EXAMINING THE EFFECT OF EXERCISE BREAKS INTENSITY ON ATTENTION AND LEARNING IN A UNIVERSITY SETTING.

EXAMINING THE EFFECT OF EXERCISE BREAK INTENSITY ON ATTENTION AND LEARNING IN A UNIVERSITY SETTING.

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ABSTRACT

During a university lecture, students' attention typically declines as the lecture progresses. Lapses in attention can interfere with learning and memory for the presented material to negatively impact a student's overall academic performance. Prior research has shown that incorporating five-minute high-intensity exercise breaks during a university lecture improved student attention and comprehension compared to a computer break or no break. Although promising, high-intensity exercises may not be suitable for a university classroom. To improve feasibility for implementation, the current study aimed to determine whether reducing the intensity of the exercise breaks could still yield similar cognitive benefits. One hundred participants watched a 50-minute online lecture with no breaks (control; n = 25) or while intermittently taking exercise breaks of high (n = 26), medium (n = 26) or low intensity (n = 23). Attention was measured throughout the lecture and comprehension was measured after learning. The groups did not significantly differ on their ability to pay attention (Time 1: $X^2(2) = 3.61$, $p = .31$; Time 2: $X^2(2) = 3.20$, $p = .36$) or comprehend ($F(1,93) = .26$, $p = .6$) the lecture material. However, when controlling for significant group differences in academic performance outside of the study ($F(3, 113) = 3.52$, $p = .02$) and baseline comprehension performance during the study, small positive improvements were observed on comprehension following an exercise break of all intensities (Cohen's $d < .67$ and $>.08$), but with the largest effect size seen for high intensity exercise breaks towards the end of the lecture. These positive trends point to the benefit exercise breaks on learning in a university setting and establish the foundation for further research.

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LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
ANCOVA	Analysis of Covariance
RPE	Ratings of Perceived Exertion
HR	Heart Rate
PFC	Prefrontal Cortex
BDNF	Brain Derived Neurotrophic Factor
SE	Standard error
SD	Standard deviation
d	Cohen's d

DECLARATION OF ACADEMIC ACHIEVEMENT

Michelle Ogrodnik's role:

- Amended ethics application at McMaster University
- Designed study protocol and chose measures
- Created standard operating procedure
- Set up lab equipment and materials
- Trained and supervised undergraduate research students and volunteers who assisted with data collection
- Led data collection, analysis, and interpretation
- Set up lab equipment and materials
- Responsible for manuscript preparation

Role of co-authors:

- JH & BF assisted MO with ethics amendment
- JH & BF assisted MO with study design and selection of measures
- JH & BF assisted MO with data interpretation
- JH obtained study funding

* BF = Dr. Barbara Fenesi

Introduction

Academic institutions are under increasing societal pressure to meet the demands of producing academically successful individuals; consequently, students often saturate their time with sedentary scholastic activities at the cost of being physically active (Wilkins et al., 2003). Although replacing physical activity with scholastic activities may seem advantageous for academic growth, there is accumulating evidence that this replacement may actually be counterproductive. Instead, incorporating physical activity in the classroom may be a critical component to supporting the cognitive functions needed for effective academic performance (Chang et al., 2012).

In higher education, the didactic lecture remains the primary instructional delivery method. This mode of content delivery is very passive. Students are required to sustain their attention for prolonged periods of time in order to understand learning material, and this proves very challenging for most students. It is estimated that students spend approximately 30% of their lecture time off-task (Lindquist & McLean, 2011; Szpunar, Moulton. & Schacter, 2013). *Mind wandering* is a common off-task behaviour characterized by internal thoughts detracting one's attentional focus away from the primary task (Smallwood & Schooler, 2006). Due to the limited processing capcity of our attention system (Engle, 2002), when the mind is occupied with these task-irrelevant thoughts, task-relevant information cannot be attended to or remembered. Ultimately, this disrupts learning and can result in poorer academic performance (Risko, Anderson, Sarwal, Engelhardt, & Kingstone, 2012; Smallwood, Fishman, & Schooler, 2007; Smallwood, McSpadden, & Schooler, 2008; Szpunar, Khan, & Schacter, 2013; Wammes, Seli, Cheyne, Boucher, & Smilek, 2016). Therefore, it is critical to examine classroom-based interventions, including exercise, that may help reduce mindwanding and promote comprehension, which was the focus of the present thesis.

Aerobic exercise and cognitive function

Overall, physical activity and exercise have a positive effect on cognition across the lifespan (Chang et al., 2012; Ratey & Loehr, 2011). In particular, aerobic exercise improves a set of cognitive processes known as executive functions—including inhibition, updating of working memory, and shifting—which govern goal oriented and planned behaviour such as sustaining focus and resisting temptations, which are needed for learning and academic performance (Banich, 2009; Best, 2010; Diamond, 2006, 2013; Miyake, Friedman, Emerson, Witzki, Howerter, & Wager, 2000; Verburgh, Königs, Scherder, & Oosterlaan, 2013). This has been demonstrated with cross-sectional research where individuals who are more physically active also have better cognition, especially on tasks that require executive functions (Best, 2010; Donnelly et al., 2016). Cognition also improves in the acute phase following a bout of aerobic exercise on tasks that require inhibitory control (Hogervorst et al., 1996; Sibley, Etnier, & Le Masurier, 2006), selective attention (Hill et al., 2010), reaction time and processing speed (Audiffren, Tomporowski, & Zagrodnik, 2008), working memory (Sibley & Beilock, 2007), and long-term memory (Coles & Tomporowski, 2008).

Aerobic exercise and student learning

Physical activity and exercise have also been shown to directly impact classroom learning; however, most of this work has been done in children (Daly-Smith et al., 2018; Watson et al., 2017). Classroom attention in children is typically quantified by the amount of off-task behaviour, such as fidgeting, that the child engages in (Jarrett et al., 1998). Children fidget less following exercise breaks compared to sedentary breaks, suggesting better on task attention (Jarrett et al., 1998). Not only has exercise been shown to improve attention, but also academic outcomes. For example, assessing math skills following walking or running outside has been shown to improve student test performance (Howie, Schatz, & Pate, 2015; Maeda & Randall, 2003; McNaughten & Gabbard, 1993;). With respect to dose, exercise induced cognitive benefits have been shown following high intensity exercise breaks lasting 10-minutes, 15-minutes, or 20-minutes (Howie, Schatz, & Pate, 2015; Janssen et al., 2014) as well as moderate intensity exercise break lasting 15-minutes (Janssen et al., 2014). Critically, research on the relation between exercise and learning is starting to influence curriculum design with a more balanced focus to ensure that the children receive adequate time for activities that promote their physical and cognitive well-being.

Less is known about the effect of exercise for university students, even though learning in the context of the sedentary didactic lecture may benefit the most. Observational data shows that university students with higher activity levels (El Ansari & Stock, 2014; Wald et al., 2014) or physical fitness (Dubuc, Aubertin-Leheudre, & Karelis, 2017) perform better academically. Fundamental research demonstrates the benefits of an acute bout of aerobic exercise for cognition in young adults (Chang et al., 2012). Very few studies have applied this research to a university classroom setting.

A recent study by Fenesi et al. (2018) sought to apply the potential role of physical activity breaks as an intervention to improve attention and learning in university students. In their study, participants watched a fifty-minute online lecture taken from an authentic university course. Before watching the lecture, participants were randomly assigned to one of three groups: 1) a high-intensity exercise break group (exercising at approximately 80% of age-predicted maximum heart rate; HR), 2) a computer game break group, or 3) a no-break control group. Those in the exercise or computer game group took three five-minute breaks across the lecture, while the control group watched the lecture without taking breaks. The researchers asked questions about mind wandering during learning to assess attention and evaluated participants' comprehension of the material using a multiple-choice test that was administered immediately after learning and again two days later. Researchers found that high-intensity exercise breaks helped students maintain their attention across the lecture, buffering against the typical increases in mind wandering observed as the lecture duration increases (Fenesi et al., 2018; Johnstone & Percival, 1976; Szpunar, Moulton & Schacter, 2013). Furthermore, these improvements in on-task attention translated to significantly higher performance on both the immediate and delayed comprehension tests for those who exercised, compared to those who played computer games or took no breaks. These results suggest that exercise may be an effective tool to help university students sustain attention and improve academic performance; however, more research is needed to confirm the benefit of exercise and determine optimal strategies for implementation.

An important factor to consider is the exercise intensity. A high intensity exercise may not be feasible to implement in a classroom. The traditional university lecture hall is not typically designed to accommodate high intensity exercises (e.g., theatre-like seating with minimal personal physical space). Also, many university students are sedentary (Westerterp, 2001) and may be overwhelmed by the physical demands of high-intensity exercise, reducing their willingness to participate. Therefore, it is critical to investigate whether exercise breaks of lower intensity can still benefit cognitive performance in the classroom.

Potential Mechanism

The mechanisms driving acute exercise induced benefits on cognition remain unclear. However, there are at least two potential mechanisms for boosting cognition that have been suggested: 1) the activation of the prefrontal cortex (PFC) enhancing executive functioning and attention, and 2) the stimulation of brain-derived neurotrophic production, enhancing memory. Interestingly, the literature suggests that these two mechanisms are optimally enhanced by different exercise intensities, and it is unclear which mechanism (or intensity) may be most important for learning and academic performance.

Some theorize that exercise improves cognition because it increases activation and oxygenation of the PFC to improve its functions (Hillman et al., 2009), which includes selective attention (Best, 2010; Hillman et al., 2009; Shimamura, 2000; Stuss & Benson, 1984). Cognition-PFC interactions seem to follow an inverted U-shaped function, with superior performance promoted by moderate-intensity exercise compared to higher or lower intensities which may over activate or under activate the PFC (Chang et al., 2012; Yerkes & Dodson, 1908). If increased activation of the PFC, and subsequently improved attention, is the mechanism driving this relation, the inverted-U model would suggest moderate intensity exercise breaks would be the best for learning.

However, there is also evidence that a bout of exercise increases brain-derived neurotrophic factor (BDNF). BDNF is an essential protein for neuron growth and survival (Ferris, Williams, & Shen, 2007; Hillman, Erickson, & Kramer, 2008) and is associated with enhanced memory (Gomez-Pinilla, Vaynman, & Ying, 2008; Szuhany, Bugatti & Otto, 2015; Vaynman, Ying, & Gomez- Pinilla, 2004). Unlike the PFC, BDNF is increased by higher intensity exercises compared to lower intensity exercises (Ferris, Williams, & Shen, 2007).

These observations are consistent with drive theory, which posits that higher levels of physiological arousal will induce the greatest cognitive benefits as a result of higher availability of BDNF (Chang et al., 2012; Hull, 1943). If increased levels of BDNF, and subsequently enhanced memory, are the mechanism underlying exercise induced cognitive improvements, drive theory would suggest higher intensity exercise breaks would be the best for learning.

