THE EFFECTS OF LOW-INTENSITY EXERCISE ON NEUROCOGNITIVE FUNCTION

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Acute aerobic exercise exerts a small beneficial effect on cognition. Much of the research to date has focused on cognitive changes following a bout of exercise, while little is currently known about changes in cognitive performance during exercise. The limited research that has been conducted suggests either positive, negative, or no effects on cognitive performance during exercise. Thus, the primary purpose of this study was to examine the effects of low-intensity cycling on cognitive function in college-aged students, indexed by response accuracy, reaction time, P3 amplitude, and P3 latency. Twenty-seven (Mage = 22.9 ± 3.0 years old) college-aged individuals were counterbalanced into low-intensity exercise (EX) and seated control (SC) conditions. During each condition, participants completed a 10-minute resting baseline period, 20 minutes of either sustained cycling or seated rest, and a 20-minute recovery period. Primary outcomes were assessed at 10-minute intervals (5 blocks total) throughout each condition via a modified oddball task. Across time blocks, both conditions exhibited faster reaction times on frequent trials but reduced accuracy to rare trials, suggesting a speed-accuracy tradeoff. There were no differences between conditions in P3 latency whereas a significant reduction in P3 amplitude was observed during the 20-minute exercise period compared to the control condition. Taken together, the results suggest that exercise at lower doses may have minimal influence on behavioral outcomes of cognitive performance but may impact more basic measures of brain function. Information gathered from this study may aid in the development of appropriate exercise prescriptions for populations looking to specifically target cognitive function deficits.

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THE EFFECTS OF LOW-INTENSITY EXERCISE ON NEUROCOGNITIVE FUNCTION

Introduction

Acute aerobic exercise exerts a small beneficial effect on cognition (Lambourne and Tomporowski, 2010; McMorris et al., 2011; Sibley & Etnier, 2003; Tomporowski, 2010). This conclusion was drawn following a number of empirical investigations, systematic reviews, and meta-analyses indicating the general and specific effects of exercise on cognitive function (Brisswalter et al., 2002, Chang et al., 2012; Etnier et al., 1997; Tomporowski, 2003). Much of the research to date has focused on cognitive changes following a bout of exercise, while little is currently known about changes in cognitive performance during exercise. Understanding this relationship may be especially important for explaining the neurobiological mechanisms underlying the alterations we see following exercise. The limited research that has been conducted suggests either positive (Chang et al., 2012; McMorris et al., 2011; Olson et al., 2016), negative (Dietrich & Sparling, 2004; Pontifex & Hillman, 2007), or no (Scanlon et al., 2017) effects on cognitive performance during exercise.

Studies examining the effects of exercise on cognition have traditionally utilized end-state measures of overt behavioral task performance such as response accuracy and reaction time. While this information has undoubtedly laid the groundwork in the field of exercise and cognition, these outcomes tell us very little about the subtle aspect of cognitive processing that may be influenced by exercise as well as provides little information about the potential mechanisms underlying the temporal effects of exercise on brain function. With the advent of advanced functional neuroimaging techniques, researchers are now able to safely and accurately measure brain function during exercise through electroencephalography (EEG; Enders et al., 2016; Ludyga et al., 2016; Scanlon et al., 2017). EEG has been used to reveal both the spatial

and temporal properties of neural activity during cognitive tasks that cannot be done with the traditional behavioral measures (Hillyard & Anllo-Vento, 1998). We can further decompose the continuous EEG signal via the event related potential (ERP) technique, which may provide researchers with valuable information about the processes that occur before, during, and after the execution of a behavior. ERPs represent voltage fluctuations that are time-locked to a specific event, such as the onset of a stimulus or the execution of a manual response. Several components of the ERP signal have been identified and are thought to reflect the sensory, cognitive, affective, and motor processes elicited by a stimulus (Kappenman & Luck, 2011). The P3 component has received a bulk of researcher attention in the exercise-cognition literature. The amplitude and latency of P3, named for its location within the ERP (i.e., third positive peak), is commonly measured in cognitive neuroscience as an index of attentional resource allocation during stimulus engagement and stimulus classification speed, respectively (Donchin & Coles, 1988; Polich, 2007). The P3 component is a stimulus-locked ERP observed approximately 300-800 ms following stimulus onset and has been instrumental in continuing our knowledge base of cognition and brain function both during and following exercise (Chang et al., 2015; Drollette et al., 2014; Olson et al., 2016; Pontifex & Hillman, 2007).

