International Journal of Business, Human and Social Sciences
ISSN: 2517-9411
Vol:7, No:11, 2013

Exercise and Cognitive Function: Time Course of the Effects

Simon B. Cooper, Stephan Bandelow, Maria L. Nute, John G. Morris, Mary E. Nevill

***Abstract*—**Previous research has indicated a variable effect of exercise on adolescents' cognitive function. However, comparisons between studies are difficult to make due to differences in: the mode, intensity and duration of exercise employed; the components of cognitive function measured (and the tests used to assess them); and the timing of the cognitive function tests in relation to the exercise. Therefore, the aim of the present study was to assess the time course (10 and 60min post-exercise) of the effects of 15min intermittent exercise on cognitive function in adolescents. 45 adolescents were recruited to participate in the study and completed two main trials (exercise and resting) in a counterbalanced crossover design. Participants completed 15min of intermittent exercise (in cycles of 1 min exercise, 30s rest). A battery of computer based cognitive function tests (Stroop test, Sternberg paradigm and visual search test) were completed 30 min pre- and 10 and 60min post-exercise (to assess attention, working memory and perception respectively).The findings of the present study indicate that on the baseline level of the Stroop test, 10min following exercise response times were slower than at any other time point on either trial (trial by session time interaction, $p = 0.0308$). However, this slowing of responses also tended to produce enhanced accuracy 10min post-exercise on the baseline level of the Stroop test (trial by session time interaction, $p = 0.0780$). Similarly, on the complex level of the visual search test there was a slowing of response times 10 min post-exercise (trial by session time interaction, $p = 0.0199$). However, this was not coupled with an improvement in accuracy (trial by session time interaction, $p = 0.2349$). The mid-morning bout of exercise did not affect response times or accuracy across the morning on the Sternberg paradigm. In conclusion, the findings of the present study suggest an equivocal effect of exercise on adolescents' cognitive function. The mid-morning bout of exercise appears to cause a speed-accuracy trade off immediately following exercise on the Stroop test (participants become slower but more accurate), whilst slowing response times on the visual search test and having no effect on performance on the Sternberg paradigm. Furthermore, this work highlights the importance of the timing of the cognitive function tests relative to the exercise and the components of cognitive function examined in future studies.

***Keywords*—**Adolescents, cognitive function, exercise.

I. Introduction

PREVIOUS meta-analyses have indicated that exercise has a small, but positive, effect on cognitive function in adults [1] and young people [2]. However, it has also been suggested that there are several mediators of the relationship between exercise and cognitive function, including: the exercise duration, exercise intensity, the population age group, the component of cognitive function examined, and the timing of the cognitive tests relative to exercise [1]-[3].

A majority of the previous literature in this area has examined adult populations [1], [3]. However, several studies have also examined young people, with the age of the young people an important mediator in the relationship between exercise and cognition in both meta-analyses [1], [2]. Specifically, the largest effect size was seen in 'middle school' students aged 8-11 (ES = 0.48), and a smaller ES (0.24) for 'high school' students aged 12-16 [2]. In the later meta-analysis, converse to the earlier findings, a larger effect size was observed for 'high school' (aged 14-17) than for 'elementary school' (aged 6-13) children (ES = 0.17 vs. 0.07) [1]. Such fluctuations in effect size may result from differences in methodology, for example the inclusion of different age ranges in each category and pooled data from largely from unpublished studies. However, they may also point to a more fundamental role of age in modifying the effects of exercise on cognitive function, and accordingly it is important to investigate this relationship specifically in young people.

The present study focuses on an adolescent population, given that cognitive function is of great importance during adolescence for academic achievement, thus any factors which could affect/optimize cognitive function in this population are of interest. Furthermore, previous findings in younger children (aged 6-11) [4], [5] may not generalize to adolescents, given that younger children have a larger brain weight relative to their body weight and a 50% greater metabolic rate per unit of brain weight [6]. In the small number of published studies on adolescents there is a general trend towards exercise having a beneficial effect on adolescents' cognitive function [7]-[11].

The proposed mechanisms by which exercise may positively influence cognitive function include increases in arousal, catecholamine concentration, heart rate and brain derived neurotrophic factor (BDNF) [1]. Clearly, these potential mechanisms would suggest that the timing of the cognitive tests relative to the exercise will impact upon the effects observed. For example, exercise induces a transient increase in BDNF, thus if this mechanism is responsible for any exercise induced changes, the timing of the cognitive tests would be critical to examine this.

