Effects of exercise intensity on anticipation timing performance during a cycling task at moderate and vigorous intensities in children aged 7-11 years

Boat, R., Morris, M. & Duncan, M.

DOI 10.1080/17461391.2019.1642387
ISSN 1746-1391
ESSN 1536-7290
Publisher: Taylor and Francis

Effects of exercise intensity on anticipation timing performance during a cycling task at moderate and vigorous intensities in children aged 7-11 years.

Ruth Boat[1], Martyn Morris[2], and Michael J. Duncan[2]

[1]Sport, Health, and Performance Enhancement Research Centre, Department of Sport Science, Nottingham Trent University

[2] Centre for Sport, Exercise and Life Sciences, Coventry University

Abstract

This study examined coincidence anticipation timing performance at moderate and fast stimulus speeds before, during, and after a 15 min cycling task. In a within-subject design, 24 children (18 males and 6 females) exercised on a cycle ergometer under two experimental conditions: exercise intensities of 50% (moderate) and 75% (vigorous) heart rate reserve. Coincidence anticipation timing was measured using the Bassin Anticipation Timer at stimulus speeds of 5 and 8 mph. A 2 (intensity) x 3 (time) repeated measures ANOVA was conducted to evaluate the effect of exercise intensity on coincidence anticipation performance before, during, and immediately after the cycling task. Results indicated that for absolute error there was no significant main effect for time (p = .633) or experimental condition (p = .782) at the 5 mph stimulus speed. However, there was a significant interaction effect between experimental condition and time (p = 0.026) at the 5 mph stimulus speed. At the 8 mph stimulus speed, there was no significant main effect for time (p = .910) or condition (p = .938), or interaction effect between experimental condition and time (p = .591). Cycling exercise at moderate intensity appears to influence anticipation timing performance during and immediately after exercise in children, but only when stimulus speeds are moderate in nature.

Keywords: Cognitive performance, aerobic exercise, paediatric populations, cycling performance

Effects of exercise intensity on anticipation timing performance during a cycling task at moderate and vigorous intensities in children aged 7-11 years.

Coincidence anticipation timing (CAT) is the capacity to anticipate the approach of a moving object at a specific mark in space and synchronise a movement response with that arrival (Fleury & Bard, 1985). It is imperative to a number of movements within sports performance, such as catching a ball or object, striking a moving object, and intercepting the actions of opposing players (Duncan, Smith, & Lyons, 2013). Consequently, CAT is essential in externally paced sports that demand uncertainty. CAT tasks require the precise completion of a number of stages, including a sensory phase, whereby, sensory information is employed to identify, correct, and guide motor actions (Goodgold-Evans, 1991); a sensory-motor integration phase in which the time and position of the approaching stimulus and the motor response are decided, and finally the execution or motor phase (Fleury & Bard, 1985).

Studies exploring the effects of exercise intensity on CAT performance have been ambiguous. Lyons, Al-Nakeeb, and Nevill (2008) examined the effects of moderate- and high-intensity (70% and 90% heart rate reserve; HRR) exercise on CAT performance in expert and novice Gaelic games players. Participants completed 20 CAT trials post exercise at moderate stimulus speeds (5 mph). A collection of analyses indicated that exercise intensity had no effect on CAT performance. However, moderate-intensity exercise did lead to improved CAT performance in the novice players only. Similar studies have also reported small or no effects of varying exercise intensities on CAT performance (Bard & Fleury, 1978; Isaacs & Pohlman, 1991). Recently, however, Duncan et al. (2013) explored CAT performance during moderate- and high-intensity exercise. Participants completed 10 CAT trials at stimulus speeds of 3, 5, and 8 mph during an incremental running task. Results indicated that high-intensity exercise was associated with poorer CAT performances, with faster stimulus speeds associated with larger decrements in CAT performance. Given the scarce number of studies that have explored the effects of different exercise intensities on coincidence anticipation performance, additional research is required to provide a more complete understanding of exercise intensity and CAT performance (Lyons et al., 2008).

A critical element underpinning the observed equivocal findings may be the timing of the performance task. In some studies (Al-Nakeeb & Lyons, 2007, Duncan et al., 2013, & Issacs & Pohlman, 1991), CAT performance and exercise were performed concurrently, whereas in others (Lyons et al., 2008) performance was assessed post-exercise. During exercise, a reduction in acetylcholine, potassium, adenosine triphosphate, phosphocreatine, and increases in muscle lactate will impede motor control; however, such biochemicals are rapidly replenished, and will quickly return to basal values (Davranche & Audiffren, 2004). As such, the timing of the CAT performance task may represent a pivotal element. Exploring performance during exercise once a steady state has been achieved has been recommended as a preferred method (Lyons et al., 2008). This suggestion is also congruent with broader research examining the effect of exercise on cognitive performance generally, where different effects are reported if cognitive performance is assessed during or immediately following exercise (Lambourne & Tomporowski, 2010).

Stimulus speed may also explain such discordant findings in the CAT literature. Although research has emphasised that stimulus speed should be a crucial consideration when exploring the effect of exercise on CAT performance (Fleury & Bard, 1985), some studies have utilised a single stimulus speed (Lyons et al., 2008). It has been shown that stimulus speed influences CAT performance (Duncan et al., 2013; Sanders, 2011); therefore, both the timing of performance task and stimulus speed requires careful consideration when conducting research of this nature.