In the few studies that have incorporated ERPs during exercise, equivocal findings have been reported. In the most recent study, Scanlon and colleagues (2017) recorded EEG during an auditory oddball task while participants were either riding or sitting on a stationary bike. The oddball is a class cognitive paradigm used to assess working memory, attention, and inhibitory control. More importantly, this paradigm elicits a robust and isolated P3 component. Results indicated no significant difference in P3 between the biking and sitting conditions. These findings are in-line with previous studies showing no differences in P3 during exercise (de Vos

et al., 2014; Gramann et al., 2010; Schmidt-Kassow et al., 2013; Zink et al., 2016). Interestingly, no specific information was provided on exercise intensity or duration, but the researchers did indicate that participants were asked to pedal slowly and consistently, without exerting themselves or raising their heart rate. Additionally, participants completed 750 trials (3 blocks of 250 trials separated by a self-paced rest period > 0.5 sec) before, during, and after pedaling. Each trial consisted of a random length pre-tone interval between 500-1,000 ms followed by tone onset lasting 16 ms. Estimated time for each block of 250 trials ranged between 2.15-4.23 minutes (total estimated exercise duration equal to 6.45-12.69 minutes). Thus, the exercise would be classified as very-light intensity taking place over a period of time not shown to improve cognitive function. Studies have also revealed decreases in P3 amplitude during exercise (Yagi et al., 1999).

Supporting this reduction, Yagi et al. (1999) showed decreased P3 amplitude to an auditory and visual oddball task during exercise compared with rest and recovery periods. The authors suggested that participants treated exercise as a secondary task requiring a larger fraction of limited attentional resources (e.g., dual-task interference). During the study, half the participants performed the rest, exercise, and recovery periods to the auditory oddball task first, immediately followed by the rest, exercise, and recovery periods to the visual oddball task, while the other half completed the visual oddball task first. The residual effects of exercise may have influenced the second block of testing, potentially washing out the initial period results. In contrast to these results, a majority of studies indicate increases in P3 amplitude and decreases in P3 latency during exercise (Grego et al., 2004; Olson et al., 2016; Pontifex & Hillman, 2007; Vogt et al., 2015).

Olson and colleagues (2016) examined ERP responses to a flanker task during low-intensity, moderate-intensity, and control conditions. Researchers found increased P3 amplitude across centro-parietal electrode sites during both exercise conditions relative to the control condition, suggesting an increase in the amount of attentional resources engaged during the dual-task performance (Polich, 2012). However, this study employed a modified flanker task with the presentation of equiprobable stimuli, whereas traditionally this task is used for assessing inhibitory cognitive control via the N2 ERP component. P3 responses vary based on probability, such that stimuli presented less frequently generate a higher amplitude and slower latency (Donchin, 1981). The reported increases in P3 amplitude across both trials types (i.e., congruent and incongruent stimuli) during exercise may have been due to greater upregulation of cognitive control and attentional resources necessary for successful task completion. Pontifex and Hillman (2007) also assessed ERP responses during exercise, instructing participants to cycle at steady-state (60% of maximal HR) for approximately 6.5 min. They similarly found increases in P3 amplitude and reductions in latency across frontal and lateral electrode sites, suggesting cortical inefficiency during stimulus engagement and delays in stimulus evaluation and classification speed. Finally, Grego et al. (2004) used a longer duration of moderate-intensity exercise (~66% VO2 max for 180 min) to study the effects of fatigue on P3 in trained cyclists during an auditory oddball task. During the 1st and 2nd time points (3 and 36 min) there were no differences in P3 amplitude between rest and exercise conditions. An increase in P3 amplitude later emerged during the 3rd time point (72 min), peaked at the 4th time point (108 min), and was diminished at the 5th and 6th time points (144 and 180 min). The authors suggested that the increases in P3 amplitude between the 3rd and 4th time points were reduced at the later time points through the combined effects of arousal and central fatigue mechanisms during prolonged exercise. Despite

the mixed results, there is general consensus that cognitive function, measured by P3, is modifiable during exercise.

