and following long-term exercise exposure (Castelli et al., 2007; Hopkins et al., 2012). Despite this, the effect of exercise on cognitive performance is equivocal. This ambivalence is due in part to the different exercise protocols, methods of assessing exercise intensity and mode of exercise employed by various studies (Lambourne and Tomporowski, 2010).

For example, when investigating the exercise intensity-cognitive performance relationship, several studies and meta-analyses have suggested an inverted U-shaped relationship (Chmura et al., 1994; McMorris and Graydon, 2000; McMorris et al., 2011) such that moderate levels of exercise increased physiological arousal and facilitated cognition, however, when physiological arousal approached a maximal level, cognitive performance began to deteriorate. In contrast, maximal levels of exercise intensity

[1] - *School of Life Sciences, Coventry University, Coventry, UK*
[2] - *Laboratory of Experimental Physiology and Biochemistry, Center of Physical Education and Sports, Federal University of Espirito Santo, Vitória/ES, Brazil.*

Authors submitted their contribution to the article to the editorial board.
Accepted for printing in the Journal of Human Kinetics vol. 51/2016 in June 2016.

have been found not to be generally associated with declines in cognition (Tomporowski, 2003) with research by Lyons et al. (2008) reporting an inverted-U relationship between exercise intensity and post-exercise coincidence anticipation performance in novice performers and not experts; whereas subsequent work by Duncan et al. (2012) found an inverted-J relationship between exercise intensity and coincidence anticipation performance (CAT) during treadmill running at 90% of heart rate reserve (HRR), where CAT performance incrementally reached an optimal point before dramatically dropping off at 90% of HRR).

Hüttermann and Memmert (2014) presented data showing an inverted-U relationship in cognitive performance for non-athletes while cycling at exercise intensities of 50, 60 and 70% of the age predicted maximal heart rate. On the contrary, a linear relationship was seen for athletes, leading the researchers to conclude that physical fitness acted as a moderator in the exercise intensity-cognitive performance relationship (Hüttermann and Memmert, 2014). However, the use of the age predicted heart rate to determine exercise intensity in the Hüttermann and Memmert's (2014) study is limited, particularly when comparing individual fitness levels. For example, regular exercise participation was shown to be associated with a lower resting heart rate (Karvonen et al., 1957), thus, the use of the age predicted heart rate alone does not accurately account for this issue nor it has any scientific basis in exercise physiology and sports medicine (Robergs and Landwehr, 2002) where exercise intensity is commonly determined as a percentage of maximal oxygen uptake.

Furthermore, considering that Hüttermann and Memmert's (2014) high exercise intensity condition was set at 70% of the age predicted maximal heart rate and a linear relationship between intensity and cognitive performances for trained athletes was reported, it suggests that cognitive performance was still on the increase. Consequently, it can be proposed that the intensity level of 70% for trained athletes was moderate at best and not high intensity as reported by Hüttermann and Memmert (2014). More recently, Davranche et al. (2015) examined the Simon task performance in 14 participants while cycling at a low, moderate or very high level of intensity, as defined by the ventilatory threshold. In their study, there was no significant difference in the reaction time (RT) across exercise intensities leading the authors to conclude that cognitive control was robust and did not appear to be influenced by the intensity of exercise. There is also debate as to the duration of exercise needed to elicit any change in cognitive performance with studies reporting changes after as little as 6 min of exercise (McMorris et al., 2008) to 100 min of exercise (Collardeau et al., 2001). There are a number of sports and exercise situations which require high levels of exertion, are aerobically based, but of relatively short duration which facilitate cognitive performance. Yet, the impact of exercise intensity during short duration aerobically based exercise has not been widely examined. Therefore, given the different conclusions drawn in the literature regarding the effect of exercise intensity on cognition, it is of extreme interest to sport performance practitioners to examine if and when exercise intensity impacts cognitive performance. Also of interest is what the actual cut off point (i.e. exercise intensity) is before cognitive performance and consequently decision making deteriorates, which may have detrimental consequences for 'in the field' performance.

.

The aim of this study was to examine the effect of short duration, moderate and high intensity exercise on a Go/NoGo task in habitually trained adults. We hypothesised that cognitive performance during moderate intensity exercise would improve; however, cognitive performance would be poorer during high intensity exercise compared to rest.