Notably, the extant literature to date has only examined adult participants. This is despite the acquisition of CAT being critical to a number of perceptual-cognitive-motor tasks during childhood such as catching and striking (Duncan et al., 2013). Coincidence anticipation skills also underpin the performance of some of the fundamental movement skills that are acquired in childhood and needed for participation in physical activity particularly those involving object control. Narrative and quantitative reviews have suggested that school age children may derive cognitive benefits from chronic physical activity participation as well as single, acute bouts of exercise (Hillman, Erickson, & Kramer, 2008; Sibley & Etnier, 2003; Tomporowski, 2003). The data demonstrating acute effects of exercise on cognitive performance in adolescents is growing, and suggestive of a beneficial effect (Cooper, et al., 2016; Hillman, et al., 2008), yet data pertaining to the effect of exercise, and exercise intensity specifically on cognitive performance in children remain under examined. Research by Duncan and Johnson (2014) has reported that moderate but not vigorous intensity cycling improved reading, and that moderate and vigorous intensity cycling enhanced spelling performance but impaired arithmetic. They suggested that exercise selectively benefits cognition in children but further research was needed examining different tasks other than academic performance. To date, no study has examined the effect of an acute bout of exercise on CAT performance in children; thus, the extension of the findings within the adult populations to children is speculative. However, given the observed physical activity benefits, an acute exercise effect on CAT performance may be likely.

Although no research has explored the effect of exercise on CAT performance in children, some studies have used a prediction motion paradigm to investigate coincidence-timing, at rest, in children (e.g., Benguigui, Broderick, Baurès, & Amorim, 2008; Benguigui. Broderick, & Ripoll, 2004; Keshavarz, Landwehr, Baurès, Oberfeld, Hecht, & Benguigui, 2010). Within this task, participants are presented with a moving object that is occluded before reaching the participant or a specified position. The participant is instructed to deliver a response (e.g., press a button) that will coincide momentarily with the moving objects immediate arrival at the participant or specified position (Benguigui et al., 2008). Results have indicated that errors in estimations increase with occluded time (when the occlusion is greater than 200 milliseconds) and with decreasing age (Benguigui et al., 2004; Benguigui et al., 2008). Although such studies have not used a CAT task per se, prediction motion tasks utilise short occlusion times that are under the visuo-motor threshold, therefore, such tasks correspond strongly to a CAT task. Given that young children appear to struggle synchronising their response with a moving object, an acute bout of exercise may well benefit CAT performance.

Extending the literature above, the aims of this investigation were (1) to explore CAT performance before, during, and immediately following moderate- and vigorous-intensity exercise in children, and (2) to examine whether the effects of moderate- and vigorous-intensity exercise on CAT performance vary with increasing stimulus speeds. We hypothesized that CAT performance would be improved during moderate-intensity exercise but inhibited during high-intensity exercise (Duncan et al., 2013; Lyons et al., 2008). Finally, we hypothesized that CAT performance would be poorer at higher stimulus speeds (Duncan et al., 2013; Sanders, 2011).

Methods

Participants

A power calculation (G*Power version 3.1; Faul, Erdfelder, Lang, & Buchner, 2007) with power = 0.80, $\alpha = .05$, and the 'as in SPSS' effect size selected, indicated a minimum sample size of $N = 22$ would be sufficient to detect a medium effect size (.50), which is typical of previous CAT performance studies (e.g., Duncan, Stanley, Smith, Price, & Leddington Wright, 2015). Our sample consisted of 24 children (18 males, 6 females) aged 7-11 years (*M* age = 9, 95% CI [7.53, 9.01]).

Following approval from a university ethics committee, parental informed consent and child consent, legal guardians completed a healthy history questionnaire, reporting that their child was free of neurological disease, cognitive impairment, attentional disorders, and physical disabilities. Children were not given any inducement to participate. Descriptive data for the sample are presented in Table 1.

Protocol

The study used a repeated-measures design whereby participants undertook two visits to the laboratory. All visits occurred at the same time of day. In the first session, participants had their height (cm) and body mass (kg) assessed using a Stadiometre and weighing scales (Seca Instruments, Frankfurt, Germany) and were fitted with a heart rate monitor (Polar RS400, Polar Electro Oy, Kempele, Finland). Resting heart rate (HR) was recorded for 5 minutes in a supine position. Recognising that the traditional 220-age equation to estimate HRmax overestimates exercise HR, HRmax was estimated using the Tanaka, Monahan, and Seals (2001) equation as this more effectively accounts for age related changes in HRmax and has been recommended for us by prior studies (Robergs & Landwehr, 2002). Exercise intensities of 50% (moderate) and 75% (vigorous) of maximal HRR (Karvonen & Vuorimaa, 1988) were then calculated, and used in the subsequent experimental trials. In the present study, HRR values of 50% and 75% were employed as threshold values to denote moderate and vigorous physical activity, respectively. A HRR value of 50% compares to a brisk walk (Ridgers, Stratton, Clark, Fairclough, & Richardson, 2006), whereas a HRR value of 75% compares to a measure of vigorous physical activity, as this intensity may increase cardiorespiratory fitness in children (Praikh & Stratton, 2011). Both also represent recommended intensities of physical activity for health benefits in children (Ridgers et al., 2006).