The purpose of this study is to examine the effects of low-intensity cycling on cognitive function in college-aged students, indexed by response accuracy, reaction time, P3 amplitude, and P3 latency. It is hypothesized that low-intensity exercise will reduce reaction time (i.e., become faster) and have no effect on response accuracy relative to the seated control condition. Furthermore, it is predicted that the exercise group with display a significant increase in P3 amplitude and reduction in P3 latency during exercise compared to the control condition

Methods

Participants

Twenty-seven (10 females) college-aged individuals (M_{age} = 22.9 ± 3.0) were recruited from the local university via recruitment emails and flyers. Inclusion criteria included: men and women aged 18-35 years; and no physical limitations or contraindications to exercise. Exclusion criteria included: current or present history of cardiovascular disease; past or present history of psychiatric or neurological disorder; currently taking medications that would prevent them from completing moderate-to-vigorous intensity exercise; and/or pregnancy or considering becoming pregnant in women. Considering the within-subjects design, enrolled participants were screened for regular sleep patterns, stimulant use (e.g., caffeine and tobacco), meal consumption, exercise participation, stress levels, and current mood prior to each testing session. Any subjects that provided irregular responses relative to their normal daily activities were re-scheduled. The Institutional Review Board at the University of North Texas approved research procedures and all participants provided written informed consent prior to data collection.

Measures

General Medical History

A complete health and medical history was obtained during the familiarization day using a self-reported medical history questionnaire. The form assessed family history or presence of disease, medical symptoms, past surgeries, tobacco/alcohol use, and prior and current medication use. Participants were also asked to complete the Physical Activity Readiness Questionnaire (PAR-Q; Shephard et al., 1981) to ensure safety for participating in the exercise condition.

Heart Rate (HR) and Intensity

HR was assessed continuously throughout the test sessions with a Polar S810 HR monitor and transmitter (Polar Electro, Kemele, Finland). HR data was collected every 10 minutes to ensure participants maintain a relative exercise intensity that fell within the prescribed zone. In order to standardize workload intensity between conditions, low-intensity exercise was defined as maintaining a HR range between 57-63% of age-predicted maximum heart rate (HR_{max}) and was calculated for each participant. HR_{max} was calculated based on ACSM guidelines (i.e., 220 - age = HR_{max}) for establishing exercise intensity zones (Garber et al., 2011).

Ratings of Perceived Exertion (RPE)

The in-task perception of physical exertion was measured using Borg's 15-point scale (Borg, 1970), which ranges from 6 to 20 with verbal anchors at 7 (very, very light), 9 (very light), 11 (fairly light), 13 (somewhat hard), 15 (hard), 17 (very hard), and 19 (very, very hard). Meta-analytic findings on RPE validity data indicate that this scale displays strong validity with common physiological measures of exertion and intensity (Chen, Fan, & Moe, 2002). The

validity of the RPE scale in terms of its correlation with standard physiological indices (e.g., blood lactate, oxygen uptake, respiratory exchange ratio) has been previously demonstrated (r=.80 to 0.95; Borg, 1998). The scale also displays both high intratest (r = .93) and retest (r = .83 to .94) reliability (Borg, 1998).

Oddball Paradigm

Participants completed a modified version of the oddball task (Luck et al., 2009) to assess sustained attention and working memory capacity. The stimuli consisted of 3 cm tall x 3 cm long black letters (B, C, D, E, F) and digits (2, 3, 4, 5, 6) presented focally on a computer screen following a continuous fixation point. Participants were asked to complete two blocks of 60 trials at five separate time points: 5, 15, 25, 35, and 45 minutes (600 total trials). The monitor was viewed at a distance of approximately 100 cm with vertical and horizontal visual angles of 1.7 X 1.7 degrees, respectively. Each stimulus was presented in black font color on a light grey background for 100 ms. To avoid potential anticipatory responses, a random intertrial interval (ITI) ranging between 800-1,200 ms was implemented prior to each stimulus presentation. Depending on instructions, participants performed a button press with their left or right thumb in response to the stimulus. Participants were instructed to respond with their right hand for digits and left hand for letters during the first set of trials and then the response mapping was reversed for the second set of trials to control for potential motor response confounds. The order of response instructions was counterbalanced between the five time points. Participants also completed a brief training block (approximately 10 trials) where response feedback was provided prior to each experimental block of trials to confirm understanding of the task. All assessments consisted of one block of trials where digits appeared 80% of the time and letters appeared 20%

of the time followed by a second block of trials where digits appeared 20% of the time and letters appeared 80% of the time. In total, each assessment consisted of 120 trials with a 20-sec rest period between each 60-trial block.