Material and Methods

Participants

Following institutional ethics approval and informed consent fifteen habitually trained adults (9 females and 6 males, aged 28 ± 5 years) that trained a minimum of 5 hours per week throughout the last 2 years participated in the study. All participants completed a health history questionnaire to ensure they met all inclusion criteria, i.e. being 'apparently healthy', physically active and accustomed to regular aerobic exercise. Participants were excluded if they had a musculoskeletal injury or cardiovascular condition which would restrict exercise performance.

Measures

To measure changes in cognitive performance participants completed a Go/NoGo task modelled on one developed by Pontifex et al. (2009) and previously used by Moore et al. (2012). The task used in the present study was a RT paradigm during which subjects performed a binary decision on each stimulus. One of the outcomes required subjects to make a motor response (go), whereas the other required subjects to withhold a response (no-go). The Go/NoGo task is considered a measure of response inhibition and is generally used to assess the ability to inhibit the "prepotent" response. Specifically, the test required participants to respond quickly and accurately to a circle of 5.5 cm diameter that occurred on 20% of the trials and not to respond to a non-target circle of 3.0 cm diameter that occurred on 80% of the trials. The cognitive task consisted of one unique block of 100 trials performed during the last 2 min of exercise once the target intensity (high-intensity exercise at 90% of HRR or moderate-intensity at 70% of HRR) had been reached. Stimuli were presented for 300 ms with a 1000 ms inter-stimulus interval via open source experiment software (Mathôt et al., 2012) at the centre of a computer monitor located on the treadmill in front of the participant.

For each trial, participants were asked to press a trigger button with their dominant hand when the target stimulus was presented. This trigger button process enabled participants to complete the Go/NoGo task during exercise, thereby addressing key criticism of prior research that studied the effects of exercise on cognitive performance (Lambourne and Tomporowski, 2010) pre and post exercise. Participant's performance on the Go/NoGo task was calculated and comprised of three measures. Two error rates were calculated, one for omission errors relating to instances where the stimulus was presented and the trigger not pressed, and another for decision errors, relating to instances when the non-target stimulus was presented and the trigger was pressed. RTs (ms) were also calculated for target stimulus trials indicating the time taken to respond when the target stimulus was presented.

A resting heart rate (HR_{rest}) was also obtained from each participant by getting them to lie down in a prone position for 10 min while wearing a heart rate monitor (Polar RS400, Polar Electro Oy, Kempele, Finland), in a quiet room void of visual or auditory distractions. A maximum heart rate (HR_{max}) was estimated as 220 minus the participant's age. Both the HR_{rest} and HR_{max} were then recorded and used to calculate 70% and 90% of heart rate reserve (HRR) (Karvonen et al., 1957).

Procedure

The study used a repeated-measures design consisting of three separate sessions performed on different days: rest, moderate intensity and high intensity sessions performed in a counterbalanced order. Participants attended the laboratory at the same time of the day in a well-rested and hydrated state with no prior consumption of caffeine or other ergogenic aids that may have influenced cognitive performance.

During the initial test session, each participant was allowed 200 attempts at the Go/NoGo task to familiarise themselves with the test protocol (Pontifex et al., 2009). An incremental running protocol on a motorised treadmill (HP Cosmos Ltd, Germany) was used to induce moderate and high intensity exercise states congruent with previous studies assessing effects of moderate and high intensity exercise on skilled (Lyons et al., 2008) and perceptual (Duncan et al., 2012) performance.

Whilst in the rest condition, participants stood on the treadmill for a period of approximately 10 min (the approximate duration for the exercise trials) before completing the Go/NoGo task. The exercise intensity protocol started at a running speed of 8 km/h. The workload was then increased by 1.6 km/h every 30/60 s until the participant reached the desired intensity as determined by 70% and 90% of heart rate reserve (HRR) (Karvonen et al., 1957). Throughout the test procedures, the heart rate was monitored. The test duration was similar for 70% and 90% conditions. The Borg's (1970) rating of perceived exertion (RPE) scale was also used as an adjunct to monitoring of the heart rate. Participants were required to achieve an RPE of 15-17 for the moderate intensity exercise condition and 18-19 for the high intensity exercise condition. Once the desired intensity was reached, as determined by both measures simultaneously (i.e. %HRR and RPE), participants were then required to maintain this intensity for further 2 min. This ensured that participants were truly at the desired steady-state intensity. At this point, participants performed a validated Go/NoGo task (Pontifex et al., 2009) while still running. The experiment with the Go/NoGo task consisted of 100 trials. Each exercise trial lasted approximately 10 min and included approximately 2 min of exercise while completing the Go/NoGo task.