Although it is possible that these two mechanisms work to activate brain function and improve learning, more research is needed to understand the optimal intensity for targeted use of exercise and physical activity for maximal benefit for cognition and learning (Hillman, Erickson & Kramer, 2008).

Purpose and Hypothesis

The present study examined the effect of exercise break intensity on learning in university students. Participants were randomly assigned to a low, moderate, or high intensity exercise break group or a no-break control group. Following the methods of Fenesi et al. (2018), all participants watched a 50-minute online university lecture and were asked questions about their levels of attention at three time points throughout. For those in an exercise break condition, they completed three five-minute exercise breaks at their respective intensities during learning, while those in the control group watched the lecture without a break. Immediately after the lecture and two days later, all participants completed a 30-question multiple-choice test.

Based on Fenesi et al. (2018), we predicted that participants in the high intensity group would sustain their attention across the lecture and have higher comprehension, both immediately and delayed, compared to the control group who would decline in attention and performance. However, it was unclear which exercise intensity would result in the best performance. When considering improved attention and PFC activation, which follows an inverted U model for optimal activation to enhance cognitive function, moderate-intensity exercise breaks would be expected to promote attention and learning more than either low or high-intensity exercise breaks. In contrast, according to drive theory and the stimulation of BDNF, high-intensity exercise breaks would be expected to improve memory more than moderate-intensity exercise breaks, with low-intensity exercise breaks being least effective. Therefore, the present study was critical for elucidating the optimal intensity of exercise needed for improvements in attention and learning, while also providing insight into the potential underlying mechanism.

METHOD

Participants

Introductory Psychology students between 18-30 years old were recruited through an online portal and were given course credit for participating. Participants in the exercise groups were recruited for an experiment about exercise and learning, and were randomly assigned to a low-intensity, moderate-intensity, or a high-intensity exercise group. Participants in the control group signed up for an experiment about presentation styles for online modules. In this way, researchers could ensure participants were unaware that they were part of the control group, which could have influenced their behaviour. A sample size estimate was computed using G*Power software (Version 3.1; www.gpower.hhu.de), based on Fenesi et al.'s (2018) effect size of physical activity breaks on attention and learning (Cohen's $f = .3$). According to G*Power estimates, 126 participants were required for our primary analysis using a 4 condition, repeated measures, within-between interaction design with $\beta = 0.8$ and $\alpha = .05$). The McMaster University Research Ethics Board approved this experiment (# 2014 131).

Exclusion criteria. Students in the exercise conditions were screened using the Physical Activity Readiness Questionnaire (PAR-Q & YOU) to ensure they were safe to complete physical activity (Canadian Society for Exercise Physiology, 2002); all participants had to have answered "no" to all questions regarding safety, and thus had no major health concerns prohibiting them from participating in our exercise intervention. We also screened for students who had not previously taken PSYCH 1XX3 at McMaster University (the course which the learning material was taken from); and were able to participate in both days of the experiment.

One hundred and twenty-one participants took part in the experiment however a total of one hundred young adult participants (82% females, age M±SD: 18.4±1.6 years; 17-31yrs old) were included in the final analysis (control: n = 25, low-intensity: n = 23, moderate-intensity: n = 26, high-intensity: n = 26). Eight participants were excluded from analyses for failing to complete both days (n = 3), leaving early (n = 3), having prior exposure to the content that was not disclosed at the start of the study (n = 1), or falling asleep during the lecture (n = 1). During the analysis, only participants who completed the comprehension test above chance level (i.e. better than 25%) were included similarly to Fenesi et al. (2018) resulting in excluding an additional thirteen participants.

Materials

Online lecture. Lecture content was drawn from McMaster's Introductory Psychology course PSYCH 1XX3; in this course, students are required to learn content through online lectures. All participants in our experiment watched a 50-minute online lecture about form perception, which is representative of an authentic content and delivery in this course.

Exercise breaks: All exercise breaks were five minutes long and were led by an experimenter. Participants in the exercise groups completed five different aerobic exercises for

50-seconds each separated by a 10 second rest period. The exercises included split jumps, jumping jacks, high knees, heeltaps, and hamstring kicks. All movements were modified to meet high, moderate, and low intensities (See Table 1 for a full list of exercises and how they were modified for the respective condition). Following each five-minute exercise break, participants were asked their Rating of Perceived Exertion (RPE) on a scale from 6-20 where 6 indicated "no exertion at all" and 20 indicated "maximal exertion" (Borg, 1982). While doing the exercises, the low-intensity group was instructed to aim for an RPE between 9-11 representing "very light to light", the moderate-intensity group an RPE between 12-13 meaning "somewhat-hard", and the high-intensity group an RPE between 14-17 representing "hard to very hard". Exercisers also wore a POLAR A300 heart rate monitor throughout the experimental session to verify exercise intensity. Participants in the control group did not report RPE but wore a heart rate monitor to create a similar experience.

Attention questions: An established attention question, previously used in classroom research investigating mind wandering, was used to measure attention (Wammes et al., 2016). The question asked participants "Which of the following responses best characterizes your mental state just before this screen appeared?" Participants could then select being: 1. "On task", 2. "Intentionally mind wandering", or 3. "Unintentionally mind wandering". The experimenter explained to participants that unintentional mind wandering occurs spontaneously while intentional mind wandering was a result of deliberate inattention (Wammes et al., 2016). However, as done in Fenesi et al (2018), an a prior decision was made to collapse across unintentional and intentional mind wandering into total off task behaviour when analyzing the data.

Comprehension test: All participants completed a comprehension test of 30 multiple-choice questions immediately following the online lecture and 48 hours later. Multiple-choice questions were authentic learning materials drawn from the Introductory Psychology (PSYCH 1XX3) test bank (See Appendix A for sample questions).

Perception questionnaires: Measures of affect, arousal, and motivation were presented before the lecture began and directly after the lecture finished. Specifically, participants were administered The Felt Arousal Scale (Svebak and Murgatroyd, 1985; Appendix B), a modified version of The Feeling Scale (Hardy & Rejeski, 1989; Appendix C), and two questions written by the researchers to measure motivation to pay attention and motivation to learn (Appendix D). The Felt Arousal Scale is a 6-point single item validated measure; participants rated their current arousal on a scale from 1-6 where 1 represented the lowest level of arousal and 6 represented the highest level of arousal. The Feeling Scale is a 10-point single item question; participants indicated their current mood +5 to -5 where +5 represented "very good", 0 represented "neutral", and -5 represented "very bad". Finally, participants answered two questions on their current levels of motivation: "I am motivated to pay attention to the lecture material" and "I am motivated to learn the lecture material." Both questions were answered on a Likert Scale ranging from 1-7 where 1 represented "absolutely disagree" and 7 represented "absolutely agree".

Physical Activity Level: Participants completed the CSEP-Path: Physical Activity and Sedentary Behaviour Questionnaire (PASB-Q; CSEP, 2013), a validated and reliable measure of physical activity. The number of minutes per week participants regularly engaged in moderate-to-vigorous physical activity was calculated by multiplying their responses on the following two questions: 1) "In a typical week, how many days do you do moderate-intensity (like brisk walking) to vigorous-intensity (like running) aerobic physical activity", and, 2) "On average for days that you do at least moderate-intensity aerobic physical activity, how many minutes do you do".

Procedure

The experimental procedure was adapted from Fenesi et al. (2018). The two-hour experiment took place over two days, separated by 48 hours. Both sessions occurred between 12:00pm-4:00pm to control for the diurnal rhythms of cortisol, a hormone known to impact memory (Lee et al., 2007). Both experimental sessions were completed in the same room and up to three participants completed the experiment at a time. Figure 1 provides a schematic of the experimental flow.

Day 1 (~90 minutes): Prior to starting any experimental procedure, participants were briefed on the experimental protocol and signed a letter of informed consent. Participants were also asked for consent to release their Introductory Psychology course grade and GPA. For the exercise groups, the experimenter demonstrated the exercises participants would be completing. To ensure participant safety, those in the high-intensity group were also shown the moderate-intensity exercises as participants were instructed to do their best to engage in the high intensity exercises but not push beyond their physical limits.

While watching the lecture, participants sat at an individual flat screen computer monitor with attached headsets. Prior to the lecture they completed perception questions on affect, arousal, and motivation (Appendix A) and were fitted with a heart rate monitor. Then, participants began watching a 50-minute online lecture. Similar to Fenesi et al. (2018), a mind-wandering question was asked three times during the online lecture to establish a baseline (~15 minutes into the lecture prior to any exercise break), Time 1 (~25 minutes into the lecture), and

Time 2 (~50 minutes into the lecture). For the exercise groups, the mind wandering questions were asked prior to each break; then, they completed the exercise break and returned to watching the lecture. For the control group, the mind wandering questions were asked at the same time point during the lecture; however, following the question they returned to watching the lecture without a break. All participants were unaware of when an attention probe or break would occur.

During the exercise break participants received no verbal encouragement to control for external motivation. Following each exercise break, participants reported their RPE and rested for two minutes. Following the last exercise break, which occurred at the end of the lecture, participants again reported their RPE and rested for two minutes. During the two minutes, participants were re-administered the perception questions on affect, arousal, and motivation (Appendix B, C & D) and then were given a comprehension test.

Day 2 (~30 mins): Forty-eight hours later, participants returned to the lab to complete the second comprehension test. Following the test, participants filled out demographics and the PASB-Q physical activity questionnaire (CSEP, 2013). Participants were then debriefed and received course credit as compensation for their participation.

Statistical Analyses

Descriptive statistics were computed for all study variables and normality was assessed through visual inspection of histograms and the Shapiro-Wilk statistic. All analyses were set at an alpha level of .05 and conducted in IBM SPSS Statistics Version 25.

Potential covariates: One-way analysis of variance (ANOVA) were used to assess baseline differences between the groups Introductory Psychology grades, baseline attention, arousal, affect, or motivation to pay attention.

Manipulation checks: RPE and HR were analyzed using two separate 3 (exercise break: 1, 2, and 3) x 4 (group: control, low, moderate, high) mixed measures ANOVAs with a within subject factor of time and a between subject factor of group to ensure adequate physiological arousal for the respective exercise intensities. Changes in arousal across the lecture was analyzed using a 2 (pre and post lecture measurements) x 4 (group: control, low, moderate, high) mixed model ANOVA with a within subjects factor of arousal and a between subjects factor of group to ensure changes in arousal reflected the different exercise intensities.

Attention: Attention was coded as on task (coded as 1) or off task (coded as 0, which collapsed intentional and unintentional reports of mind wandering). A 4 (group: control, low, moderate, high) x 2 (on or off task) chi squared test of independence was used to assess differences in attention between groups at each time point.