P3 Event-Related Potential (ERP)

Continuous EEG was recorded from 28 scalp sites (FP1, FP2, F3, F4, F7, F8, FC1, FC2, FC5, FC6, C3, C4, CP1, CP2, CP5, CP6, TP9, TP10, P3, P4, P7, P8, O1, O2, Fz, Cz, Pz, Oz) arranged in accordance with the international 10-20 system (Oostenveld & Praamstra, 2001) using a Brain Vision actiCap with active electrodes and actiCHamp amplifier system (Brain Products GmbH; Munich, Germany). Vertical (above and below the left eye) and horizontal (approximately 1 cm lateral to the outer canthus of each eye) electrooculogram (EOG) activity was recorded and monitored for eye movements and artifact. Continuous data was initially referenced to the vertex electrode (Cz) and digitized at 500 Hz with a 24-bit analog-to-digital converter. Impedances were assessed prior to each testing block and maintained below 10 kΩ throughout the session. Data was exported from PyCorder (version 1.0.9) to the ERP Principal Component Analysis (PCA) toolkit (Dien, 2010) and bandpass filtered using a 2nd order infinite impulse response (IIR) Butterworth filter with a low-pass frequency of 30 Hz and high-pass frequency of 0.1 Hz. Data was then manually inspected for large movement-related artifacts (e.g., blink artifact, eye movements, and muscle activity). Prior to segmenting, independent component analysis (ICA) was applied to continuous data for the detection and removal of eye-blinks. Stimulus-locked epochs were then created from 100 ms pre- to 1000 ms post-stimulus onset. Remaining eye blinks were removed from segmented data using ICA blink templates generated within the PCA Toolkit, with one generated from the dataset of all subjects and one

default template provided by the toolkit author. ICA components that correlated at 0.9 with scalp topographies of either blink template were removed. Additionally, trials with a difference of 100 μV between minimum and maximum values in that trial or channels differing in the segment by more than 30 μV from the neighboring six closest channels were marked bad and removed. Trials with >10% of channels marked as bad were also removed. Remaining bad channels were corrected through spherical interpolation obtained from ‘‘good” channels of the scalp voltage field within each segment. Lastly, epochs were re-referenced to the left and right mastoids (Bertrand et al., 1985; Tucker et al., 1994), averaged by trial type, and baseline corrected using the 100 ms pre-stimulus period. Only correct trials were averaged to assess P3 component amplitude and latency. Consistent with previous ERP research (Polich, 2007) and due to the scalp distribution reflecting the component of interest, P3 amplitude and latency were assessed at centro-parietal (CP1, CP2, Cz, Pz) electrode sites. Amplitude was measured as the mean amplitude of the difference wave between rare and frequent stimuli within an *a priori* time window of 300–700 ms post-stimulus onset for the grand averaged waveform while latency was measured as the maximal centroid latency of the difference wave between rare and frequent stimuli during the same time window.

Procedures

Participants visited the laboratory on three separate occasions (see Figure 1) at approximately the same time of day separated by at least 24 hours between sessions. On day 1, participants provided written informed consent and were asked to complete the PAR-Q and a brief health history form. Next, participants were familiarized with the exercise equipment, EEG recording chamber, and cognitive testing. Briefly, the participant sat on the recumbent cycle

ergometer approximately 100 cm from the computer monitor. Participants were asked to pedal for 5-min at a self-selected pace and resistance to become familiar with the mechanics of the equipment. Adjustments in equipment distance were made throughout the 5-min period and were recorded for use during the remaining test days. Subjects were also asked to perform 50 trials of the oddball task during this time to ensure they understand the directions. Feedback indicating response accuracy and reaction time were provided on practice trials in order for participants to make adjustments during the testing period. On days 2 and 3, participants were counterbalanced into a low-intensity exercise (EX) or seated control (SC) condition. The recumbent bike was adjusted to the previously recorded position for both session. Participants were then fitted with a polar S810 HR monitor and EEG cap. Next, participants were seated on the recumbent bike and asked to place their feet in the pedal straps. During the EX condition, participant pedaled at a self-selected pace for 20-min while resistance was adjusted to match a low-intensity range based on HR and RPE values calculated during the familiarization session. During the SC condition, participants left their feet on the pedals and sat quietly during the same 20-min period. Overall, participants completed 10-min rest, 20-min test, and 20-min recovery periods with a 5-min block of neurocognitive testing taking place every 10-min. Measures of RPE, and HR were recorded at the end of each testing block as well as the moment they entered the lab. Upon completion of both test sessions, participants were debriefed on the purpose of the study.