Analysis

The effects of exercise intensity on error rates (omission errors and decision errors) and the RT were analysed using separate 3 (exercise intensity) ways repeated measures analysis of variance. Where significant differences were found, Bonferroni post-hoc pairwise comparisons were used to determine where the differences lay. Partial eta squared (η^2) was also used as a measure of effect size. The Statistical Package for Social Sciences (SPSS, Version 20, Chicago, Il, USA) was used for all analysis and statistical significance was set, a priori, at $p = 0.05$.

Results

Results indicated significant exercise intensity main effects for the RT ($F_{2, 28} = 6.169$, $p = 0.01$, Partial $\eta^2 = 0.320$, Figure 1). Bonferroni post-hoc pairwise comparisons indicated significantly slower RTs during high intensity exercise compared to rest ($p = 0.023$) and moderate intensity exercise ($p = 0.039$). The omission error rate ($F_{2, 28} = 4.108$, $p = 0.027$, Partial $\eta^2 = 0.255$) and decision error rate ($F_{2, 28} = 9.213$, $p = 0.011$, Partial $\eta^2 = 0.397$) were also significantly different across exercise intensities. Post-hoc analysis indicated a significantly higher omission error rate at high intensity compared to moderate ($p = 0.038$) intensity exercise and rest ($p = 0.043$). This pattern was replicated for the decision error rate with higher decision errors being made at high intensity exercise compared to moderate intensity ($p = 0.008$) and rest ($p = 0.002$). Means and SE of omission and decision error rates are shown in Figure 2.

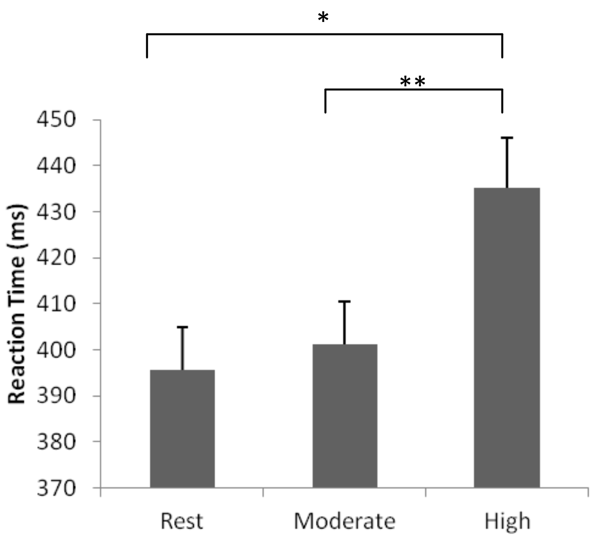

Figure 1
*Mean ± SE of Go/NoGo task RTs (ms) to target stimuli during rest, moderate and high intensity treadmill running (*p = 0.023, ** p = 0.039)*

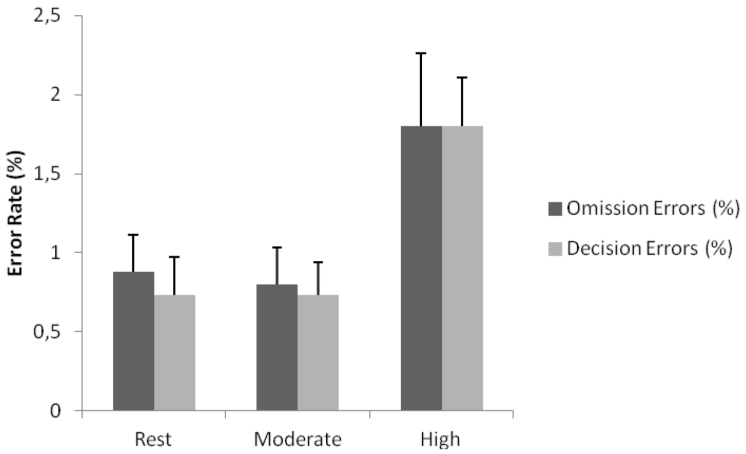

Figure 2
Mean ± SE of Go/NoGo task omission error and decision error rates (%) to target stimuli during rest, moderate and high intensity treadmill running

Discussion

The aim of the present study was to examine the effect of exercise intensity on a Go/NoGo task performance. The results align with prior work by Duncan et al. (2012) who investigated the relationship between running speeds of 4.8, 8.0 and 12.8 km/h, exercise intensities of 70% and 90% of HRR and cognitive performance, with the largest decrements in cognitive performance taking place at 12.8 km/h and exercise intensity of 90% of HRR, but do not align with other studies suggesting that moderate intensity exercise results in enhanced cognitive performance (Chmura et al., 1994; McMorris and Graydon, 2000; McMorris et al., 2011). Cognitive performance is significantly impaired during high intensity exercise (90% of HRR) which extends the findings proposed by Hüttermann and Memmert (2014) who failed to reach an exercise intensity at which cognitive performance was negatively affected in trained athletes.