Comprehension: A 4 (group: control, low, moderate, high) x 2 (immediate and delayed test) mixed-model ANOVA was conducted with a between-subject factor of group and within-subject factor of time to determine group differences in comprehension. A post hoc analysis was performed whereby change scores were computed between baseline test performance and performance on test questions following an exercise break for each participant to control for more individual variance on test performance (Figure 5). A 2 (change scores on content after break 1 and after break 2 from baseline) x 2 (immediate and delayed test) x 4 (group: control, low, moderate, high) ANCOVA, with a within subjects factor of content, test, and a between subjects factor of group was conducted. A covariate of introductory psychology grades was used to control for variance in academic performance between groups. Cohen's *d* was calculated to determine effect sizes.

Affect and motivation: Changes in affect and motivation across the lecture were assessed using 2 (pre or post learning) x 4 (group: control, low, moderate, high) ANOVAs using a within subjects factor of measurement and a between subjects factor of group to determine whether different conditions led to different changes in affect or motivation, which can impact attention and learning (Bower, 1981).

Physical activity level: Pearson's correlations were conducted to test whether an association existed between physical activity levels and comprehension performance.

RESULTS

Potential covariates:

To ensure similarity between groups, baseline measures were compared. When assessing Introductory Psychology grades, a one-way ANOVA found a significant main effect of group ($F(3, 113) = 3.52$, $p = .017$). Post hoc analyses revealed that the high-intensity group ($M =$ 83.2±9.04 %) and control group ($M = 81.2±7.22$ %) had significantly higher grades than the low ($M = 74.9±15.38$ %) and moderate-intensity groups ($M = 75.6±12.59$ %) but were not statistically different from each other. No baseline differences were found between groups on measures of attention ($X^2(3) = 3.72$, $p = .29$), arousal ($F(3, 96) = .24$, $p =.87$), affect ($F(3, 96) =$ $.27$, $p = .85$), or motivation to pay attention ($F(3, 96) = .67$, $p =.58$).

Manipulation checks

Our exercise intervention was successful at inducing the desired exercise intensity for each group. This was confirmed by RPE as well as heart rate during the lecture and changes in perceived arousal across the lecture. A significant main effect of group was found for RPE ($F(2,72) = 98.02$, $p < 0.001$). Bonferroni post-hoc comparisons found significant differences between all groups, where RPE increasing linearly with intensity from low ($M = 8.8±1.5$) to moderate (*M* = 11.5±1.4) to high (*M* = 15.3±2.3).

Due to issues with heart rate monitors 25 participants were missing heart rate data (control = 7, low = 7, moderate = 11), and only complete cases were analyzed. The number of complete cases was comparable across groups (Control, n= 21; Low, n=22, Moderate, n=21; High, n=23). There was a significant main effect of time ($F(2,80) = 4.97$, $p = .008$) and group ($F(3,80) = 182.9$, $p < .001$) on heart rate. Bonferroni post hoc comparisons found all groups were significantly different from each other (all *p*s < .001). The high intensity group met the vigorous physical activity guidelines, reaching approximately 80% of age-predicted heart rate max across the breaks (*M* = 168±8.8, 171±11.8, 168±12bpm). Those in the moderate intensity group were exercising at approximately 60% of age-predicted heart rate max (*M* = 117±15.3, 119±15.1, 116±15.3 bpm) while those in the low intensity group were exercising at less than 50% (*M* = 96±13.5, 96±16, 94±15.2bpm).

A question of perceived arousal was taken at the beginning and end of the lecture (Svebak and Murgatroyd, 1985; See Appendix B). Though there were no significant differences in arousal at the beginning of the lecture ($F(3, 96) = .24$, $p =.87$), there was a main effect of group at the end of the lecture ($F(3, 96) = 8.27$, $p < 0.001$). Bonferroni post hoc comparisons found significant differences in the change of perceived arousal levels between the high intensity (*M* = 1.27±1.71) and control group (*M* = -.48±1.56) as well as the moderate (*M* = .81±1.17) and control at the end of the lecture. Changes in arousal were not significantly different between the low intensity group (*M* = -.26±1.36) and control. As the low intensity condition was not meant to induce major changes in arousal, we can infer that our exercise interventions successfully manipulated intensity.

Attention

Table 2 and Figure 3 represent the results for attention. A significant main effect of time was found, where participant attention was significant lower at the end of the lecture compared to the beginning ($X^2(1) = 2.90$, $p = .004$). However, there were no significant differences between groups following the first attention probe at Time 1 ($X^2(2) = 3.61$, $p = .31$) or the second at Time 2 ($X^2(2) = 3.20$, $p = .36$) suggesting exercise breaks did not buffer decreased attention with increased time on task.

Comprehension

Table 3 and Figure 4 represent the results for overall comprehension. Four questions were removed from the final analysis, for all participants, due to below chance performance (< 25%); therefore, a total of 26 questions were analyzed. No main effect of time [$F(1,93) = 2.84$, $p = .10$] or group [$F(1,93) = .26$, $p = .6$] was found (See Table 3 for means of each group).

As noted above in the manipulation check, there were significant differences between groups on final Introductory Psychology grades; the high intensity and control groups had significantly higher final grades than the moderate or low intensity groups ($p < .05$). Therefore, a post hoc analysis aimed to reduce variance both at the individual and group level. At the individual level, comprehension questions were broken down by timing of learning and change scores from baseline were calculated to control for participants' baseline academic performance (Figure 5). Lecture content was broken down into 3 groups: baseline content (content that occurred prior to any intervention, n = 11), content following break 1 (middle content, n = 6), and content following break 2 (end content, n = 9) for both the immediate and delayed tests (See Table 4, unadjusted, and Table 5, adjusted, for mean values of each segment). This was done for both immediate and delayed comprehension performance. The data were analyzed using a repeated measures ANCOVA on the change scores with a between-subject factor of group, two within-subject factors of content timing (middle of lecture, end of lecture) and test (immediate, delayed). To control for variance at the group level, a covariate of Introductory Psychology grades was used. No main effect for test, condition, or significant interactions were found ($F(1,92) = .380$, $p = .539$; $F(3,92) = 1.652$, $p = .183$; $F(3,92) = .012$, $p = .468$), respectively.

However, as Figures 6-9 show, there were several interesting trends. With respect to the immediate test (Figure 6), the exercise groups had greater comprehension performance than in the control group on content following the first and second exercise breaks (ranging from small to moderate effect sizes; Table 6), with the high intensity exercise group yielding greatest improvements at the end of the lecture. Although there were also no significant differences for delayed test performance ($F(1,92) = .380$, $p = .539$), similar trends were observed among groups as seen on immediate testing(see Figure 7). Furthermore, when collapsing across day, high intensity exercisers had higher comprehension performance for content at the end of the lecture compared to the other groups (Figure 8). Indeed, trends in comprehension seemed to follow a dose response relationship, such that comprehension increased linearly with increasing intensity of the exercise breaks though not significant (Figure 9).

Affect and motivation

Affect and motivation were not impacted by our intervention. There were no group differences in motivation to pay attention (before lecture $F(3,96) = .67$, $p = .58$ after lecture $F(3,96) = .64$, $p = .59$) or motivation to learn (before lecture $F(3,96) = .53$, $p = .66$; after lecture $F(3,96) = .92$, $p = .43$). In addition, changes in motivation to pay attention, changes in motivation to learn, or changes in affect were not significantly different between groups ($F(3,96) = 1.36$, $p = .26$; $F(3,96) = .59$, $p = .62$; $F(3,96) = 1.22$, $p = .31$; See Table 7 for all change scores).

Physical activity levels

When correlating physical activity with academic performance, no significant relation was found in any condition on either immediate or delayed testing (all *p*s > .11).

DISCUSSION

The purpose of this study was to examine the effect of exercise breaks during learning to promote on task attention and comprehension in university students, and to evaluate whether the intensity of the exercise influenced this relation. Although we expected that exercise breaks would improve attention and learning, there was no effect on attention and memory at the group level. However, this sample had greater variance than the previous study by Fenesi et al. (2018). Specifically, significant differences were found between groups on their final Introductory Psychology grades. When controlling for this individual difference, a small positive effects of improved comprehension performance were observed for content presented following low and moderate intensity exercise breaks, and a moderate positive effect following high intensity exercise breaks, although these trends did not reach significance.

Individual Differences

Academic performance

Final Introductory Psychology grades were higher for the control and high intensity groups compared to the low and moderate intensity groups. This may have impacted the efficacy of our exercise intervention. Prior research has suggested that baseline differences in cognitive ability influence a person's responsiveness to an intervention (Fenesi, Kramer & Kim, 2016). Perhaps high-intensity exercise was less effective at enhancing attention in those who have developed alternative cognitive strategies to manage high-focus requirements prevalent during learning. In contrast, those who do not have coping mechanisms for sustained attention learning tasks, HIIT may up-regulate rudimentary vigilance and arousal and allow them to perform equally well as those with coping mechanisms. Therefore, additional benefit conferred by the exercise breaks may have been negligible. Indeed, there is some evidence to suggest that the effects of exercise on cognition may be more beneficial for lower performers. Drollette et al., (2014) found that a single bout of aerobic exercise improved performance on an inhibitory control task for lower performing children but not for high performing students. These results suggest that academic performance may be an important individual difference to investigate when assessing the effectiveness of exercise breaks to promote learning.

Levels of physical activity and academic performance

In our study, no relation was found between participants level of physical activity (defined as minutes per week engaging in moderate-to-vigorous physical activity) and academic performance. However, typically in children and younger adults there is a positive relation of regular physical activity, improved cognition, and academic performance (Chang et al., 2012). It is unclear as to why this relation was not seen in our sample; however, it is possible that this relation may be better captured by aerobic fitness rather than physical activity. An objective measure of fitness (such as VO_2 peak) may be a better measure for future research. Indeed, the association between cardiovascular fitness and increased academic performance has been established in children (Van Dusen, Kelder, Kohl, Ranjit, & Perry, 2011). As well, higher fit elementary students have been found to perform better on standardized testing (Gomez-Pinilla & Hillman, 2013; Hillman, Erikson & Kramer, 2008; Sibley & Etnier, 2003). Although there are several proposed mechanisms behind exercise induced benefits on cognitive function, the exact mechanism remains unclear; understanding how physical activity and fitness may affect one's cognitive response to an acute bout of exercise will be important, particularly when considering the feasibility of exercise as a potential intervention in the classroom.