Data Analysis

Descriptive statistics were first performed on participant demographics data using SPSS Statistical Software version 24 (SPSS Inc., Chicago, IL). A within-subjects experimental design was utilized to examine the effects of low-intensity exercise on primary outcomes of

neurocognitive function. All outcome measures were assessed throughout each condition at either five or six time points (see Figure 1 for study diagram). Repeated measures analysis of variance (RM-ANOVA) was used for P3 amplitude and latency, response accuracy, reaction time, HR, and RPE with a 2-tailed alpha level of .05 for all statistical tests. As a manipulation check of exercise intensity, a 2 (Condition: EX, SC) x 6 (Time Block: 0, 1, 2, 3, 4, 5) RM-ANOVA was conducted to compare HR and RPE across conditions. This analysis expectedly produced a quadratic trend in HR and RPE from rest to exercise and exercise to recovery period only in the EX condition, with no change observed in the SC condition. Behavioral performance data (i.e., response time and accuracy) was submitted to a 2 (Condition: EX, SC) x 5 (Time Block: 1, 2, 3, 4, 5) x 2 (Trial Type: Rare, Frequent) RM-ANOVA. Trials with reaction time and accuracy scores beyond the individual mean ± 3 SD for each trial type were excluded to reduce the potential effect of outliers. Based on previous research (Olson et al., 2016; Pontifex & Hillman, 2007) and due to P3 being most robust at centro-parietal regions (Donchin, 1981; Johnson, 1993), statistical analyses for P3 amplitude and latency were performed using an *a priori* 4-electrode region of interest (ROI) averaged across centro-parietal electrode sites (Cz, CP1, CP2, Pz). Accordingly, mean P3 amplitude and centroid latency data were submitted to a 2 (Condition: EX, SC) x 5 (Time Block: 1, 2, 3, 4, 5) x 2 (Trial Type: Rare, Frequent) RM-ANOVA. All planned comparisons and post-hoc analyses were conducted using Bonferroni corrected *t* tests. Effect sizes (ESs) are presented as partial eta squared (η^2_p) for ANOVA results.

Results

Preliminary analyses revealed no significant sex differences in BMI, age, anxiety levels, or perceived stress levels. However, a significant difference in depressive symptoms between

groups was revealed, indicating that females displayed higher levels of depression compared to males. Similarly, there were no significant sex differences in ratings of perceived exertion or heart rate responses throughout the test session. Subsequent analyses were collapsed across sex. Initially, 50 participants were recruited to participate in the study. A total of 23 participants were removed from the analysis due to incomplete data (n = 18) or irregular EEG recordings contaminated with excessive eye blinks and movement artifact (n = 5).

Heart Rate (HR)

As expected, average HR during exercise fell within the appropriate 57-63% HR_{max} range (115.44 ± 11.52) for the exercise condition. Additionally, the two-factor RM-ANOVA for HR revealed Condition, $F(1,26) = 64.55$, $p < .001$, $\eta^2_p = .71$, and Time, $F(5,22) = 22.80$, $p < .001$, $\eta^2_p = .84$, main effects. These effects were superseded by a Condition x Time interaction, $F(5,22) = 31.42$, $p < .001$, $\eta^2_p = .88$, such that HR was similar during the rest periods and higher during the exercise bout in the exercise condition compared to the control condition, confirming the prescribed intensity was met by participants in the exercise group (see Figure 2).

Perceived Exertion (RPE)

Significant Condition, $F(1,26) = 16.54$, $p < .001$, $\eta^2_p = .39$, and Time, $F(5,22) = 13.52$, $p < .001$, $\eta^2_p = .75$, main effects were found for RPE. A Condition x Time interaction superseded these main effects, $F(5,22) = 16.09$, $p < .001$, $\eta^2_p = .79$, indicating RPE was similar during the rest periods and higher during the exercise bout in the exercise condition compared to the control condition, further confirming the prescribed intensity was met by participants in the exercise group (see Figure 2).