The results of the current study are also contrary to those recently published by Davranche et al. (2015) which reported no effect of exercise intensity on the Simon task performance during a 20 min cycling task. Moreover, Davranche et al. (2015) highlighted in their study that there was no sign of worsening RTs during very high intensity exercise. From a sporting point of view, it is extremely important to determine at what point cognitive performance is negatively affected by exercise intensity and the resulting fatigue. For example, in soccer it is well known that a large number of goals are scored in the final minutes of a game when the relationship between fatigue and decision making of some players may be at their poorest. Consequently, further investigation is required so that a clearer theoretical explanation can be proposed which will help clarify the effects of exercise intensity on cognitive performance.

A number of authors who have proposed a theoretical explanation for effect of exercise intensity on cognitive performance have suggested that acute aerobic exercise is an arousing stressor (Audiffren, 2009) and as such the theoretical explanations have been anchored in unidimensional theories of arousal including the inverted-U theory (Yerkes and Dodson, 1908). However, if arousal is assumed to be a mechanism by which performance changes, then some form of explanation is also required for the role of cognition in this process (Hardy and Parfitt, 1991). It may be that due to the multidimensional construct of arousal, which has a cognitive and physiological component, the Catastrophe Model (Fazey and Hardy, 1988) may provide a more accurate account of the relationship between cognitive performance and exercise intensity. Specifically, the Catastrophe Model predicts that when physiological arousal and cognitive anxiety are low, performance will follow an inverted-U, which has been reported before (Chmura et al., 1994; McMorris and Graydon, 2000; McMorris et al., 2011). However, when physiological arousal and cognitive anxiety are at their highest, the effect on performance will be at its worst which is what was found in the present study at an exercise intensity of 90%. Although cognitive anxiety was not measured in the present study, it can be assumed that due to extremely demanding nature of the physiological component (i.e. 90%) of the study that cognitive anxiety would be at its highest, which goes some way in supporting the predictions of the Catastrophe Model (Fazey and Hardy, 1988). Such intensity of exercise has also been suggested to be anxiety provoking in the study by Davranche et al. (2015).

In this context, higher intensity exercise coupled with performance of cognitive tasks may result in increased demands of the concurrent activities leading to greater demand on attentional resources and potentially poorer performance. For example, Müller et al. (2007) found that there was a prioritization for postural control over the cognitive stimulus when the highest threat was to postural stability. Müller et al. (2007) suggested that it was not until the appropriate postural responses had been initiated (or inhibited) that the cognitive stimulus could be completely attended to. In the context of the present study, an exercise intensity of 90% may therefore pose a greater threat to postural stability resulting in poorer cognitive performance. The results of the present study would broadly support the assertion that allocation of attentional resources is inhibited during high intensity exercise resulting in poorer cognitive task performance compared to lower exercise intensities. Furthermore, such an argument may explain the discrepancy between the results presented in the current study and those of Davranche et al. (2015). Considering the Davranche et al.'s study (2015), the use of a cycle based exercise modality reduced the postural prioritisation effect, unlike the current study where postural prioritisation during treadmill running may have been more of a factor. Indeed in their meta-regression analysis, Lambourne and Tomporowski (2010) had previously reported that cycle and treadmill based exercise produced different results in respect to effects of exercise intensity on cognitive performance. In the present study, it is possible that when running at high intensity a speed accuracy trade-off was evidenced as, in order to continue to run and remain upright, RTs worsened and additional errors were made..

It is also important to note that during moderate and high intensity exercise conditions, the cognitive workload required to perform at such velocity on a treadmill is very high. Thus, when comparing the resting condition with the exercise conditions, there is an effect of exercise and a strong dual task effect. This may be one reason why there was no observation of facilitation in the moderate intensity condition and impaired performance in the high intensity condition. The use of a 10 min rest period as a control condition in the present study was undertaken to provide a 'true rest' period of the same duration as the exercise bouts and to avoid comparing to 'rest' pre-exercise where there may have been anticipatory responses as a result of the upcoming tasks. For future studies, a more relevant control condition could comprise of very low exercise intensity rather than simply standing on a treadmill.