Measures

Attention

The current study used a self-report question, asked three times across the lecture, to assess on task attention prior to each exercise break. Because we only assessed attention at these time points, other potential lapses in attention may have been missed (Schooler et al., 2011). Although we used more points of assessment than other studies (Szpunar et al., 2013), there is a growing trend to include more attention probes, with some research using up to 4 times within a 21-minute lecture (Szpunar, Khan & Schacter, 2013). Given that lapses in attention tend to occur after approximately 10-18 minutes into a lecture our baseline question (at approximately 15 minutes in) was likely effective at capturing mind wandering at the beginning of the lecture (Johnstone & Percival, 1976; Szpunar, Moulton & Schacter, 2013). However, we may have missed bouts of mind wandering towards the end of the lecture, as the frequency of mind wandering increases to approximately every 3-4 minutes (Johnstone & Percival, 1976; Szpunar, Moulton & Schacter, 2013). Future work should consider incorporating more probes near the end of a lecture to ensure an accurate representation of inattention.

Additionally, though the validated mind wandering question has been used in most mind wandering research in education (Wammes, Boucher, et al., 2016), it is important to recognize the bias associated with self-report measures. Future research assessing exercise breaks and learning should consider also including an objective measure of inattention to help validate self-reported inattention. In work with children, observed bouts of fidgeting have been used as a more objective measure, as fidgeting is a physical manifestation of off-task behaviour in children (Ma et al., 2014; Mullender-Wijnsma et al., 2016). However, this may not be an appropriate measure for adult learners who have been trained to be more covert with their inattention. Other potential objective measurement tools may include eye tracking (Foulsham, Farley, & Kingstone, 2013; Uzzaman & Joordens, 2011) or the amount of blinking (Smilek, Carriere & Cheyne, 2010), which have shown some promising positive correlations with bouts of mind wandering. Though still preliminary, researchers have also started working to identify brain-signals that may be indicative of inattention through EEG recording (Braboszcz & Delorme, 2011; Schooler et al., 2011; Smallwood, Beach, Schooler & Handy, 2008). Coupling self-reported mind wandering with an objective measure may help ensure greater measurement accuracy in future work.

Comprehension

In order to make this lab-based study as authentic as possible, content was drawn directly from an Introductory Psychology course at McMaster. However, the selected lecture content and comprehension questions may have been too challenging for the short lab-based research experience, masking potential differences in learning from the experimental manipulation. On average, immediate test performance ranged from 43-47% between groups, and delayed testing 41-44%. In the actual course, students watch the online lecture from home and are able to rewind and pause when content is challenging. In the present study however, our participants were only allowed to pause the module when instructed to take a break. Additionally, the comprehension questions were originally written under the assumption that students would not only watched the module but also study the content prior to taking the test. Additionally, in the course, participants take the test online and are encouraged to use their notes and collaborate with peers. The constraints of our study (i.e., having students take the test immediately after watching the content and two days later with no studying, notes, or collaboration) may explain the extremely low averages in performance. Future work should use content and tests that allow for a greater range in academic performance to gain clearer insight into the effects of exercise on learning specifically.

Potential Mechanisms

This study was not designed to determine the mechanism underling exercise-cognition improvements; however, of the two mechanisms proposed, namely PFC activation and BDNF, it is reasonable to try and draw potential hypotheses from the data. As the PFC hypothesis functions under the assumption that exercise increases PFC activation which then improves executive functioning and attention (Best, 2010; Hillman et al., 2009; Shimamura, 2000; Stuss & Benson, 1984), this hypothesis was not supported by our data which did not find improvements in attention following exercise. With respect to increases in BDNF, a small positive effect on learning was observed following an exercise break at any intensity and at the end of the lecture, the largest effect was seen for high intensity exercise. These trends are consistent with results from Fenesi et al. (2018), who found high intensity exercise breaks to benefit learning. It is possible that these comprehension benefits are a result of improved memory following increases in BDNF which has been previously documented (Gomez-Pinilla, Vaynman, & Ying, 2008; Szuhany, Bugatti & Otto, 2015; Vaynman, Ying, & Gomez- Pinilla, 2004); however, it cannot be certain without measuring changes in BDNF. Additionally, based on our limited measure of attention we cannot rule out PFC activation as a potential mechanism. The improvements in comprehension performance particularly towards the end of the lecture are in line with our understanding of attention; as mentioned above, lapses in attention are most frequent near the end of the lecture (Johnstone & Percival, 1976; Szpunar, Moulton & Schacter, 2013). Future research is needed to understand the mechanism driving exercise-induced changes in cognition.

Limitations

As mentioned above, the measures of attention and comprehension are limitations to this study. Refining these measures for future experiments will be important for researchers to gain a better understanding of how exercise impacts attention and learning in the classroom. Furthermore, the majority of participants identified as female; although, sex may influence how exercise impacts physical performance it has not been found to influence cognitive outcomes in young adults (Hülya Aşçı, 2009). Finally, our recruitment criteria required participants to be safe to exercise from a health perspective (PAR-Q and YOU - Canadian Society for Exercise Physiology, 2002), and therefore students with physical disabilities did not participate in our study. It is critical to consider accessibility at the forefront of designing classroom interventions (Rose & Meyer, 2002) rather than adapting protocols later on to meet the needs of all learners. Thus, future research should improve the outreach to a more diverse sample of participants to ensure protocols are accessible for all students.

Future Directions

Further studies are necessary to examine whether exercise breaks can promote attention and boost student learning. Investigating individual differences that influence this relationship, including academic aptitude, while concurrently determining the role of exercise duration, frequency, timing, and intensity are critical steps towards understanding how exercise benefits learning. Additionally, the boundary conditions including lecture length or lecture content must be explored.

Researchers must also consider the role of student and instructor perceptions by taking a mixed methods approach. Surveying and interviewing participants about their opinions of exercise breaks will create a holistic perspective, which is necessary when considering implementation. Importantly, this work should include more marginalized voices and experiences, such as students and teachers with disabilities, to ensure this intervention is accessible. Working to better understand the mechanism through which exercise benefits cognitive function may help this research become more personalized; for example, if increases in BDNF is a major underlying mechanism, exercise breaks could be structured such that students can do whatever exercise is best for their bodies that also increase levels of BDNF. Further, given that adult learners learn best when they understand the purpose of what they are doing (Knowles, Holton & Swanson, 2005), investigating the role of educating students about the benefits of exercise is important component to consider moving forward. Combining efficacy and enjoyment will be critical for future implementation.

Conclusion

In this study, exercise breaks did not promote increased attention and learning overall; however, exercise did not hinder performance. When controlling for some individual variance, we found small positive effects of exercise breaks on comprehension that warrant future investigation. Given the sedentary nature of university students (Keating, Guan, Piñero & Bridges, 2005), it is critical to investigate ways to promote a more active lifestyle. Continuing to investigate this program of research is important as exercise breaks could be a holistic intervention—benefiting not just the learning process but also students' physical health

(Warburton, Nicol & Bredin, 2006) and mental wellbeing (Schuch et al., 2016; Wipfli, Rethorst & Landers, 2008).

Table 1: Exercise breaks and their modifications in each intensity

High Intensity (RPE ~ 14-17)	**Moderate Intensity** (RPE ~ 12-13)	**Low Intensity** (RPE ~ 9-11)
Jumping split jumps	Split jumps with mid-way step	Hip flexor stretch
Jumping jacks	Side steps with jumping jack arms	Arms sweeps with overhead stretch
High knees (running pace)	High knee holds (walking pace)	Knee tuck holds
Jumping heel taps	In and out hops	Alternating calf stretches
Hamstring kickers (running pace)	Hamstring kickers (walking pace)	Quad stretch

Note: Low intensity stretches alternated every ~10 seconds.

Table 2. Descriptive statistics for attention.

	High intensity breaks (N=26)			**Moderate intensity breaks** (N=26)			**Low intensity breaks** (N=23)			**Control** (N=25)		
	Baseline	T1	T2	Baseline	T1	T2	Baseline	T1	T2	Baseline	T1	T2
On task	16	13	9	20	16	9	14	17	13	14	14	10
Off task	10	13	17	6	10	17	9	6	10	11	11	15
Unintentional	1	2	6	0	0	2	0	0	2	2	1	5
Intentional	9	11	11	6	10	15	9	6	8	9	10	10

Note. In attention (reporting off task) represented the collapsed unintentional and intentional responses.

Table 3. Descriptive statistics for comprehension.

	Immediate test		Delayed test	
	Mean %	Std. Dev	Mean %	Std. Dev
Control	45.7	±11.5	43.5	±10.9
Low intensity	47.2	±10.4	42.9	±14.5
Moderate intensity	43.7	±12.0	44.2	±13.3
High intensity	43.4	±10.3	41.8	±12.1

Table 4. Mean comprehension broken down by time.

	Baseline content		Content after Break 1		Content after Break 2	
	Mean	Std. Dev	Mean	Std. Dev	Mean	Std. Dev
Immediate test						
Control	0.47	±0.19	0.47	±0.22	0.43	±0.13
Low intensity	0.44	±0.20	0.53	±0.22	0.47	±0.14
Moderate intensity	0.42	±0.15	0.49	±0.27	0.43	±0.17
High intensity	0.40	±0.15	0.45	±0.19	0.47	±0.16
Delayed test						
Control	0.35	±0.16	0.47	±0.21	0.49	±0.12
Low intensity	0.38	±0.22	0.49	±0.26	0.47	±0.18
Moderate intensity	0.40	±0.19	0.46	±0.28	0.43	±0.20
High intensity	0.38	±0.17	0.45	±0.27	0.43	±0.16

Table 5. Mean comprehension broken down by time (adjusted: controlling for introductory psychology grades).

	Baseline content		Content after Break 1		Content after Break 2	
	Mean	Std. Dev	Mean	Std. Dev	Mean	Std. Dev
Immediate test						
Control	0.47	±0.19	0.47	±0.21	0.43	±0.14
Low intensity	0.47	±0.18	0.53	±0.23	0.48	±0.14
Moderate intensity	0.41	±0.14	0.49	±0.25	0.43	±0.17
High intensity	0.39	±0.13	0.36	±0.18	0.47	±0.17
Delayed test						
Control	0.49	±0.16	0.47	±0.21	0.34	±0.12
Low intensity	0.45	±0.22	0.45	±0.28	0.35	±0.17
Moderate intensity	0.42	±0.19	0.44	±0.28	0.38	±0.20
High intensity	0.43	±0.17	0.45	±0.27	0.38	±0.16

Table 6. Effect sizes following an exercise break (adjusted: controlling for baseline performance and introductory psychology grades).

			After Break 1 (Middle)			After Break 2 (End)		
			Means	*Std. Dev*	*Effect size*	*Means*	*Std. Dev*	*Effect size*
	Test							
Control to Low	Immediate	Control	- 0.004	0.26	0.20	- 0.03	0.21	0.08
		Low	0.05	0.28		- 0.02	0.22	
	Delayed	Control	- 0.01	0.25	0.02	- 0.14	0.21	0.08
		Low	- 0.01	0.27		- 0.12	0.23	
Control to Moderate	Immediate	Control	- 0.004	0.26	0.28	- 0.03	0.21	0.15
		Moderate	0.07	0.27		0.004	0.20	
	Delayed	Control	- 0.01	0.25	0.15	- 0.14	0.21	0.39
		Moderate	0.02	0.25		- 0.06	0.21	
Control to High	Immediate	Control	- 0.004	0.26	0.24	- 0.03	0.21	0.67
		High	0.06	0.27		0.02	0.21	
	Delayed	Control	- 0.01	0.25	0.13	- 0.14	0.21	0.49
		High	0.11	0.26		- 0.03	0.21	

Note: Effect sizes represent Cohen's d.