However, the mediating effect of the timing of the cognitive tests has only been examined to a limited extent in the literature to date, and this is exclusively through pooling data sets via meta-analyses. For example, similar (small and

S. B. Cooper is with the Sport, Health & Performance Enhancement (SHAPE) Research Group, School of Science & Technology, Nottingham Trent University, UK (phone: +44 1158 488059; e-mail: Simon.Cooper@ntu.ac.uk).

S. Bandelow, M. L. Nute, J. G. Morris & M. E.Nevill are with the Institute of Youth Sport, School of Sport, Exercise & Health Sciences, Loughborough University, UK.

positive) effects of exercise on cognitive function during exercise, immediately (<1min) following exercise and after a delay (>1min) following exercise have been found [1]. Conversely, it has also been suggested that exercise had a detrimental effect on cognitive function when measured during the exercise, though a positive effect when cognitive function was assessed following exercise [3]. Thus, the time course of the effects of exercise on cognitive function remains unclear. Furthermore, the aforementioned meta-analyses have pooled data mostly from adult studies, thus the time course of the effects of exercise on cognitive function in adolescents remains unknown.

Therefore, the aim of the present study was to assess the time course (10 and 60min post exercise) of the effects of 15 min intermittent exercise (thus has practical application to the school morning) on a range of components of cognitive function (attention, memory and visual search) in adolescents.

II. Methods

A. Participant Characteristics

Fifty-four schoolchildren aged 11 to 13 years were recruited to participate in the study. However, 13 participants failed to complete the study because they were either absent from school for one of the experimental trials (n = 11) or failed to comply with the dietary control conditions (n = 2). During familiarization, simple measures of height, body mass and waist circumference were taken. Height was measured using a Leicester Height Measure (Seca, Hamburg, Germany), accurate to 0.1cm. Body mass was measured using a Seca 770 digital scale (Seca, Hamburg, Germany), accurate to 0.1kg. These measures allowed the determination of Body Mass Index (BMI), calculated by dividing body mass [kg] by the square of the height [m^2]. Waist circumference was measured at the narrowest point of the torso between the xiphoid process of the sternum and the iliac crest, to the nearest 0.1cm. For descriptive purposes, the anthropometric characteristics of the participants who completed the study (n = 41) are provided in Table I.

TABLE I
Anthropometric Characteristics of Participants

	n	Age [yrs]	Height [cm]	Body Mass [kg]	BMI [$kg.m^{-2}$]	Waist Circumference [cm]
Male	17	12.2±0.7	148.9±7.7	40.1±7.7	17.9±2.3	63.6±6.6
Female	24	12.2±0.6	152.8±4.8	46.2±9.2	20.1±3.0	66.8±7.7
Overall	41	12.2±0.6	151.1±6.5	43.7±9.0	19.1±2.9	65.4±7.4

All values are mean ± standard deviation.

B. Study Design

The study was approved by the institutions ethical advisory committee. Participants were recruited from a local secondary school and in accordance with the ethical guidelines of the British Education Research Authority for school based research, school level consent was obtained from head teachers. In addition, written parental informed consent was obtained and a health screen questionnaire completed (covering any medical issues relating to the child) to ensure all participants were in good health.

Each participant undertook a familiarization session, which preceded the first of two experimental trials by seven days. During familiarization, the protocol of the study was explained and participants were provided with an opportunity to familiarize themselves with the methods involved, which included completing the battery of cognitive function tests. In addition, participants were provided with an opportunity to ask questions and clarify any part of the tests they did not fully understand.

The study employed a randomized crossover design, with participants blind until arrival at school on each day of testing. The experimental trials consisted of an exercise trial and a resting trial. Therefore, participants acted as their own controls. Trials were scheduled eight days apart and participants reported to school at the normal time. The experimental protocol is shown in Fig. 1.

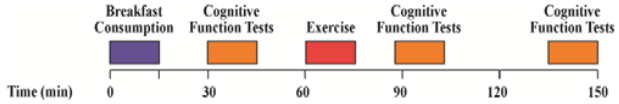

Fig. 1 Experimental Protocol

C. Dietary Control

Participants consumed a meal of their choice the evening before their first experimental trial and were asked to repeat this meal for their subsequent trial. Following this meal, participants were asked to observe an overnight fast from 10pm. In order to maintain euhydration, participants were allowed to drink water *ad libitum* during this time. In addition, participants were asked to avoid any unusually vigorous exercise for 24h prior to each experimental trial. Prior to each main trial, a telephone call was made to participants' parents to remind them of this information. Participants who had not followed these requirements were removed from the study (n = 2).