Participants then completed two experimental conditions: moderate intensity and vigorous intensity exercise (one condition per day/visit). Conditions were counterbalanced and separated by at least 24 hours. The experimental sessions consisted of 15 minutes of aerobic exercise on a cycle ergometer (Corvial Pediatric, Lode B.V., Netherlands) at 50% and 75% of maximal HRR for moderate and vigorous conditions, respectively. This duration was chosen as it ensures the exercise is at steady state. Also, meta regression analysis by Lambourne and Tomporowski (2010) suggested that exercise durations of less than 10 minutes may result in negative effects on cognition due to dual task interference, common at the onset of exercise, which may not be truly representative of the effects of exercise on cognition. The 15-minute duration employed ensures that metabolic demands of exercise, which may influence cognitive performance, as suggested by Dietrich's (2003) hyperfrontality hypothesis are accounted for. Heart rate was monitored during all experimental trials. Cycling resistance was modified throughout to ensure that HRR remained at the correct intensity, as has been the case in similar studies (e.g., Duncan & Johnson, 2014).

Participants completed measures of CAT immediately before, during: at 7 minutes 30 seconds, and immediately following both experimental cycling tasks. Participants performed five trials on the CAT task at stimulus speeds of 5 and 8 mph. The rationale for the choice of stimulus speeds was based on prior work, which had determined a stimulus speed of 5 mph as 'intermediate' (Duncan et al., 2013; Lyons et al., 2008). In order to explore the effect of varying stimulus speed, the stimulus speed of 8 mph was selected to represent a 'fast' speed, similar to previous work (Lobjois, Benguigui, & Bertsch, 2006). Presentation of stimulus speeds was counterbalanced.

The Basin Anticipation Timer (Model 35575, Lafayette, USA) was positioned vertically in front of the cycle ergometer. This enabled participants to complete the CAT trial during the experimental cycling tasks (at 7 minutes 30 seconds) whilst cycling. Participants completed the CAT trials immediately before and after the experimental cycling tasks whilst stationary on the cycle ergometer. Prior to each experimental trial, each participant was familiarised with the Basin Anticipation timer and had five practice attempts at the stimulus speed used in the present study. Three sections of runway (2.24 m) were mounted onto the cycle ergometer. The sequentially lighted LED lamps, which were facing the participant, illuminated in a linear pattern with movement occurring from top to bottom, with light number 13 as the target. For each trial, scores were recorded in milliseconds (ms) and whether the response was early or late. The start and end speeds remained constant at 5 and 8 miles h^{-1} for all trials. To reduce the likelihood that the participant could internally time the trial, cue delay (visual warning system) was set as random on the timer with a minimum delay of one second and a maximum delay of 2 seconds (Duncan et al., 2013). For each trial, the signal was initiated by the experimenter. The participant was asked to press a trigger button, with their dominant hand, as close to the arrival time of the stimulus at the target location as possible. This is congruent with other research which has examined CAT during exercise (Duncan et al., 2013; Duncan et al., 2015).

Each participant's raw scores across each of the stimulus speeds were summarised into three error scores as a way of generating the dependent variables. This is consistent with previous recognised protocols using CAT (Duncan et al., 2013; Duncan et al., 2015; Isaacs & Pohlman, 1991; Lyons et al., 2008; Sanders, 2011). First, *constant error* represents the temporal interval (milliseconds) between the arrival of the visual stimulus and the end of the participant's motor response. It signifies the mean response of the participant and the direction of error (i.e., early or late). Second, *variable error* was the participant's standard deviation from their mean response, and symbolises the variability/inconsistency of responses (Lyons et al., 2008). However, as variable error signifies the standard deviation from the mean, the data are positively skewed (all the values are positive). Therefore, the data set were log transformed as log-transforming data in this way has been shown to overcome skewness in previous work (Lyons et al., 2008). Third, *absolute error* was the value of each raw score discounting whether the response was early or late. Absolute error provides the best depiction of both the individual and combined effects of task characteristics as a whole (Sanders, 2011), and therefore represents the most popular reported CAT outcome variable within the literature (Lyons et al., 2008; Sanders, 2011). Similar to variable error, the data for absolute error were skewed, therefore the data was log transformed akin to previous research (Lyons et al., 2008).

Data Analysis

To evaluate the effects of exercise intensity on CAT performance before, during, and immediately after the cycling task, a 2 (intensity) x 3 (time) repeated measures Analysis of Variance (ANOVA) was employed. Where significant differences were found, LSD post hoc pairwise comparisons were used to determine where the differences lay. Estimates of epsilon were used to test the assumption of sphericity. Epsilon estimate values were all close to 1, therefore, sphericity was not violated. The generalised eta squared statistic (ηG^2), a measure of effect size, was reported to allow comparisons with other studies. In addition, the omega-squared (ω^2) statistic, a measure of effect size, was presented to provide an indication of the variance explained by the condition. The Statistical Package for Social Sciences (SPSS, Version 24, Chicago, IL, USA) was used for all analysis and statistical significance was set, a priori, at $p = 0.05$.