Until now the focus of the argument has mainly revolved around the effects of changes in exercise intensity on cognitive performance with very little discussion on the influence of the cognitive test on performance outcomes. The importance of choosing an appropriate cognitive test cannot be underestimated, for example, Memmert et al. (2009) who investigated the relationship between visual attention and expertise in sport using a functional field of a view task, a multiple-object tracking task, and an attentional blindness task found that team sports experts showed no better performance on the basic attention tasks than athletes from non-team sports or novice athletes which is unlike the Hüttermann and Memmert (2014) and the present study where significant differences in cognitive performancewere reported. However, Memmert et al. (2009) failed to include any form of a physiological component in their study and although the authors suggested that any attentional focus task that reveal group differences could potentially be used to design training programs to improve sport-specific attention capacity, we propose that this proposal should be viewed with caution unless some form of exercise intensity is included.

We also acknowledge that the Go/NoGo test of cognitive performance employed in the present study was simple in nature and unlike the protocol used in the Hüttermann and Memmert's (2014) study that used a more cognitively demanding attentional breadth cognitive test, which may be the reason for the disparity of results between the present study and that of Hutterman and Memmert (2014). A more complex version of the same Go/NoGo task used in the present study is available (Pontifex et al., 2009) which includes an additional square distracter stimulus which may provide a more detailed account of cognitive performance. However, a cautionary note is that in the present study it was difficult to utilise a more complex cognitive performance test while running at 90% of HRR due to the trade-off between the time requirement to complete the test and the physical capacity of individuals to remain running at this intensity. Therefore, future research will seriously need to consider alternative and effective ways that can both ensure the safety of the participant while exercising at high intensities whilst at the same time completing more difficult and demanding cognitive tests.

A further limitation in the present study is that the thresholds for moderate and high intensity exercise were calculated using the Karvonen formula (Karvonen et al., 1957). This was employed in order to account for individual variation in a resting heart rate as a consequence of different fitness levels in participants. The use of the Karvonen formula in the present study was also chosen because it is recommended as a means to set a target heart rate by the American College of Sports Medicine (2006) and had been cited in prior studies reporting the effect of moderate and high intensity exercise on cognitive performance (Borg, 1970; Duncan et al., 2012; Lyons et al., 2008). However, future studies may be more effective by either using an alternative equation to estimate the maximum heart rate or by establishing exercise intensity as a percentage of VO2max.

In conclusion, the present study suggests that high intensity exercise results in poorer cognitive performance in habitually active adults compared to rest or moderate intensity exercise. To accurately understand the exercise intensity and cognitive performance relationship in athletes, research must adopt a multidimensional approach that includes both a high exercise intensity condition of at least 90% of either VO2max or HRR and an equally demanding cognitive task that is transferable to actual sport performance.

References

American College of Sports Medicine. *ACSM's Guidelines for exercise testing and prescription* Baltimore PA: Lippincott Williams and Wilkins; 2006

Audiffren M. *Acute exercise and physiological functions: a cognitive-energetics approach,* 2009. In: McMorris T, Tomporowski PD. (Eds). *Exercise and cognitive function*. John Wiley and Sons. Hoboken NJ. 3-39; 2009

Borg G. Perceived exertion as an indicator of somatic stress. *Scand J Rehabil Med,* 1970; 2: 92-98

Castelli D, Hillman C, Buck S, Erwin H. Physical fitness and academic achievement in 3rd and 5th grade students. *J Sport Exercise Psy,* 2007; 29: 239-252

Chmura J, Nazar K, Kaciuba-Uscilko H. Choice reaction time during graded exercise in relation to blood lactate and plasma catecholamine thresholds. *Int J Sports Med,* 1994; 15: 172-176

Coles K, Tomporowski PD. Effects of acute exercise on executive processing, short-term and long-term memory. *J Sport Sci,* 2008; 26: 333-344

Collardeau M, Brisswalter JB, Vercruyssen F, Audiffren M, Goubalt V. Single and choice reaction time during prolonged exercise in trained subjects: influence of carbohydrate availability. *Eur. J. Appl. Physiol*, 2001; 86: 150–156