D. Exercise Protocol

Participants completed a 15 minute bout of mid-morning exercise, consisting of 10x1min bouts of running, interspersed by 30s rest periods. Participants were asked to complete 20m shuttle runs at an intensity to elicit '5' on the Robertson OMNI scale [12], to reflect exercise which made them 'slightly tired'. Participants were reminded of this during each rest period, during which they were asked to indicate their current feelings on the Roberston OMNI scale and their heart rate was

recorded (Polar Wearlink heart rate monitor and Polar S610i watch; Polar, Finland). The duration and intensity of the exercise was chosen so it was sufficiently brief to fit into a normal school morning and reflected adolescents' usual physical activity patterns. Consequently, the exercise protocol could be incorporated into a school morning and potentially has practical application, especially given the well documented social, emotional, physical and health benefits of break time/recess to young people [13].

Participants exercised at 5±1 on the Roberston OMNI scale, covering 130±20m·min^{-1} and their heart rate during the exercise was 169±14 beats·min^{-1}. Heart rate was also recorded across the remainder of the trials and was similar between the exercise (99±13 beats·min^{-1}) and resting (92±9 beats·min^{-1}) trials ($p>0.05$).

E. Cognitive Function Tests

The battery of cognitive function tests was administered via a laptop computer and lasted approximately 10min. The battery of tests included a test of visual search, a Stroop test and the Sternberg paradigm. The cognitive function tests were completed 30min pre-exercise and 10 and 60min post-exercise. Written instructions appeared on the screen at the start of each test, which were repeated verbally by an investigator. Each cognitive function test was preceded by 3-6 practice stimuli, where feedback was provided regarding whether the participants' response was correct or not. Data from these practice stimuli were discarded and once the test started no feedback was provided. The cognitive function tests were administered to groups of 10-12 participants at any one time, in silence and separated such that participants could not interact with each other during the cognitive testing. The same testing procedure has been previously used successfully in a similar study population [8] and the tests were administered in the order they are described here.

Visual Search Test: The visual search test consisted of two test levels, each consisting of 21 stimuli. On each test level, participants were instructed to respond as quickly as possible to the stimuli by pressing the space bar on the keyboard. In both test levels there were 21 different locations for the stimuli, with the order of the locations randomized.

The stimuli in the baseline level were triangles drawn in solid green lines on a black background, providing a measure of simple visuo-motor speed. The complex level had random green dots covering the screen, which were redrawn every 250 ms to induce the visual effect of a flickering background, acting as a background distractor. The target triangles were drawn with a few dots on each line and the density of these dots increased until the participant responded (the lines becoming denser until a response was registered). This provided a measure of complex visual processing. The variables of interest on both levels were the response times of correct responses and the percentage of correct responses made (accuracy).

Stroop Test: The Stroop test measures the sensitivity to interference and the ability to suppress an automated response (i.e. the time required to identify the color rather than read the word) [14] and is a commonly used measure of selective attention [15]. The Stroop test consisted of two levels. Both levels involved the test word being placed in the centre of the screen, with the target and distractor presented randomly on the right or left of the test word. The target position was counterbalanced for the left and right side within each test level. The participant was asked to respond as quickly as possible, using the left and right arrow keys, to identify the position of the target word.

The baseline level contained 20 stimuli, where the test word was printed in white on the centre of the screen and the participant had to select the target word, from the target and distractor, which were also printed in white. The color-interference level contained 40 stimuli and involved the participant selecting the color the test word was written in, rather than the actual word (which was an incongruent color), again using the right and left arrow keys to identify the target. The choices remained on the screen until the participant responded. The variables of interest were the response times of correct responses and the percentage of correct responses made (accuracy).

Sternberg Paradigm: The Sternberg Paradigm [16] is a test of working memory and has three levels. Each test level presented a different working memory load; one, three or five items. On the one-item level, the target was always the number '3'. This level contained 16 stimuli and provides a measure of basic information processing speed. The three- and five-item levels had target lists of three and five letters respectively, each containing 32 stimuli.