Results

Mean [95% CI] of constant error, variable error, and absolute error (secs) at stimulus speeds of 5 and 8 mph before, at 7 minutes 30 seconds during, and immediately after the cycling task at 50% and 75% HRR are presented in Table 2. Results revealed that for constant error there was no significant main effect for time $F(2,45) = 0.021$, $p = 0.979$, $\eta G^2 = 0.881$, $\omega^2 = 1.754$) or experimental condition ($F(1,23) = 0.121$, $p = 0.731$, $\eta G^2 = 0.000$, $\omega^2 = -0.001$), or interaction effect between experimental condition and time ($F(2,46) = 1.100$, $p = 0.342$, $\eta G^2 = 0.003$, $\omega^2 = 0.002$,) at the 5mph stimulus speed (Figure 1). At the 8 mph stimulus speed, the results revealed that there was no significant main effect for time $F(2,46) = 1.081$, $p = 0.348$, $\eta G^2 = 0.005$, $\omega^2 = 0.003$) or experimental condition ($F(1,23) = 1.372$, $p = 0.253$, $\eta G^2 = 0.005$, $\omega^2 = 0.002$), or interaction effect between experimental condition and time ($F(2,46) = 0.158$, $p = 0.854$, $\eta G^2 = 0.002$, $\omega^2 = -0.003$).

Results revealed that for variable error there was a significant main effect for time, but that time explained only a limited proportion of the variance $F(2,46) = 4.021$, $p = 0.025$ $\eta G^2 = 0.057$, $\omega^2 = 0.097$). The LSD post hoc pairwise comparison indicated that variable error was significantly lower prior to exercise compared to during the cycling task at the 5mph stimulus speed ($p = 0.032$). However, there was no significant main effect for experimental condition ($F(1,23) = 0.616$, $p = 0.440$, $\eta G^2 = 0.008$, $\omega^2 = -0.005$), or interaction effect between experimental condition and time ($F(2,46) = 1.615$, $p = 0.210$, $\eta G^2 = 0.015$, $\omega^2 = 0.009$) at the 5mph stimulus speed (Figure 2). At the 8 mph stimulus speed, the results revealed that there was no significant main effect for time $F(2,46) = 1.717$, $p = 0.191$, $\eta G^2 = 0.043$, $\omega^2 = 0.060$) or experimental condition ($F(1,23) = 0.554$, $p = 0.464$, $\eta G^2 = 0.011$, $\omega^2 = -0.007$), or interaction effect between experimental condition and time ($F(2,46) = 0.460$, $p = 0.634$, $\eta G^2 = 0.012$, $\omega^2 = -0.005$).

Results revealed that for absolute error there was no significant main effect for time ($F(2,46) = 0.461$, $p = 0.633$, $\eta G^2 = 0.003$, $\omega^2 = -0.001$) or experimental condition ($F(1,23) = 0.079$, $p = 0.782$, $\eta G^2 = 0.001$, $\omega^2 = -0.009$) at the 5 mph stimulus speed. However, there was a significant interaction effect between experimental condition and time, but that interaction explained only a limited proportion of the variance ($F(2,46) = 3.967$, $p = 0.026$, $\eta G^2 = 0.030$,

$\omega^2 = 0.026$), at the 5 mph stimulus speed (Figure 3). The LSD post hoc pairwise comparison indicated that a higher absolute error during the cycling task at vigorous intensity exercise (75% HRR) compared to moderate intensity exercise (50% HRR) appeared to be driving the differences ($p = 0.065$). At the 8 mph stimulus speed, the results revealed that there was no significant main effect for time $F(2,46) = 0.094$, $p = 0.910$, $\eta G^2 = 0.001$, $\omega^2 = -0.010$) or experimental condition ($F(1,23) = 0.006$, $p = 0.938$, $\eta G^2 = 0.000$, $\omega^2 = -0.007$), or interaction effect between experimental condition and time ($F(2,46) = 0.531$, $p = 0.591$, $\eta G^2 = 0.005$, $\omega^2 = 0.000$).

Three, 2 (intensity) x 2 (speed) x 3 (time) repeated measures ANOVA's were also conducted to investigate the effects of exercise intensity on CAT performance before, during, and immediately after the cycling task for constant error, variable error, and absolute error. However, no differences were evident (all $p > 0.05$).

Discussion

This is the first study to examine the effect of exercise intensity on CAT performance in children. The results suggest that 15 minutes cycling based exercise does influence CAT performance in children aged 7-11 years. For absolute error, the speed of stimulus also appeared to influence CAT performance. At moderate intensity cycling exercise, CAT performance was improved during and immediately after exercise compared to rest. However, during vigorous intensity cycling exercise, CAT performance was reduced (i.e., error scores were larger) during and immediately after exercise compared to rest. These findings were only found when the stimulus speed was moderate in nature (i.e., 5 mph). Furthermore, the results suggest that we failed to reject the null hypothesis, which indicates that no changes in CAT performance as a consequence of exercise intensity were observed when the stimulus speed was considered fast (i.e. 8 mph).