Table 7. Changes in motivation and affect.

	Motivation to pay attention		Motivation to learn		Affect	
	Change score	Std. Dev	Change score	Std. Dev	Change score	Std. Dev
Control	-1.3	±1.2	-1.2	±1.1	-0.68	±.95
Low intensity	0.65	±1.1	-0.70	±1.3	0.08	±1.5
Moderate intensity	-0.73	±1.4	-0.77	±1.5	0.15	±1.2
High intensity	-1.2	±1.5	-.93	±1.3	-0.15	±2.6

Figure 1. Study design.

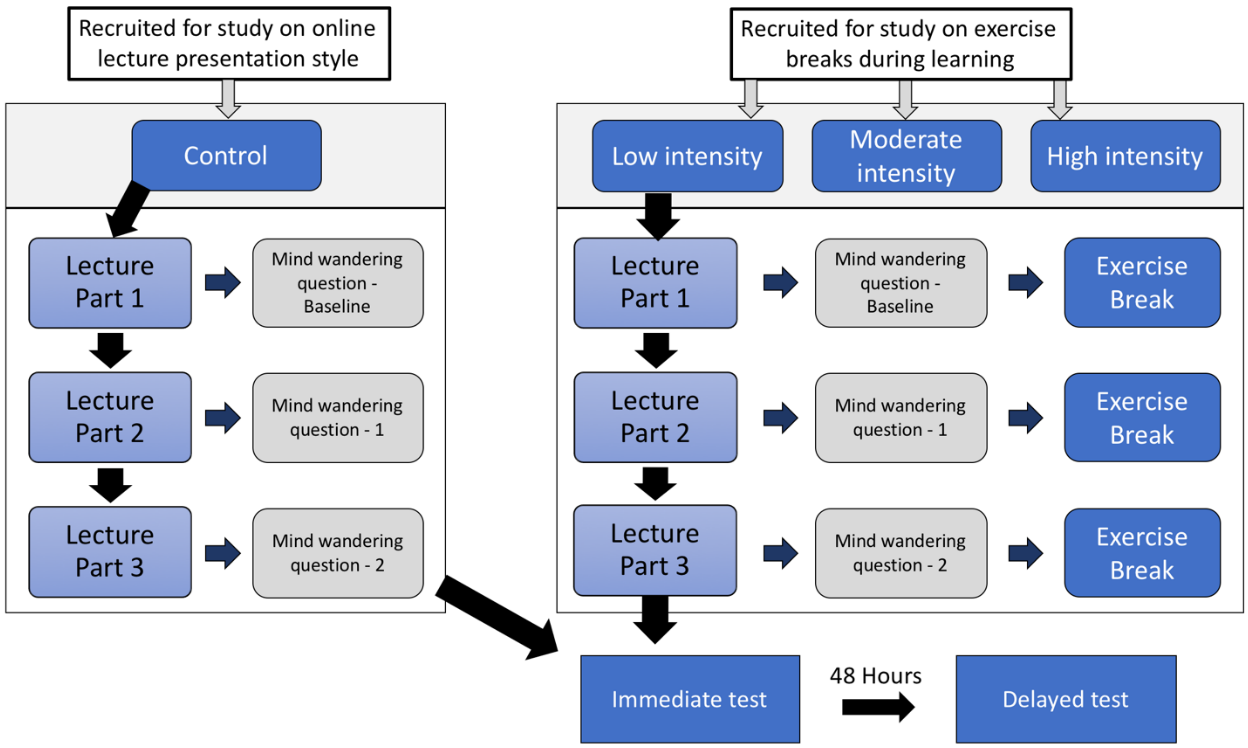

Figure 1. Questionnaires on affect, motivation to pay attention, and motivation to learn were taken before and after the lecture. Participants were required to rest for 2 minutes following their exercise breaks to allow for affective states to return to baseline.

Figure 2. Heart rate across the lecture.

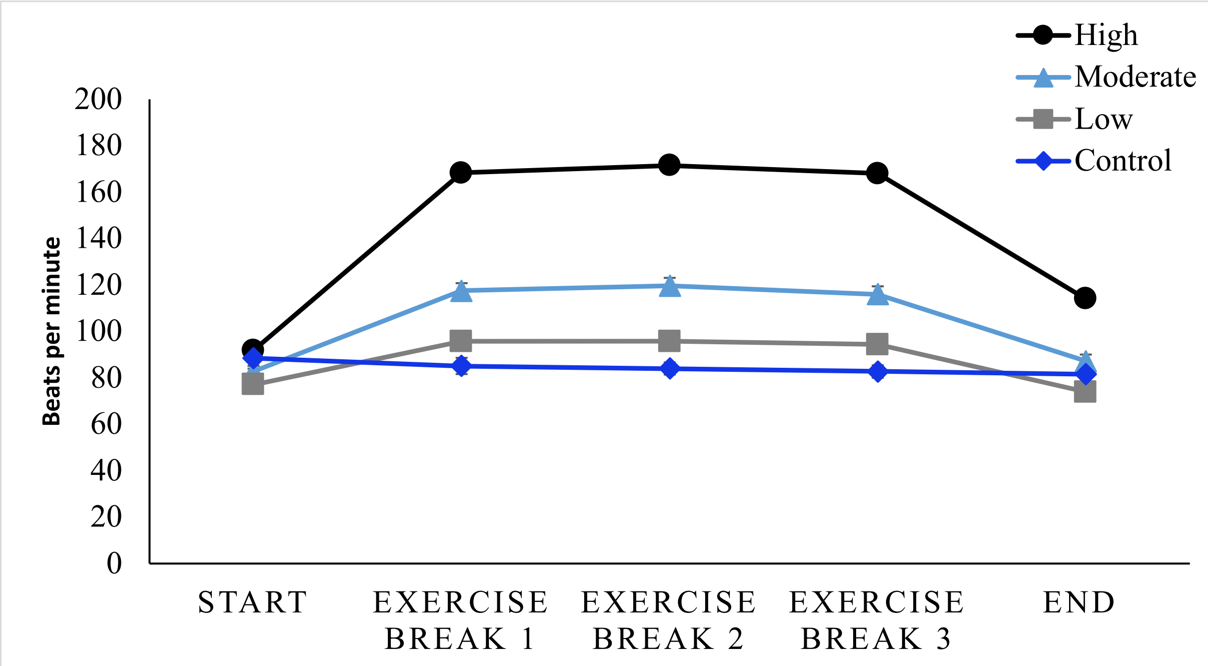

Figure 2. Heart rate across the lecture. Exercise breaks increased HR to ~80% of age-predicted HR max resulting in a moderate-to-vigorous level of intensity in the high intensity group only. All groups had significantly different heart rates at all three exercise breaks with high-intensity having the largest spikes, then moderate, followed by control (all $p < .001$). Bars represent ±SE.

Figure 3. Attention across the lecture.

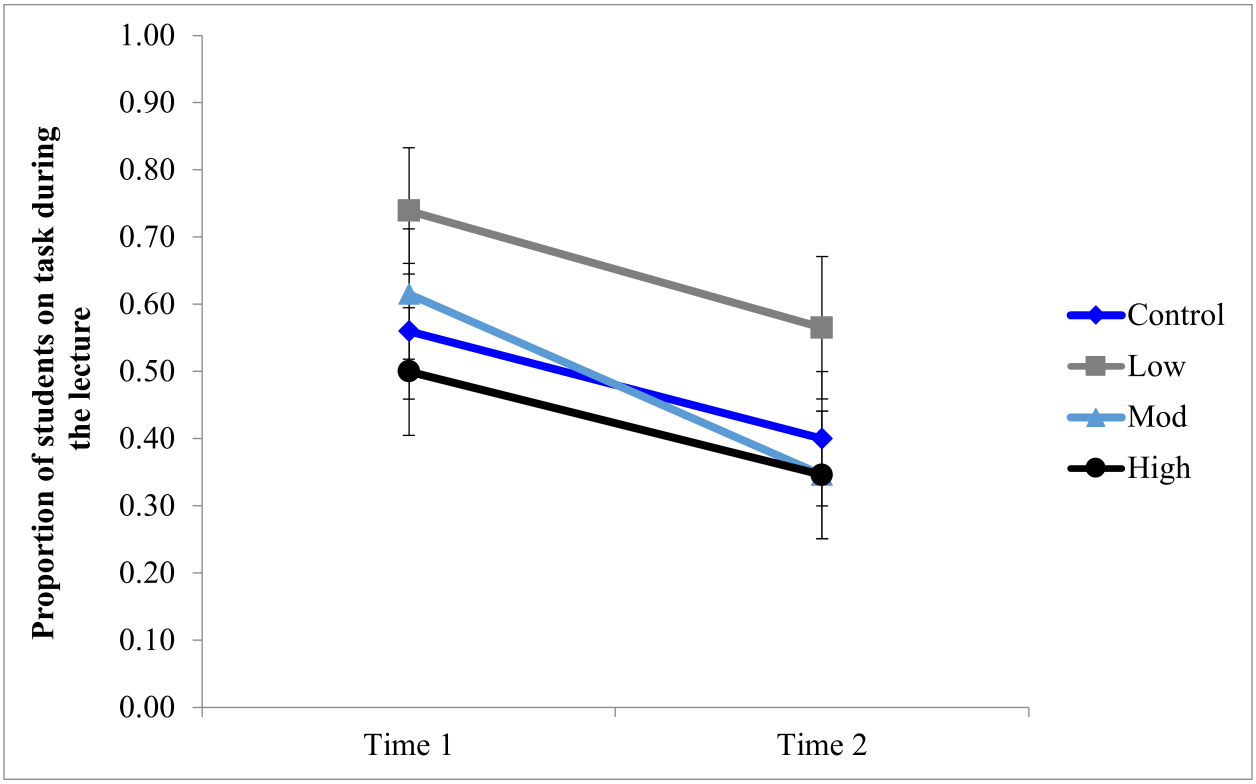

Figure 3. As the lecture progressed, regardless of condition, participants had significant decreases in attention. However, no significant differences were noted between groups suggested exercise did not buffer increased inattention with increased time on task. Proportion of participants reporting on-task attention are represented above for simplicity, but analyses were conducted on dichotomous attention values (1=on task, 0=off task). Bars represent ±SE.

Figure 4. Comprehension of lecture material.