Response Accuracy and Reaction Time

As expected, accuracy results revealed a significant Congruency main effect between frequent and rare trials, $F(1,26) = 57.15$, $p < .001$, $\eta^2_p = .69$, indicating less accurate responses on rare trials (81.6 ± 2.3%) relative to frequent trials (98.2 ± 0.2%). There was also a Time main effect nearing significance, $F(4,23) = 2.72$, $p = .055$, $\eta^2_p = .32$, suggesting reductions in accuracy over time. The Congruency main effect was superseded by a Time x Congruency interaction, $F(4,23) = 4.54$, $p = .008$, $\eta^2_p = .44$, such that rare trial accuracy reduced over time, while frequent trial accuracy remained steady throughout the test session. No additional main effects or interactions were found for response accuracy measures. For reaction time, a Congruency main effect was found, $F(1,26) = 248.63$, $p < .000$, $\eta^2_p = .91$, such that reaction time to frequent trials was faster (272.8 ± 8.8 ms) compared to rare trials (361.0 ± 9.5 ms). No additional main effects or interactions were found for reaction time (see Figure 4).

P3 Amplitude and Latency

The RM-ANOVA for P3 latency revealed a significant Congruency main effect, $F(1,26) = 37.05$, $p = .006$, $\eta^2_p = .59$, indicating faster latency to frequent (477.45 ± 4.98 ms) compared to rare (496.04 ± 4.85 ms) trials. No additional main effects or interaction were found for P3 latency. For P3 amplitude, main effects for Time $F(4,23) = 4.73$, $p = .006$, $\eta^2_p = .45$, and Congruency $F(1,26) = 57.47$, $p < .000$, $\eta^2_p = .69$, were found. These main effects were superseded by a Condition x Time interaction, $F(4,23) = 3.50$, $p = .023$, $\eta^2_p = .38$, such that P3 amplitudes in general were reduced during exercise (blocks 2 and 3) whereas they remained stable throughout the seated control condition (see Figure 5).

Discussion

The primary aim of this study was to examine the effects of low-intensity cycling on cognitive function in college-aged students indexed by behavioral performance (response accuracy, reaction time) and neuroelectric responses (P3 amplitude and latency) to the oddball paradigm. It was hypothesized that low-intensity exercise would significantly reduce reaction time and demonstrate no influence on response accuracy. It was also hypothesized that exercising at low-intensity would increase P3 amplitude and reduce P3 latency in the exercise group compared to the seated control group. Our hypotheses were not fully supported for both behavioral and neuroelectric findings. While there were trends for reduced reaction time on rare trials, they were similar between the exercise and seated control conditions. Aside from this trend, there were no additional between-group effects observed for reaction time. In partial support of our hypothesis, results for response accuracy indicated no significant group differences as well as an interaction whereby accuracy on the rare trials was reduced over time across both conditions. While several studies have found impairments in similar behavioral performance measures during exercise (Dietrich & Sparling, 2004; Olson et al., 2016; Pontifex and Hillman, 2007), not all studies are in agreement (Davranche et al., 2015; Schmit et al., 2015). These differences are likely due to methodological differences, including exercise intensity and duration, cognitive task, and study population. Furthermore, overt behavioral measures may not be the most precise measure of cognitive function due to the lack of sensitivity that is required to detect subtle differences occurring in the brain during acute aerobic exercise.

Regarding P3 amplitude and latency, we found contrasting results relative to a number of previous investigations (Olson et al., 2016; Polich, 2012; Pontifex & Hillman, 2007). In particular, P3 amplitude responses resembled a quadratic trend where it was similar between

groups at baseline, suppressed during both blocks of exercise, and returned to baseline levels during the recovery period. Latency responses, on the other hand, were similar between groups throughout the test session. These findings are supported by previous research that has found similar decreases in P3 amplitude to the oddball task during exercise (Yagi et al., 1999). The authors suggested that during exercise, the oddball task is treated like a secondary task requiring a larger fraction of limited attentional resources (i.e., distraction/dual-task interference). That is, participants are not only required to complete the task successfully, but they must also split attention to the exercise bout they are asked to perform. However, it should be noted that Yagi and colleagues also had their participants complete auditory and visual oddball tasks as well as had them complete exercise and control sessions back to back without counterbalancing. Thus, the findings may be influenced by potential task, order, or residual exercise effects. Lastly, the authors omitted an independent analysis of rare and frequent stimuli on behavioral and neural responses such that only data from rare (i.e., 20% occurrence) trials was analyzed included.