Given the paucity of research examining the effect of exercise intensity on anticipation timing in children it is difficult to draw direct comparisons to previously published work. However, the findings of the current work do align with prior studies using an adult population by Lyons et al. (2008), Duncan, et al. (2013) and Isaacs and Pohlman (1991). These aforementioned studies all documented improved CAT performance either during (Duncan et al., 2013) or following (Lyons et al., 2008; Isaacs and Pohlman, 1991) moderate intensity exercise. It has been suggested that exercise intensity that is moderate in nature may elicit optimal levels of CNS arousal (Chmura, Nazar, & Kaciuba-Uścilko, 1994; McMorris & Graydon, 2000) which, among other performance indicators, improves reaction time. Åstrand, Rodahl, Dahl, and Strømme. (2003) further add that moderate intensity exercise is beneficial to performance due to increased blood flow to the brain, warming up of the musculature, and increased speed of nerve transmission within the PNS. Such an explanation may apply in the current study as the 50% HRR condition may have led to an increase in general activation, which subsequently enhanced CAT performance. Conversely, it is possible that the increased dual demand of responding to the timing task and continuing to cycle during the vigorous intensity condition resulted in the children being unable to satisfactorily meet both demands with error scores being larger. In the current study the cycling cadence needed to be maintained at each intensity, thus, when intensity was higher (e.g., more difficult task demand), and resource availability cannot meet resource demands, performance on the second task may be likely to decline (Beurskens & Bock, 2012). Although this has previously not been documented in children, in some ways this suggestion is not surprising. This is because an increase in dual task-costs occurs mainly in tasks requiring visual processing on information (as in the CAT task), and errors tend to be higher when task difficulty is greater when managing two tasks (as when cycling at vigorous intensity and attending to the CAT task; Menant, Sturnieks, Brodie, Smith, & Lord, 2014).

These suggestions are, however, speculative as assessment of CNS arousal or blood flow to the brain is difficult to assess in children during exercise.

The magnitude of differences (drawn from the inferential statistics), seen between exercise intensities in the present study also needs to be contextualised. The differences found in the present study are similar to those reported by Lyons et al. (2008) and Duncan et al. (2013) in adults. They are also commensurate with durations reported for timing of catching (or not catching) actions when stimuli are sighted (Savelsbergh & van der Kamp, 2000) and as such, the differences reported here may be considered as meaningful in the context of CAT.

Despite this, any differences in timing error were only evident when stimulus speed was 5 mph. When stimulus speed was 8 mph, there was no significant effect of exercise intensity on CAT timing performance. The rationale for the choice of stimulus speeds was based on prior work in adults which has determined a stimulus speed of 5 mph as ‘intermediate’ (Lyons et al., 2008; Duncan et al., 2013) and 8 mph as ‘fast’ (Lobjois et al., 2006). The optimal stimulus speed to assess coincidence anticipation timing is not known (Sanders, 2011) and it may be that the fast stimulus speed used in the current study was not sensitive enough for children to accurately respond too. Future work documenting ‘typical’ anticipation timing stimulus speeds in children would therefore be welcome, and would provide a robust guide as to which stimulus speeds may be more sensitive when assessing CAT in paediatric populations.

It is also important to note that the exercise intensities selected in the current study of 50% HRR and 75% HRR were chosen to reflect recognised thresholds for moderate and vigorous physical activity in children (Parikh & Stratton, 2011). These exercise intensities reflect thresholds related to health benefits in governmental guidelines for children’s physical activity. As a consequence, the protocol employed in the current study sought to examine exercise intensities that were ecologically valid.

Moreover, the results suggest that for variable error, there was a greater variability in CAT responses during and immediately post the cycling task, compared to just before exercise, irrespective of intensity of exercise. It seems that the anticipation scores were somewhat ‘noisier’ especially during the cycling task. This may be due to an increase in dual-tasks costs, which arises when individuals are required to manage two branches of similar (e.g., visual) information (i.e., when cycling and attending to the CAT task in the present study), compared to when managing two tasks requiring different types of processing (e.g., one visual and one auditory; Duncan et al., 2015; Menant et al., 2014). Furthermore, the increased physiological requirements of the 15-minute cycling task, coupled with the increased cognitive demands of the CAT task, may have led to decrements in CAT performance, as changes in pedal frequency would not be possible when cycling at a set intensity (Duncan et al., 2015).

Despite the findings presented here, this study is not without limitation. By assessing CAT during exercise, we sought to build on prior recommendations (Lyons et al., 2008) that CAT should be assessed during rather than post exercise. The current study also built on suggestions made by Lyons et al. (2008) that using different stimulus speeds is required to better understand the effect of exercise on CAT. However, when this approach is used, it is possible that divided attentional mechanisms, rather than exercise intensity alone, is responsible for decreased performance (Isaacs & Pohlman, 1991). The differences in CAT seen across exercise intensities and stimulus speeds in the present study may therefore be a result of divided attention, rather than simply the exercise intensity alone. However, the switch-press response (largely a sensory-based response with a very small motor component) was deliberately chosen so as to consider this point. It is also important to note that although allocation of treatment was concealed to participants, and heart rate and other forms of feedback (e.g., cadence, speed) were removed from participants' sight, it is not possible to ensure complete blinding during such experimental trials. In addition, it is possible that important main effects were masked when adding the additional factor of speed in the three-way ANOVA; this is because the main effect would essentially look at combined effects from the pooled data.

Furthermore, research that has utilised a prediction motion paradigm to investigate coincidence-timing, at rest, in children have shown that errors in estimations increase with declining age (e.g., Benguigui et al., 2008; Benguigui et al., 2004). In our study, we grouped children ranging from 7-11 years old; therefore, the cognitive and motor development could have been significantly different (Benguigui et al., 2008). This could have potentially hindered important differences in the CAT performance of the oldest and youngest child. Future research should explore the effect of exercise intensity on CAT performance in different age groups of children (e.g., 7, 10, and 13 years old).

Conclusion

Given the lack of research that has examined CAT specifically, and cognitive performance more generally, during exercise at different intensities, we are aware that the data presented here is exploratory. However, the present study provides important novel findings that 15 minutes cycling based exercise at moderate intensity, appears to improve anticipation timing during and immediately after exercise in children, but only when stimulus speeds are moderate in nature.