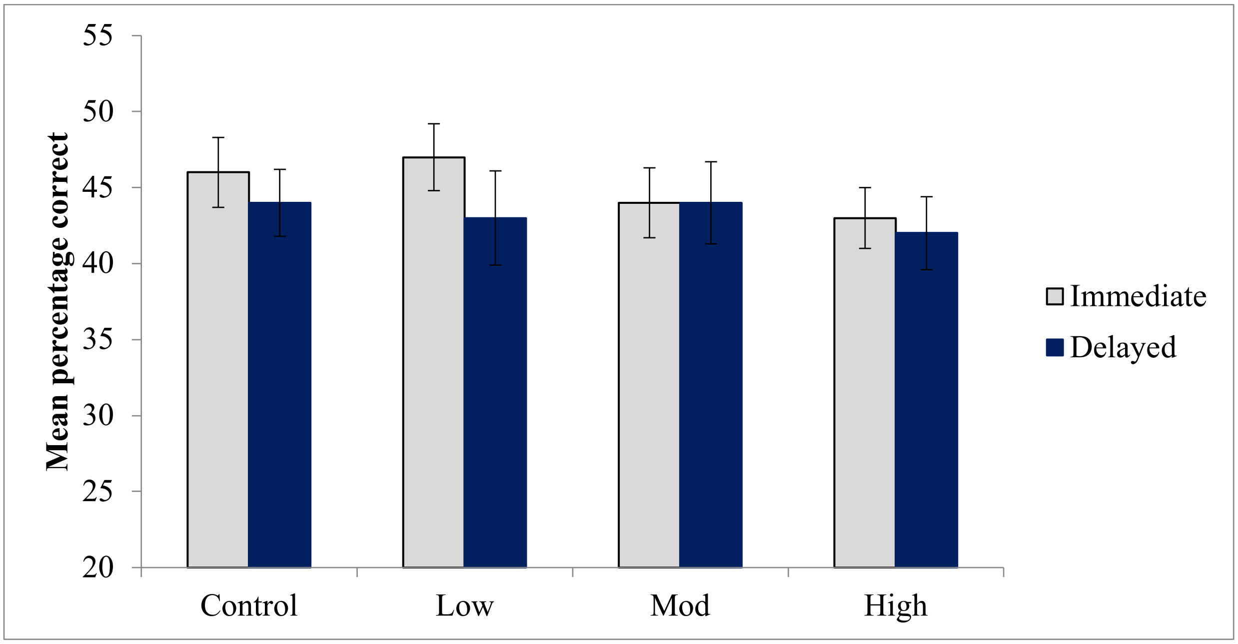

Figure 4. There were no significant differences in comprehension for either the immediate or delayed test. Bars represent ±SE.

Figure 5. The breakdown of lecture content by time.

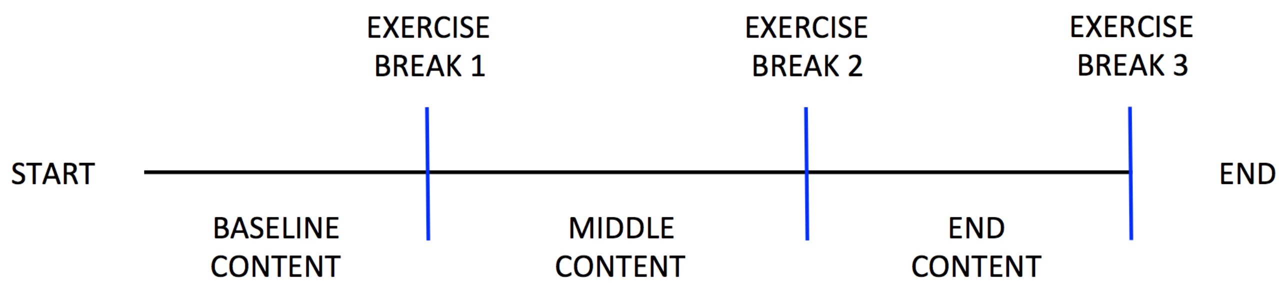

Figure 5. Lecture content was broken down into 3 groups: baseline content (content that occurred prior to any intervention, N = 11), content following break 1 (middle content, N = 6), and content following break 2 (end content, N = 9) for both the immediate and delayed tests. There was no content following break 3.

Figure 6. Change in comprehension on the immediate comprehension test (adjusted).

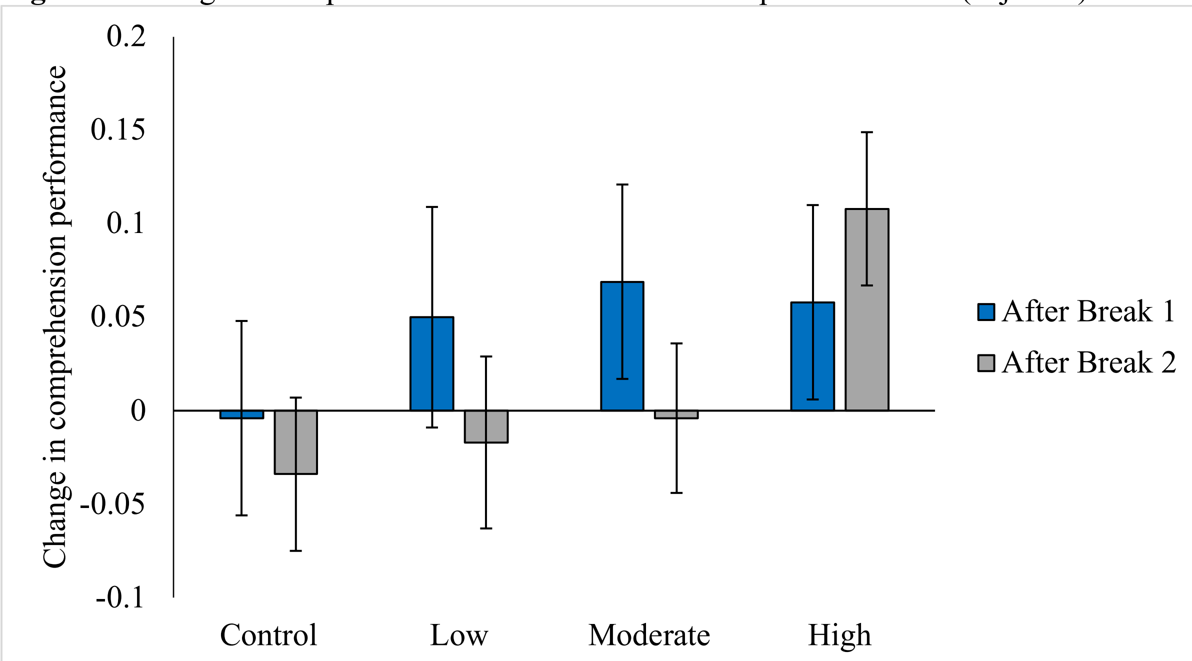

Figure 6. Change scores of student performance on the immediate comprehension test (controlling for introductory psychology grades). No significant differences noted. Bars represent ±SE.

Figure 7. Change in comprehension performance on delayed comprehension test (adjusted).

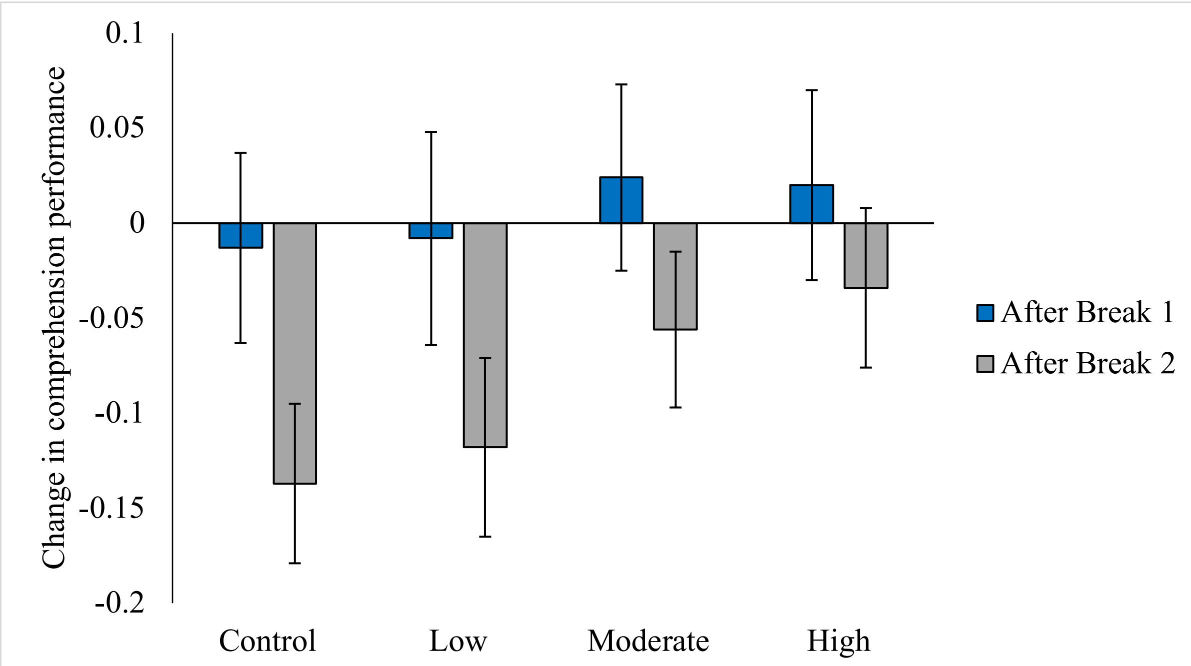

Figure 7. Change scores of student performance on the delayed comprehension test (controlling for introductory psychology grades). No significant differences noted. Bars represent ±SE.

Figure 8. Change in test performance across test (adjusted).