At the start of each level, the target items were displayed together with instructions to press the right arrow key if the stimulus was a target item and the left arrow key otherwise. The correct responses were counterbalanced on each level between the right and left arrow keys. The choice stimuli were presented on the centre of the screen with an inter-stimulus interval (ISI) of 1 second, during which the screen was blank. The choices remained on the screen until the participant responded. The variables of interest were the response times of correct responses and the percentage of correct responses made (accuracy).

F. Breakfast

A range of breakfast foods were provided for participants on their first trial, from which they chose *ad libitum*. The quantity of food taken by each participant was recorded and any leftovers weighed using a Salter 1029 WHDRT scale (Salter, Hamburg, Germany) to allow determination of the breakfast consumed by each participant. Due to the well documented effect of breakfast consumption and composition on adolescents' cognitive function [6], [17], [18], on the subsequent trial an identical breakfast was provided along with instructions that all the breakfast must be consumed within 15min. All participants followed this instruction. The breakfast consumed consisted of (mean ± SD): 294±112 kcal, 57.1±18.9g of carbohydrate, 7.3±4.4g of protein and 4.4±3.5g of fat.

G. Statistical Analysis

The cognitive function data were analyzed using R (www.r-project.org, version 2.9.1). Response time analyses were performed using the nlme package for R, which implements mixed effect models. Accuracy analyses were performed with the lme4 package for R, which implements mixed effect models with non-normal outcome data distributions, similar to generalized linear models. Accuracy data analyses assumed a binomial outcome data distribution to best account for the binary (correct/incorrect) nature of the data. Analyses were conducted using a three-way trial (exercise/resting) by session time (30min pre-exercise/10min post-exercise/60min post-exercise) by test level (baseline/complex) interaction. Where appropriate, two-way trial (exercise/resting) by session time (30min pre-exercise/10min post-exercise/60min post-exercise) interactions for each test level (baseline/complex) were conducted. For all analyses, significance was set as $p < 0.05$.

III. Results

For all cognitive tests the response times were first log transformed to normalize the distributions, which exhibited the right-hand skew typical of human response times. According to task complexity, minimum and maximum response time cut-offs were set to exclude those responses that can be considered anticipations and delayed responses. As such, minimum response time cut-offs were set at 300ms for the visual search test, 250ms for the Stroop test and 200ms for the Sternberg paradigm. Maximum response time cut-offs were set at 2000ms (baseline level) and 10000ms (complex level) for the visual search test, 3000ms (baseline level) and 5000ms (complex level) for the Stroop test and 3000ms (all levels) for the Sternberg paradigm. Only the response times of correct responses were used for response time analysis across all three cognitive tests.

A. Visual Search Test

Response Times: There was no difference in the pattern of change in response times across the morning between the baseline and complex levels of the visual search test, between the exercise and resting trials (trial by session time by test level interaction, $p = 0.2566$). Furthermore, when considering only the baseline level, there was no difference in response times across the morning between the exercise and resting trials (trial by session time interaction, $p = 0.0695$). However, on the complex level of the visual search test, there was a significant trial by session time interaction ($t_{(2,5073)} = 2.3$, $p = 0.0199$), whereby response times improved across the morning on the resting trial, but were slower 10 min post-exercise on the exercise trial (Fig. 2).

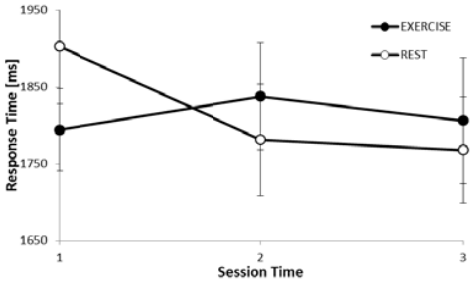

Fig. 2 Response times (mean ± SEM) across the morning on the complex level of the visual search test, on the exercise and resting trials (trial by session time interaction, $p = 0.0199$)

Accuracy: There was no difference in the pattern of change in accuracy across the morning between the baseline and complex levels of the visual search test, between the exercise and resting trials (trial by session time by test level interaction, $p = 0.9812$). Furthermore, when analyzing the baseline and complex levels separately, there was no difference in the pattern of change in accuracy across the morning between the exercise and resting trials (trial by session time interactions: baseline level, $p = 0.2322$; complex level, $p = 0.2349$).