References

Al-Nakeeb, Y., & Lyons, M. (2007). Performance of tasks with high demands on anticipation and concentration under various conditions of physical exertion. In: Proceedings of the 12th Annual Congress of the European College of Sport Science, Jyvaskyla, Finland.

Åstrand, P. O., Rodahl, K., Dahl, H. A., & Strømme, S. B. (2003). *Textbook of work physiology: physiological basis of exercise* (4^{th} Ed.). Champaign Ill: Human Kinetics.

Bard, C., & Fleury, M. (1978). Influence of imposed metabolic fatigue on visual capacity components. *Perceptual and Motor Skills, 47*, 1283-1287.

Benguigui, N., Broderick, M. P., Baurès, R., & Amorim, M. A. (2008). Motion prediction and the velocity effect in children. *British Journal of Developmental Psychology, 26*, 389-407.

Benguigui, N., Broderick, M. P., & Ripoll, H. (2004). Age differences in estimating arrival-time. *Neuroscience Letters, 369*, 191-196.

Beurskens, R. & Bock, O. (2012). Age-related deficits in dual-task walking: A review. *Neural Plasticity*, 131608.

Chmura, J., Nazar, K., & Kaciuba-Uścilko, H. (1994). Choice reaction time during exercise in relation to blood lactate and plasma catecholamines thresholds. *International Journal of Sports Medicine, 15*, 172-176

Cooper, S. B., Bandelow, S., Nute, M. L., Ding, K. J., Stannard, R. L., Morris, J. G., & Nevil, M. E. (2016) Sprint-based exercise and cognitive function in Adolescents. *Preventative Medicine Reports, 4,* 155-161.

Davranche, K., & Audiffren, M. (2004). Facilitating effects of exercise on information processing. *Journal of Sport Science, 22*, 419-428.

Davranche, K., Brisswalter, J., Radel, R. (2015) Where are the limits of the effects of exercise intensity on cognitive control? *Journal of Sport and Health Science, 4*, 56–63.

Dietrich, A. (2003.) Functional neuroanatomy of altered states of consciousness: The transient hypofrontality hypothesis. *Consciousness and Cognition, 12*, 231-256.

Duncan, M., & Johnson, A. (2014). The effect of differing intensities of acute cycling on preadolescent academic achievement. *European Journal of Sport Science, 14*, 279-286.

Duncan, M., Smith, M., Lyons, M. (2013). The effect of exercise intensity on coincidence anticipation performance at different stimulus speeds. *European Journal of Sport Science, 13,* 559–566.

Duncan, M., Stanley, M., Smith, M., Price, M. J., & Leddington-Wright, S. (2015). Coincidence anticipation timing performance during an acute bout of brisk walking in older adults: Effect of stimulus speed. *Neural Plasticity, 12*, 1-8.

Faul, F., Erdfelder, E., Lang, A. G., Buchner, A. (2007). G*Power 3: A flexible analysis programme for the social, behavioural, and biomedical sciences. *Behavior Research Methods, 39*, 175-191.

Fleury, M., & Bard, C. (1985). Age, stimulus velocity and task complexity as determiners of coincident timing behaviour. *Journal of Human Movement Studies, 11*, 305-317.

Goodgold-Evans, S. (1991). Cognitive strategies during coincident timing tasks. *Physical Therapy, 71*, 236-243.

Hillman, C., Erickson, K. I., & Kramer, A. F. (2008). Be smart, exercise your heart: Exercise effects on brain and cognition. *Nature Reviews Neuroscience, 9,* 58-65.

Isaacs, L. D., & Pohlman, R. L. (1991). Effects of exercise intensity on an accompanying timing task. *Journal of Human Movement Studies, 20*, 123-131.

Karvonen J., & Vuorimaa, T. (1988). Heart rate and exercise intensity during sports activities. *Sports Medicine, 5,* 303-312.

Keshavarz, B., Landwehr, K., Baurès, R., Oberfeld, D., Hecht, H., & Benguigui, N. (2010).

Age-Correlated Incremental Consideration of Velocity Information in Relative Time-to-Arrival Judgments. Ecological Psychology, 22, 212-221.

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

Lobjois, R., Benguigui, N., & Bertsch, J. (2006). The effect of aging and tennis playing on coincidence-timing accuracy. *Journal of Aging and Physical Activity*, *14*, 75-98.

Lyons, M., Al-Nakeeb, Y., & Nevill, A. (2008). The effect of moderate and high intensity fatigue on coincidence anticipation in expert and novice Gaelic games players. *European Journal of Sport Science, 8,* 205-216.

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

Menant, J. C., Sturnieks, D. L., Brodie, M. A. D., Smith, S.T. & Lord, S.R. (2014). Visuospatial tasks affect locomotor control more than nonspatial tasks in older people. PLoS ONE 9(10): e109802.

Parikh, T., & Stratton, G. (2011). Influence of intensity of physical activity on adiposity and cardiorespiratory fitness in 5-18 year olds. *Sports Medicine, 41*, 477-488.

Ridgers, N. D., Stratton, G., Clark, E., Fairclough, S. G., & Richardson, D. G. (2006). Day-today and seasonal variability of physical activity during school recess. *Preventative Medicine, 42,* 372-374.