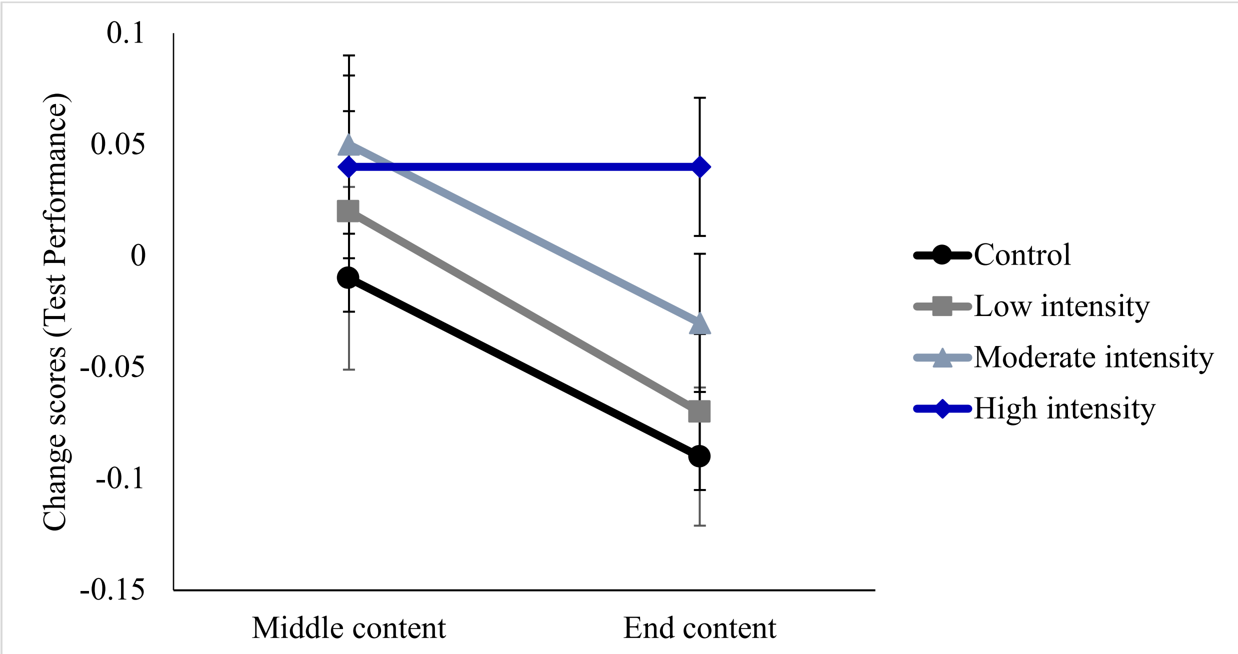

Figure 8. Trends in the change performance on content after the first and second exercise break collapsed across day (controlling for introductory psychology grades). No significant differences noted. Bars represent ±SE.

Figure 9. Change in test performance by group (adjusted).

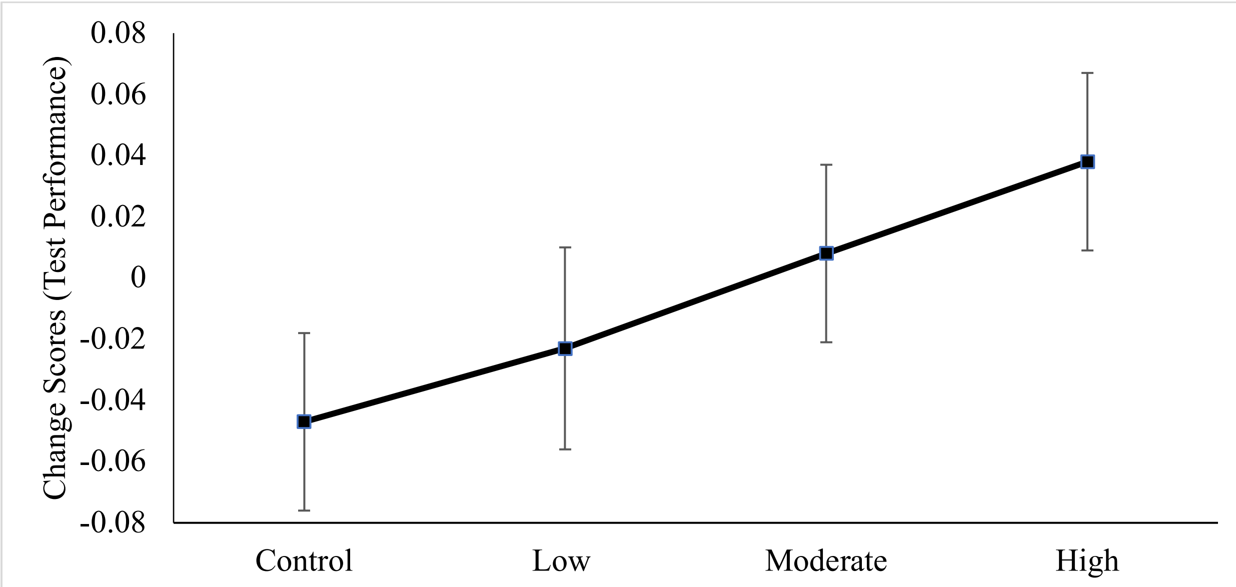

Figure 9. Trends in the change performance on content collapsed across test and day (controlling for introductory psychology grades). No significant differences noted. Bars represent ±SE

Appendix A. Sample comprehension questions.

Which of the following statements regarding perceptual constancies is correct?

a) Shape constancy is the ability of the brain to perceive changes in the shapes of objects.
b) Size constancy is the ability of the brain to adjust for changes in distance.
c) Location constancy is the ability of the brain to adjust for changes in perspective.
d) Colour constancy is the ability of the brain to adjust for changes in amplitude.

How can different types of processing influence perception?

a) Using top-down processing, specific characteristics of a stimulus guide perception
b) Using top-down processing, our own expectations hinder perception
c) Using bottom-up processing, the entire stimulus is analyzed instead of specific features
d) Using bottom-up processing, features from the stimulus are compared to features in memory when processing objects

Appendix B. The Felt Arousal Scale (Sveback & Murgatroyd, 1985).

How aroused do you currently feel? Please circle the appropriate number below. By "arousal" we meant how "worked-up" you feel. You might experience high arousal in one of a variety of ways, for example as excitement or anxiety or anger. Low arousal might also be experienced in one of a number of different ways, for example as relaxation, boredom or calmness.

6 HIGH AROUSAL

5

4

3

2

1 LOW AROUSAL

Appendix C. The Feeling Scale – Modified from Hardy & Rejeski (1989).

How would you rate your current mood? Please circle the appropriate number below.

-5	-4	-3	-2	-1	0	+1	+2	+3	+4	+5
Very Bad		Bad		Fairly Bad	Neutral	Fairly Good		Good		Very Good

Appendix D. Motivation questions.

A. I am motivated to pay attention to the lecture material. Please circle the appropriate number below.

1 absolutely disagree

2 mostly disagree

3 somewhat disagree

4 neutral

5 somewhat agree

6 mostly agree

7 absolutely agree

B. I am motivated to learn the lecture material. Please circle the appropriate number below.

1 absolutely disagree

2 mostly disagree

3 somewhat disagree

4 neutral

5 somewhat agree

6 mostly agree

7 absolutely agree

REFERENCES

Audiffren, M., Tomporowski, P., & Zagrodnik, J. (2008). Acute aerobic exercise and information processing: energizing motor processes doing a choice reaction time task. *Acta Psychologica*, *129*(0), 410–419.

Banich, M. T. (2009). Executive function: The search for an integrated account. *Current directions in psychological science*, *18*(2), 89–94.

Best, J. R. (2010). Effects of physical activity on children's executive function: Contributions of experimental research on aerobic exercise. *Developmental Review*, *30*(4), 331–351.

Borg, G. A. (1982). Psychophysical bases of perceived exertion. *Medicine and science in sports and exercise*, *14*(5), 377–381.

Bower, G. H. (1981). Mood and memory. *American psychologist*, *36*(2), 129.

Braboszcz, C., & Delorme, A. (2011). Lost in thoughts: Neural markers of low alertness during mind wandering. *NeuroImage*, *54*(4), 3040–3047.

Chang, Y. K., Labban, J. D., Gapin, J. I., & Etnier, J. L. (2012). The effects of acute exercise on cognitive performance: A meta-analysis. *Brain Research*, *1453*, 87–101.

Coles, K., & Tomporowski, P. D. (2008). Effects of acute exercise on executive processing, short-term and long-term memory. *Journal of Sports Sciences, 26*(3), 333–344.

CSEP. 2013. Canadian Society for Exercise Physiology-Physical Activity Training for Health (CSEP-PATH). CSEP, Ottawa, Ont., Canada.

Daly-Smith, A. J., Zwolinsky, S., McKenna, J., Tomporowski, P. D., Defeyter, M. A., & Manley, A. (2018). Systematic review of acute physically active learning and classroom movement breaks on children's physical activity, cognition, academic performance and classroom behaviour: understanding critical design features. *BMJ Open Sport & Exercise Medicine*, *4*(1), e000341.

Diamond, A. (2006). The early development of executive functions. *Lifespan cognition: Mechanisms of change*, *210*, 70–95.

Diamond, A. (2013). Executive functions. *Annual review of psychology*, *64*, 135–168.

Donnelly, J. E., Hillman, C. H., Castelli, D. M., Etnier, J. L., Lee, S., Tomporowski, P., … Szabo-reed, A. N. (2016). Physical activity, fitness, cognitive function, and academic achievement in children: A systematic review. *Medicine and Science in Sports and Exercise 48*(6), 1197–1222.

Drollette, E. S., Scudder, M. R., Raine, L. B., Moore, R. D., Saliba, B. J., Pontifex, M. B., & Hillman, C. H. (2014). Acute exercise facilitates brain function and cognition in children who need it most: An ERP study of individual differences in inhibitory control capacity. *Developmental Cognitive Neuroscience, 7*, 52–64.

Dubuc, M., Aubertin-Leheudre, M., & Karelis, A. (2017). Relationship between academic performance with physical, psychosocial, lifestyle, and sociodemographic factors in female undergraduate students. *International Journal of Preventative Medicine,* 8, 22.

El Ansari, W., & Stock, C. (2014). Relationship between attainment of recommended physical activity guidelines and academic achievement: Undergraduate students in Egypt. *Global Journal of Health Science*, *6*(5), 274–283.

Engle, R. W. R. R. W. (2002). Working memory capacity as executive attention. *Current Directions in Psychological Science*, *11*(1), 19–23.

Fenesi, B., Kramer, E., & Kim, J. A. (2016). Split-Attention and Coherence Principles in Multimedia Instruction Can Rescue Performance for Learners with Lower Working Memory Capacity. *Journal of Applied Cognitive Psychology, 30*(5), 691–699.

Fenesi, B., Lucibello, K., Kim, J., & Heisz, J. (2018). Sweat so you don't forget: Exercise breaks during learning increases on-task attention and comprehension. *Journal of Applied Research in Memory and Cognition.* Advanced online publication: https://doi.org/10.1016/j.jarmac.2018.01.012

Ferris, L. T., Williams, J. S., & Shen, C. (2007). The effect of acute exercise on serum brain-derived neurotrophic factor levels and cognitive function. *Medicine & Science in Sports & Exercise*, *39*(4), 728–734.

Foulsham, T., Farley, J., & Kingstone, A. (2013). Mind wandering in sentence reading: Decoupling the link between mind and eye. *Canadian Journal of Experimental Psychology*, *67*(1), 51–59.

Gomez-Pinilla, F., & Hillman, C. H. (2013). The influence of exercise on cognitive abilities. *Comprehensive Physiology, 3*(1), 403–428.