B. Stroop Test

Response Times: There was no difference in the pattern of change in response times across the morning between the baseline and complex levels of the Stroop test, between the exercise and resting trials (trial by session time by test level interaction, $p = 0.0698$). However, this interaction did approach significance. Upon further analysis, when considering only the complex level, there was no difference in response times across the morning between the exercise and resting trials (trial by session time interaction, $p = 0.4963$). However, on the baseline level of the Stroop test, there was a significant trial by session time interaction ($t_{(2,4689)} = 2.2$, $p = 0.0308$), whereby response times were slower 10 min post-exercise on the resting trial when compared to any other time point on either trial (Fig. 3).

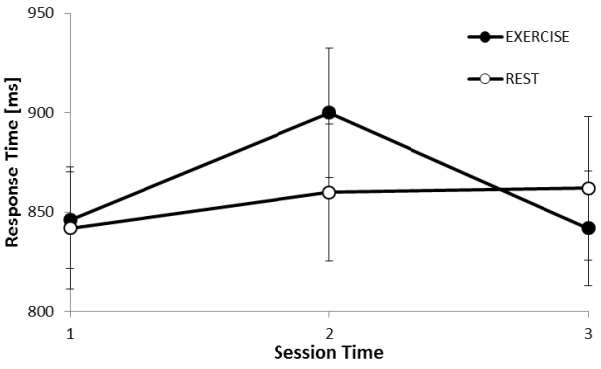

Fig. 3 Response times (mean ± SEM) across the morning on the baseline level of the Stroop test, on the exercise and resting trials (trial by session time interaction, $p = 0.0308$)

Accuracy: There was no difference in the pattern of change in accuracy across the morning between the baseline and complex levels of the Stroop test, between the exercise and resting trials (trial by session time by test level interaction, p = 0.1626). Similar to the findings for response times, upon further analysis, there was no difference in response times across the morning between the exercise and resting trials on the complex level of the Stroop test (trial by session time interaction, p = 0.6248). However, on the baseline level of the Stroop test, there was a tendency for accuracy to be enhanced 10 min post-exercise when compared to the resting trial (trial by session time interaction ($z_{(2,4940)}$ = 1.7, p = 0.0780, Fig. 4), though this did not reach statistical significance.

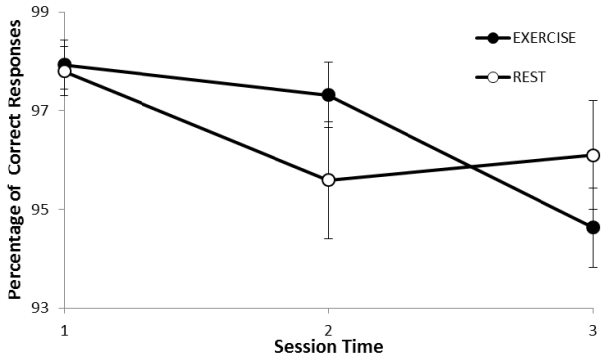

Fig. 4 Accuracy (mean ± SEM) across the morning on the baseline level of the Stroop test, on the exercise and resting trials (trial by session time interaction, p = 0.0780).

C. Sternberg Paradigm

Response Times: There was no difference in the pattern of change in response across the morning between the different levels of the Sternberg paradigm, between the exercise and resting trials (trial by session time by test level interaction, p = 0.2537). Furthermore, when analyzing the one-, three- and five-item levels separately, there was no difference in the pattern of change in response times across the morning between the exercise and resting trials (trial by session time interactions: one-item level, p = 0.2033; three-item level, p = 0.2918; five-item level, p = 0.8627).

Accuracy: There was no difference in the pattern of change in accuracy across the morning between the different levels of the Sternberg paradigm, between the exercise and resting trials (trial by session time by test level interaction, p = 0.1943). Furthermore, when analyzing the one-, three- and five-item levels separately, there was no difference in the pattern of change in accuracy across the morning between the exercise and resting trials (trial by session time interactions: one-item level, p = 0.2590; three-item level, p = 0.8672; five-item level, p = 0.6824).