Robergs, R. A., & Landwehr, L. R. (2002). The surprising history of the HR max = 220-age equation. *International Journal of Exercise Physiology, 5,* 1-10.

Sanders, G. (2011). Sex differences in coincidence anticipation timing (CAT): A review. *Perceptual and Motor Skills, 112*, 61-90.

Savelsbergh, G. J. P., & van der Kamp, J. (2000). Adaptation in the timing of catching under changing environmental constraints. *Research Quarterly for Exercise and Sport*, 71, 195-200.

Sibley, B. S., & Etnier, J. L. (2003). The relationship between physical activity and cognition in children: A meta-analysis. *Pediatric Exercise Science, 15,* 243-256.

Tanaka, H., Monahan, K. D., & Seals, D. R. (2001). Age-predicted maximal heart rate revisited. *Journal of the American College of Cardiology, 37*, 153-156.

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

Table 1

Mean [95% CI] and range of participants age, height, and body mass.

	Mean [95% CI]	*Range*
Age (years)	9.00 [7.53, 9.01]	7.00 – 11.00
Height (m)	1.35 [1.30, 1.39]	1.21 – 1.45
Body Mass (kg)	30.70 [27.19, 34.21]	21.00 - 44.90

Table 2

Mean [95% CI] of constant error, variable error, and absolute error (secs) at stimulus speeds of 5 and 8 mph before, at 7 min 30 secs, and after 15 min cycling at 50% HRR or 15 min cycling at 75% HRR.

	50% HRR			75% HRR		
	Before	7 min 30 secs during	After	Before	7 min 30 secs during	After
Constant error 5 mph (secs)	.07 [0.03, 0.10]	.05 [0.01, 0.09]	.06 [0.03, 0.09]	.06 [0.02, 0.09]	.07 [0.03, 0.11]	.06 [0.02, 0.11]
Constant error 8 mph (secs)	.05 [0.03, 0.08]	.06 [0.03, 0.09]	.07 [0.04, 0.09]	.06 [0.02, 0.10]	.07 [0.04, 0.11]	.07 [0.04, 0.10]
Variable error 5 mph (secs)	.07 [0.05, 0.09]	.09 [0.06, 0.11]	.07 [0.06, 0.09]	.06 [0.05, 0.08]	.11 [0.06, 0.15]	.08 [0.05, 0.12]
Variable error 8 mph (secs)	.08 [0.06, 0.10]	.08 [0.05, 0.11]	.07 [0.05. 0.08]	.08 [0.05, 0.10]	.11 [0.05, 0.17]	.07 [0.04, 0.09]
Absolute error 5 mph (secs)	.12 [0.08, 0.14]	.10 [0.07, 0.13]	.11 [0.08, 0.13]	.09 [0.07, 0.11]	.13 [0.09, 0.17]	.11 [0.07, 0.14]
Absolute error 8 mph (secs)	.09 [0.07, 0.11]	.13 [0.05, 0.20]	.09 [0.07, 0.10]	.09 [0.07, 0.12]	.10 [0.06, 0.13]	.12 [0.08, 0.15]

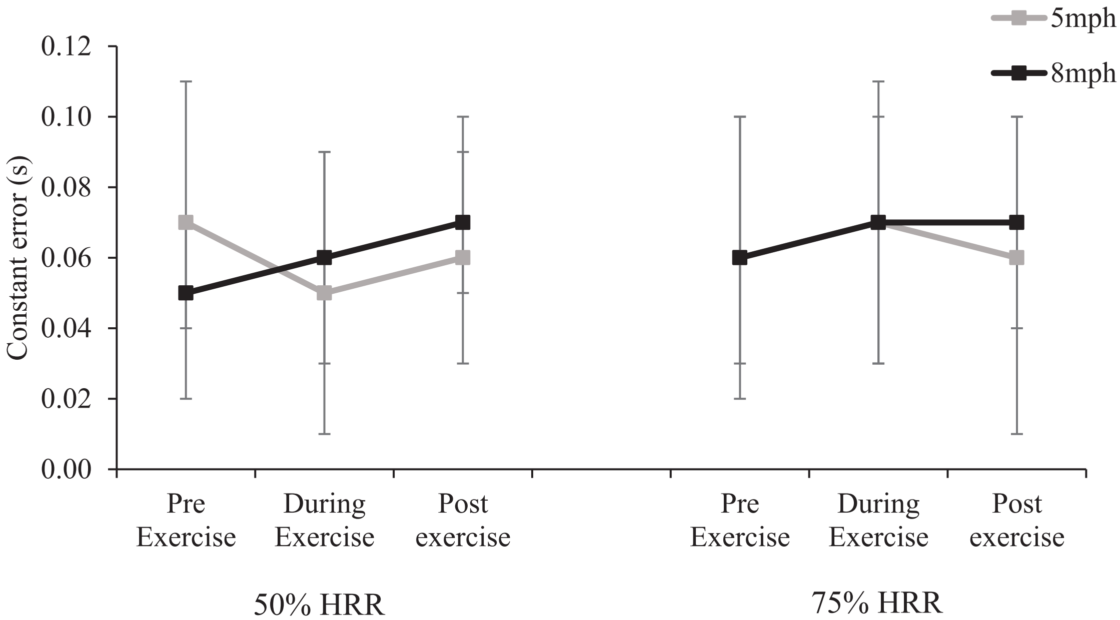

Figure 1: Mean of constant error (secs) at pre, during, and post exercise, at stimulus speeds of 5 and 8 mph in moderate (50% HRR) and vigorous (75% HRR) exercise intensity conditions.