Gomez-Pinilla, F., Vaynman, S., & Ying, Z. (2010). Brain-derived neurotrophic factor functions as a metabotrophin to mediate the effects of exercise on cognition. *European Journal of Neuroscience*, *28*(11), 2278–2287.

Hardy, C., & Rejeski, W. (1989). Not what, but how one feels: the measurement of affect during exercise. *Journal of Sport & Exercise Psychology, 11*(3), 304–317.

Hillman, C. H., Pontifex, M. B., Raine, L. B., Castelli, D. M., Hall, E. E., & Kramer, A. F. (2009). The effect of acute treadmill walking on cognitive control and academic achievement in preadolescent children. *Neuroscience*, *159*(3), 1044–54.

Hillman, C., Erickson, K. A. K. (2008). Be smart, exercise your heart: exercise effects on brain and cognition. *Nature Reviews Neuroscience*, *9*(1), 58.

Hogervorst, E., Riedel, W., Jeukendrup, A., Jolles, J. (1996). Cognitive performance after strenuous physical exercise. *Perceptual and Motor Skills, 83*, 497–488.

Howie, Schatz, J., & Pate, R. (2015). Acute effects of classroom exercise breaks on executive function and math performance: A dose-response study. *Research Quarterly for Exercise and Sport, 86*(3), 217–224.

Hull, C. L. (1943). An introduction to behavior theory. In Richard M. Elliot (Ed.), *Principles of Behavior* (pp. 422). Oxford, England: Appleton-Century-Crofts.

Hülya Aşçı, F. (2009). Sex differences in psychological effects of exercise. *International Journal of Psychology, 44*(4), 313–320.

Janssen, M., Chinapaw, M. J. M., Rauh, S. P., Toussaint, H. M., van Mechelen, W., & Verhagen, E. A. L. M. (2014). A short physical activity break from cognitive tasks increases selective attention in primary school children aged 10 to 11. *Mental Health and Physical Activity, 7*(3) 129–134.

Jarrett, O. S., Maxwell, D. M., Dickerson, C., Hoge, P., Davies, G., & Yetley, A. (1998). Impact of recess on classroom behavior: Group effects and individual differences. *The Journal of Educational Research*, *92*(2), 121–126.

Johnstone, A. H., & Percival, F. (1976). Attention breaks in lectures. *Education in Chemistry, 13*(2), 49–50.

Keating, X. D., Guan, J., Pinero, J. C., & Bridges, D. M. (2005). A meta-analysis of college students' physical activity behaviors. *Journal of American College Health*, *54*(2), 116–125.

Knowles, M. S., Holton, E. F., & Swanson, R. A. (2005). The adult learner. Burlington, MA.

Lee, B. K., Glass, T. A., McAtee, M. J., Wand, G. S., Bandeen-Roche, K., Bolla, K. I., & Schwartz, B. S. (2007). Associations of salivary cortisol with cognitive function in the Baltimore memory study. *Archives of General Psychiatry*, *64*(7), 810–818.

Lindquist, S. I., & McLean, J. P. (2011). Daydreaming and its correlates in an educational environment. *Learning and Individual Differences, 21*(2), 1158–167.

Ma, J. K., Mare, L. Le, & Gurd, B. J. (2014). Classroom-based high-intensity interval activity improves off-task behaviour in primary school students. *Applied Physiology, Nutrition, and Metabolism*, *39*(12), 1332–1337.

Maeda, J. K., & Randall, L. M. (2003). Can academic success come from five minutes of physical activity? *Brock Education Journal*, *13*(1), 14–22.

McMorris, T., Sproule, J., Turner, A., & Hale, B. J. (2011). Acute, intermediate intensity exercise, and speed and accuracy in working memory tasks: A meta-analytical comparison of effects. *Physiology and Behavior*, *102*(3–4), 421–428.

McNaughten, D., & Gabbard, C. (1993). Physical exertion and immediate mental performance. *Perceptual and Motor Skills*, *77*, 1155–1159.

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex "frontal lobe" tasks: A latent variable analysis. *Cognitive psychology*, *41*(1), 49-100.

Mullender-Wijnsma, M. J., Hartman, E., de Greeff, J. W., Doolaard, S., Bosker, R. J., & Visscher, C. (2016). Physically active math and language lessons improve academic achievement: A cluster randomized controlled trial. *Pediatrics*, *137*(3), e20152743.

Ratey, J. J., & Loehr, J. E. (2011). The positive impact of physical activity on cognition during adulthood: A review of underlying mechanisms, evidence and recommendations. *Reviews in the Neurosciences*, *22*(2), 171–185.

Risko, E. F., Anderson, N., Sarwal, A., Engelhardt, M., & Kingstone, A. (2012). Everyday attention: Variation in mind wandering and memory in a lecture. *Applied Cognitive Psychology*, *26*(2), 234–242.

Schooler, J. W., Smallwood, J., Christoff, K., Handy, T. C., Reichle, E. D., & Sayette, M. A. (2011). Meta-awareness, perceptual decoupling and the wandering mind. *Trends in Cognitive Sciences*, *15*(7), 319–326.

Schuch, F. B., Vancampfort, D., Richards, J., Rosenbaum, S., Ward, P. B., & Stubbs, B. (2016). Exercise as a treatment for depression: A meta-analysis adjusting for publication bias. *Journal of Psychiatric Research*, *77*, 42–51.

Shimamura, a P., & Shimamura, a P. (2000). The role of the prefrontal cortex in dynamic filtering. *Psychobiology*, *28*(2), 207–218.

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

Sibley, B. A., & Beilock, S. L. (2007). Exercise and working memory: An individual differences investigation. *Journal of Sport and Exercise Psychology*, *29*(6), 783–791.

Sibley, B. A., Etnier, J. L., & Le Masurier, G. C. (2006). Effects of an acute bout of exercise on cognitive aspects of stroop performance. *Journal of Sport and Exercise Psychology, 28*(3), 285–299.

Smallwood, J., Fishman, D. J., & Schooler, J. W. (2007). Counting the cost of an absent mind: Mind wandering as an underrecognized influence on educational performance. *Psychonomic Bulletin and Review*, *14*(2), 230–236.

Smallwood, J., McSpadden, M., & Schooler, J. W. (2008). When attention matters: The curious incident of the wandering mind. *Memory and Cognition*, *36*(6), 1144–1150.

Smallwood, J., & Schooler, J. W. (2006). The restless mind. *Psychological Bulletin*, *132*(6), 946–958.

Smallwood, J., Smallwood, J., Beach, E., & Schooler, J. W. (2008) Going AWOL in the brain: Mind wandering reduces cortical analysis of external events, *Journal of Cognitive Neuroscience,* 20(3), 458–469.

Smilek, D., Carriere, J. S. A., Cheyne, J. A., Smilek, D., Carriere, J. S. A., & Cheyne, J. A. (2010). Out of mind, out of sight: Eye blinking as indicator and embodiment of mind wandering. *Psychological Science*, *21*(6), 786–789.

Stuss, D. T., & Benson, D. F. (1984). Neuropsychological studies of the frontal lobes. *Psychological Bulletin*, *95*(1), 3–28.

Svebak, S., & Murgatroyd, S. (1985). Metamotivational dominance: a multimethod validation of reversal theory constructs. *Journal of Personality and Social Psychology*, *48*(1), 107–116.

Szpunar, K. K., Khan, N. Y., & Schacter, D. L. (2013). Interpolated memory tests reduce mind wandering and improve learning of online lectures. *Proceedings of the National Academy of Sciences*, *110*(16), 6313–6317.

Szpunar, K., Moulton, S., & Schacter, D. (2013). Mind wandering and education: from the classroom to online learning. *Frontiers in Psychology, 4*, 495.

Szuhany, K. L., Bugatti, M., & Otto, M. W. (2015). A meta-analytic review of the effects of exercise on brain-derived neurotrophic factor. *Journal of Psychiatric Research, 60*, 56–64.

Uzzaman, S., & Joordens, S. (2011). The eyes know what you are thinking: Eye movements as an objective measure of mind wandering. *Consciousness and Cognition, 20*(4), 1882–1886.

Van Dusen, D. P., Kelder, S. H., Kohl, H. W., Ranjit, N., & Perry, C. L. (2011). Associations of physical fitness and academic performance among schoolchildren, *Journal of School Health, 81*(12), 733–740.

Vaynman, S., Ying, Z., & Gomez-Pinilla, F. (2004). Hippocampal BDNF mediates the efficacy of exercise on synaptic plasticity and cognition. *European Journal of Neuroscience*, *20*(10), 2580–2590.

Verburgh, L., Königs, M., Scherder, E. J. A., & Oosterlaan, J. (2014). Physical exercise and executive functions in preadolescent children, adolescents and young adults: a meta-analysis. *British Journal of Sports Medicine*, *48*(12), 973–979.

Wald, A., Muennig, P. A., O'Connell, K. A., & Garber, C. E. (2014). Associations between healthy lifestyle behaviors and academic performance in U.S. undergraduates: A secondary analysis of the American college health association's national college health assessment ii. *American Journal of Health Promotion*, *28*(5), 298–305.

Wammes, J. D., Boucher, P. O., Seli, P., Cheyne, J. A., & Smilek, D. (2016). Mind wandering during lectures I: Changes in rates across an entire semester. *Scholarship of Teaching and Learning in Psychology*, *2*(1), 13–32.

Wammes, J. D., Seli, P., Cheyne, J. A., Boucher, P. O., & Smilek, D. (2016). Mind wandering during lectures II: Relation to academic performance. *Scholarship of Teaching and Learning in Psychology*, *2*(1), 33–38.

Warburton, D. E. R., Nicol, C. W., & Bredin, S. S. D. (2006). Health benefits of physical activity: the evidence. *CMAJ : Canadian Medical Association*, *174*(6), 801–9.

Watson, A., Timperio, A., Brown, H., Best, K., & Hesketh, K. D. (2017). Effect of classroom-based physical activity interventions on academic and physical activity outcomes: A systematic review and meta-analysis. *International Journal of Behavioral Nutrition and Physical Activity*, *14*(1), 114.

Westerterp, K. R. (2001). Pattern and intensity of physical activity. *Nature*, *410*, 539–540.

Wilkins, J., Graham, G., Parker, S., Westfall, S., Fraser, R., & Tembo, M. (2003). Time in the arts and physical education and school achievement. *Journal of Curriculum Studies*, *35*(6), 721–734.

Wipfli, B. B. M., Rethorst, C. D. C., & Landers, D. D. M. (2008). The anxiolytic effects of exercise: A meta-analysis of randomized trials and dose-response analysis. *Journal of Sport & Exercise Psychology*, *30*(4), 392–410.

Yerkes, R. M., & Dodson, J. D. (1908). The relation of strength of stimulus to rapidity of habit-formation. *The Journal of Comparative Neurology and Psychology*, *18*, 459–482.