IV. Discussion

The main findings of the present study are that 10min post-exercise, response times slowed on the complex level of the visual search test and the baseline level of the Stroop test, when compared to the resting trial. This was combined with a tendency for increased accuracy 10 min post-exercise on the baseline level of the Stroop test. However, the mid-morning bout of exercise had no effect on accuracy on the visual search test, or performance on the Sternberg paradigm. These findings suggest that the effect of the mid-morning bout of exercise were transient and that 60min post-exercise, there was no difference in cognitive function between the exercise and resting trials. Furthermore, the findings also suggest that the effects of exercise on cognitive function are dependent on the component of cognitive function examined, with the present study demonstrating effects on perception (as assessed by the visual search test) and attention (as assessed by the Stroop test), but not on working memory (as assessed by the Sternberg paradigm).

No previous studies have specifically examined the time course of the effects of exercise on cognitive function and these effects are difficult to interpret from previous studies due to the varied timing of the cognitive tests relative to the exercise. This has meant a reliance on meta-analyses (including data from adult studies), which have also provided conflicting results. For example, it has been suggested that exercise impaired cognitive function during exercise, though post-exercise an enhancement in cognitive function was seen [3]. In comparison, it has also been suggested that exercise enhanced cognitive function during exercise, immediately following exercise and also after a delay following exercise (though this was defined as > 1min following exercise) [1]. The present study is the first to examine the effects of exercise at two time points post-exercise (10 and 60min), suggesting that any exercise induced effects on adolescents' cognitive function are transient (only present 10min, and not 60min, post-exercise).

The present study also adds to the literature regarding the effects of a single bout of exercise on adolescents' cognitive function. A bulk of the previous literature suggests a beneficial effect of a single bout of exercise on adolescents' cognitive function [7]-[11], though some studies suggest there is no effect [19], [20]. Previous studies are however difficult to compare due to the potential mediating variables in the exercise-cognition relationship, including: exercise modality, exercise intensity, exercise duration, and the components of cognitive function examined (and the tests used to assess these).

Perhaps the easiest comparisons can be drawn with previous data from our own laboratory [8], using a similar exercise modality, duration, intensity and cognitive testing battery. The previous findings suggest that the speed of working memory (as assessed by the Sternberg paradigm) was enhanced 45min following exercise, whereas the findings of the present study suggest that working memory was not affected (10 or 60min post-exercise). However, attention (as assessed by Stroop test) and perception (as assessed by visual search test) were affected 10min (but not 60min) post-exercise. Furthermore, taken together, the findings of the two studies suggest that whilst attention and perception are affected more immediately (10min) following exercise, working memory may be affected

after a short delay (positive effects seen 45min, but not 60min, post-exercise). However, given that these data come from two separate studies the findings must be interpreted cautiously. Furthermore, these findings add weight to the evidence suggesting that the effects of exercise are dependent on the component of cognitive function examined and further work should continue to examine these relationships.

The differing time course of the effects of exercise on different components of cognitive function also suggest that the mechanisms by which exercise affects each component of cognitive function may be different. Several mechanisms have been postulated to mediate the exercise-cognition relationship, including: increases in arousal, enhanced blood flow to the brain, increased catecholamine concentrations, elevations in heart rate, increased brain derived neurotrophic factor (BDNF) and changes to signaling within the brain [1], [5], [21]. The time course of these changes post-exercise will be different, thus these (and other variables) may each affect different components of cognitive function, thus determining the exercise-cognition relationship.

In summary, the findings of the present study suggest that the exercise-cognition relationship in adolescents is mediated by both the time of cognitive testing relative to exercise and the component of cognitive function examined. Specifically, adolescents performed slower but more accurately on the Stroop test (assessing attention) 10min post exercise, as well as slower 10min post exercise on the visual search test (assessing perception). However, there was no effect of the mid-morning bout of exercise on performance on the Sternberg paradigm (assessing working memory). Furthermore, these findings suggest that the effect of the mid-morning bout of exercise were transient and that 60min post-exercise, there was no difference in cognitive function between the exercise and resting trials. Therefore, both the timing of cognitive testing relative to exercise and the specific components of cognitive function examined must be considered in future studies examining the relationship between an acute bout of exercise and cognitive function in young people.

REFERENCES

[1] Y.K. Chang, J.D. Labban, J. I. Gapin, and J. L. Etnier, "The effects of acute exercise on cognitive performance: a meta-analysis," *Brain Res*, vol. 1453, pp. 87-101, 2012.