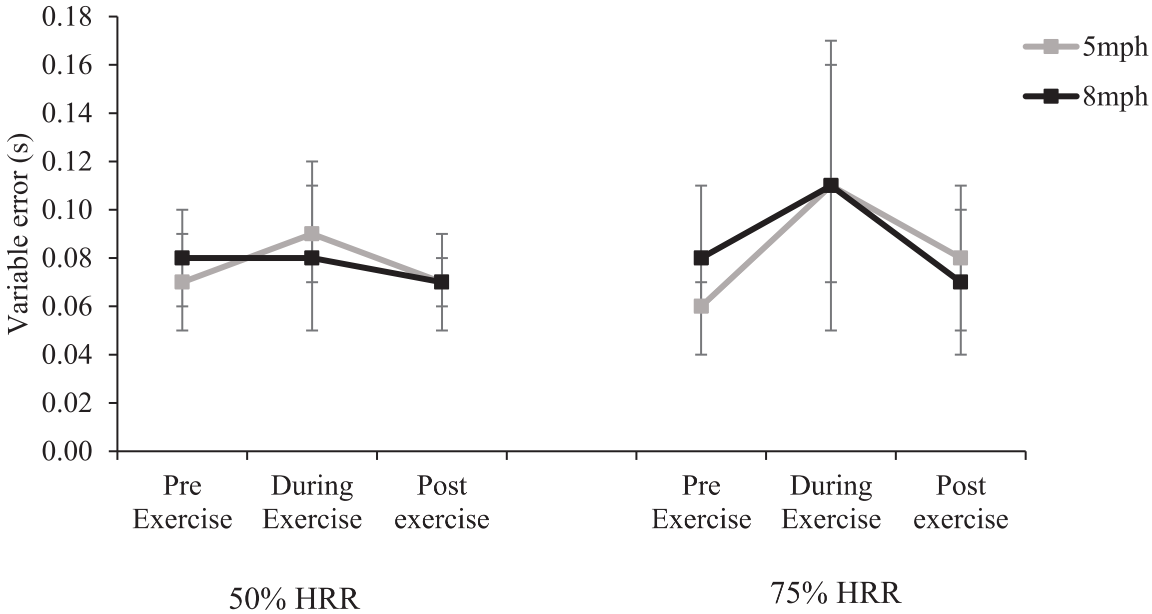

Figure 2: Mean of variable error (secs) at pre, during, and post exercise, at stimulus speeds of 5 and 8 mph in moderate (50% HRR) and vigorous (75% HRR) exercise intensity conditions.

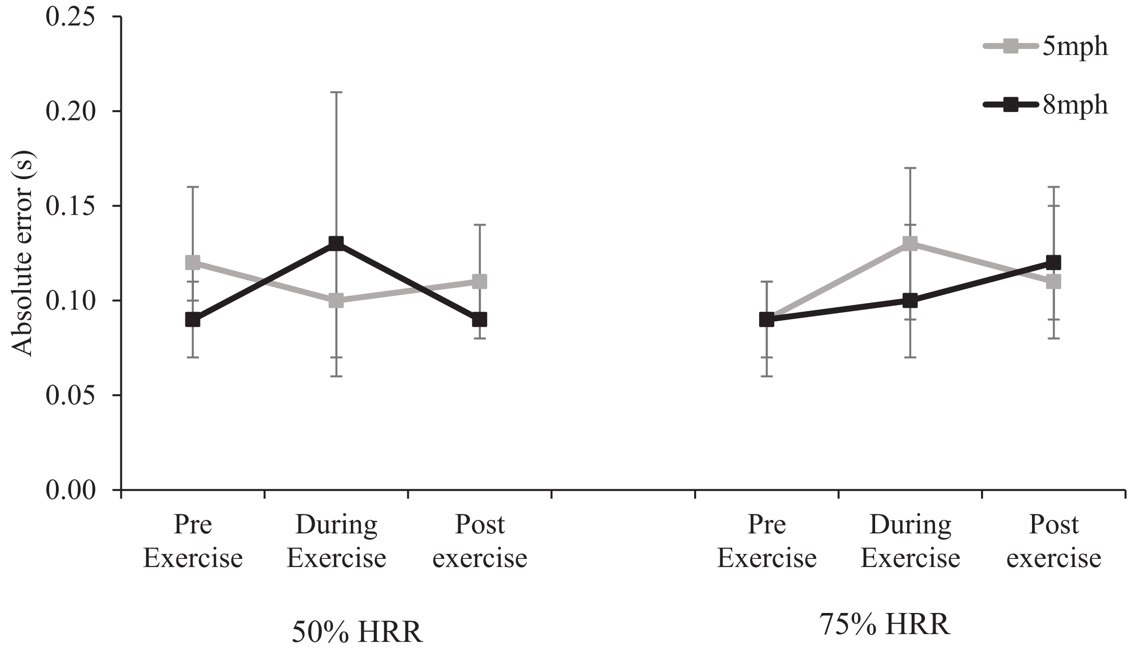

Figure 3: Mean of absolute error (secs) at pre, during, and post exercise, at stimulus speeds of 5 and 8 mph in moderate (50% HRR) and vigorous (75% HRR) exercise intensity conditions.