Davranche K, Brisswalter J, Radel R. Where are the limits of the effects of exercise intensity on cognitive control? *J Sport Health Sci*, 2015; 4: 56-63

Duncan M, Smith M, Lyons M. The effect of exercise intensity on coincidence anticipation performance at different stimulus speeds. *Eur J Sport Sci*, 2012; 13: 559-66

Fazey JA, Hardy L. *The inverted-U hypothesis: A catastrophe for sport psychology*. British Association of Sports Sciences Monograph no. 1. Leeds: The National Coaching Foundation; 1988

Green DM, Swets JA. *Signal detection theory and psychophysics*. Huntington, NY: Kreiger;1974

Hardy JPL, Parfitt G. A catastrophe model of anxiety and performance. *Brit J Psychol*, 1991; 82: 163-178

Hopkins ME, Davis FC, Vantieghem MR, Whalen PJ, Bucci DJ. Differential effects of acute and regular physical exercise on cognition and affect. *Neuroscience,* 2012; 215: 59-68

Hüttermann S, Memmert D. Does the inverted-U function disappear in expert athletes? An analysis of the attentional behaviour under physical exercise of athletes and non-athletes. *Physiol Behav*, 2014; 131: 87-92

Kahneman D. *Attention and Effort*. Englewood Cliffs, NJ, Prentice Hall; 1973

Karvonen MJ, Kentala E, Mustala O.The effects of training heart rate: a longitudinal study. *Annales Medicinae Experimentalis et Biologiae Fenniae,* 1957; 35: 307-315

Lambourne K, Tomporowski P. The effect of exercise-induced arousal on cognitive task performance: A meta-regression analysis. *Brain Res*, 2010; 1341: 12-24

Lyons M, Al-Nakeeb Y, Nevill A. The effect of moderate and high intensity fatigue on coincidence anticipation in expert and novice Gaelic games players. *Eur J Sport Sci*, 2008; 8: 205-216

Mathôt S, Schreij D, Theeuwes J. Open Sesame: An open-source, graphical experiment builder for the social sciences. *Behav Res Met*, 2012; 44: 314-324

McMorris T, Graydon J. The effect of exercise on the decision-making performance of experienced and inexperienced soccer players. *Res Q Exercise Sport,* 1996; 67: 109-114

McMorris T, Graydon J. The effect of incremental exercise on cognitive performance. *Int J Sport Psychol,* 2000; 31: 66-81

McMorris T, Collard K, Corbett J, Dicks M, Swain JP. A test of the catecholamines hypothesis for an acute exercise-cognition interaction. *Pharmacol. Biochem. Behav*, 2008; 89: 106–115

McMorris T, Sproule J, Turner A, Hale BJ. Acute, intermediate intensity exercise, and speed and accuracy in working memory tasks: A meta-analytical comparison of effects. *Physiol Behav,* 2011; 102: 421-428

Memmert D, Simons DJ, Grimme T. The relationship between visual attention and expertise in sports. *Psychol Sport Exer*, 2009; 10: 146–151

Moore RD, Romine MW, O'Connor PJ, Tomporowski PD. The influence of exercise-induced fatigue on cognitive function. *J Sports Sci,* 2012; 30: 841-850

Müller MLTM, Redfern MS, Jennings JR. Postural prioritization defines the interaction between a reaction time task and postural perturbations *Exp Brain Res,* 2007; 183: 447–456

Pontifex MB, Hillman CH, Polich J. Age, physical fitness and attention: P3a and P3b. *Psychophysiology,* 2009; 46: 379-387

Robergs RA, Landwehr R. The surprising history of the HR max = 220-age equation. *J Ex Physiol*, 2002; 5: 1-10

Tomporowski P. Cognitive and behavioural responses to acute exercise in youth: a review. *Pediatr Exerc Sci,* 2003; 15: 348-359

Tomporowski PD, Cureton K, Armstrong LE, Kane GM, Sparling PB. Millard-Stafford M. Short-term effects of aerobic exercise on executive processes and emotional reactivity. *Int J Sports Ex Psychol,* 2005; 3: 131-146

Yerkes RM, Dodson JD. The relation of strength of stimulus to rapidity of habit formation. *J Comp Neurol Psychol*, 1908; 18: 459-482

Corresponding author:

Mike Smith
School of Life Sciences, Coventry University,
James Starley Building, Priory Street, Coventry, UK, CV 5HB.
Phone: 02476888613:
E-mail: m.smith@coventry.ac.uk