[2] B.A. Sibley, and J.L Etnier, "The relationship between physical activity and cognition in children: a meta-analysis," *Ped Ex Sci*, vol. 15, pp. 243-256, 2003.

[3] K. Lambourne, and P. Tomporowski, "The effect of exercise-induced arousal on cognitive task performance: a meta-regression analysis," *Brain Res.*, vol. 1341, pp. 12-24, 2010.

[4] D. Ellemberg, and M. St-Louis-Deschênes, "The effect of acute physical exercise on cognitive function during development," *Psych Sport Ex*, vol. 11, pp. 122-126, 2010.

[5] C.H. Hillman, M.B. Pontifex, L.B. Raine, D.M. Castelli, E.E. Hall, and A.F. Kramer, "The effect of acute treadmill walking on cognitive control and academic achievement in preadolescent children," *Neurosci*, vol. 159, pp. 1044-1054, 2009.

[6] A. Hoyland, L. Dye, and C.L. Lawton, "A systematic review of the effect of breakfast on the cognitive performance of children and adolescents," *Nut Res Rev*, vol. 22, pp. 220-243, 2009.

[7] H. Budde, C. Voelcker-Rehage, S. Pietraβyk-Kendziorra, P. Ribiero, and G. Tidow, "Acute coordinative exercise improves attentional performance in adolescents", *NeurosciLett*, vol. 441, pp. 219-223, 2008.

[8] S.B. Cooper. S. Bandelow, M.L. Nute, J.G. Morris, and M.E. Nevill, "The effects of a mid-morning bout of exercise on adolescents' cognitive function," *Ment Health Phys Act*, vol. 5, pp. 183-190, 2012b.

[9] D. McNaughten, & C. Gabbard, "Physical exertion and immediate mental performance of sixth-grade children," *Perc Motor Skills*, vol. 77, pp. 1155-1159, 1993.

[10] A.K. Travlos, "High intensity physical education classes and cognitive performance in eighth-grade students: an applied study," *Int J Sp Ex Psych*, vol. 8, pp. 302-311, 2010.

[11] Y. Zervas, A. Danis, and V. Klissouras, "Influence of physical exertion on mental performance with reference to training," *Perc Motor Skills*, vol. 72, pp. 1215-1221, 1991.

[12] A.C. Utter, R.J. Robertson, D.C. Nieman, and J. Kang, "Children's OMNI scale of perceived exertion: walking/running evaluation," *Med Sci Sport Exerc*, vol. 34, pp. 139-144, 2002.

[13] C.L. Ramstetter, R. Murray, and A.S. Garner, "The crucial role of recess in schools," *J School Health*, vol. 80, pp. 817-826, 2010.

[14] J.R. Stroop, "Stroop Test", *J Exp Psych*, vol. 18, pp. 643-662, 1935.

[15] A.H. van Zomeren, and W.H. Brouwer, "Assessment of attention," in *A Handbook of Neuropsychological Assessment*, J.R. Crawford, D.M. Parker, and W.W. McKinlay, Eds. UK: Lawrence Erlbaum Associates, 1992.

[16] S. Sternberg, "Memory-scanning: memory processes revealed by reaction time experiments," *Am Sci*, vol. 57, pp. 421-457, 1969.

[17] S.B Cooper, S. Bandelow, and M.E. Nevill, "Breakfast consumption and cognitive function in adolescent schoolchildren," *PhysBeh*, vol. 103, pp. 431-439, 2011.

[18] S.B. Cooper, S. Bandelow, M.L. Nute, J.G. Morris, and M.E. Nevill, "Breakfast glycaemic index and cognitive function in adolescent school children," *Br J Nutr*, vol. 107, pp. 1823-1832, 2012a.

[19] S. Raviv, and M. Low, "Influence of physical activity on concentration among junior high-school students," *Perc Motor Skills*, vol. 70, pp. 67-74, 1990.

[20] S. Stroth, S. Kubesch, K. Dieterle, M. Ruschow, R. Heim, and M. Kiefer, "Physical fitness, but not acute exercise modulates event-related potential indices for executive control in healthy adolescents," *Brain Res*, vol. 1269, pp. 14-24, 2009.

[21] J. Brisswalter, M. Collerdeau, and A. René, "Effects of acute physical exercise characteristics on cognitive performance," *Sports Med*, vol. 32, pp. 555-566, 2002.