Findings from the current investigation are further supported by the transient hypofrontality theory (Audiffren et al., 2009; Dietrich, 2009; Pesce, 2009), which posits that successful task performance during exercise results in a situation where attention is drawn away from the cognitive task in order to maintain the necessary metabolic, neuromuscular, and cardiovascular response for sustaining exercise. Similarly, it has been proposed that there are limited attentional and information processing resources available in the brain (Broadbent, 1958; Keele, 1973), and these resources are especially susceptible stressors, such as exercise (Arnsten, 2009; Ramos and Arnsten, 2007). Thus, performing a cognitive task while exercising may increase the demand placed upon available neural resources of the prefrontal cortex likely due to control of bodily movements required to sustain exercise as well as cognitive demands required

by the task (Dietrich & Spalding, 2004). The resources typically reserved for successful task completion are shifted toward maintaining exercise demands and this reduction in neural resources may eventually lead to reduced cognitive performance. In order to further understand this process, it is important for researchers to focus on accurately measuring the neural operations that mediate these complex cognitive processes.

Contrasting the current findings, a more recent and similarly designed study found increases in P3 amplitude during sustained low- and moderate-intensity exercise compared to a control condition (Olson et al., 2016). However, one key difference that may explain these divergent results is the use of a flanker task, which is traditionally used for assessing inhibitory cognitive control via the N2 ERP component. Reaction time and response accuracy results from the study also suggested a potential speed accuracy trade-off on the most difficult incongruent trials of the flanker task. The lack of reaction time and accuracy findings in the current investigation may be partially due to the use of a simple cognitive task that presented fewer rare trials relative to the more complex incongruent flanker stimuli that was presented for a larger number of trials. A similar study by Vogt et al. (2015) found an increase in P3 amplitudes to a mental arithmetic test that was completed during a moderate-intensity bout of self-paced cycling in a virtual environment. The authors found that P3 responses were only increased during exercise within the virtual environment, with no changes being observed during exercise alone. Moreover, no significant differences were observed in behavioral performance measures between exercise and control conditions. As with previous interpretations, it was suggested that the virtual environment coupled with the cognitive task demands may have created an increase in cognitive load (i.e., more demand). Thus, exercise *per se* was not the cause of upregulated P3

responses. Considering a lack of consensus on the exercise-cognition relationship, future research examining exercise dose and cognitive domain variables is warranted.

Limitations

As with any study examining the influence of exercise on cognitive function, there are several potential limitations worth mentioning. First, subjects performed faster on frequent trials but less accurate on rare trials, which may have been due to boredom associated with the length of the testing sessions (50 minutes). Over time, participants may be losing focus and start anticipating the presentation of a stimulus. The improvements in reaction time during frequent trials is likely due to the reduction in accuracy during rare trials (i.e., speed-accuracy tradeoff). We did not include a direct measure of boredom, focus, attention, or concentration that could have helped us determine how subjects were feeling over the course of each session. Future investigations may consider adding additional measures or active breaks that will counter the potential influence of boredom.

Second, the exercise duration and intensity may not have been long or difficult enough to have a positive effect on the primary outcome measures. For example, a meta-analysis by Lambourne and Tomporowski (2010) suggests that cognitive impairments in cognitive performance during the first 20 minutes of exercise regardless of intensity. However, following the impairments observed from 0 to 20 minutes, general improvements in cognition are found. Therefore, a 20-minute bout of low-intensity exercise may have been too short to provide a beneficial effect on cognitive function. Researchers should consider examining dose-response relationships between exercise duration, intensity, and cognitive function. Additionally,

incorporating other potential moderators (e.g., exercise type, exercise frequency) that have been shown to influence the cognition-exercise relationship is important for future research.

Third, the addition of EEG artifact or skin potentials could have affected the P3 amplitude and latency responses. Over time, especially during exercise, skin potentials are likely to occur due to perspiration and heat. This not only creates the possibility of skin potentials but may also lead to bridging between electrodes. To reduce the likelihood of this occurring, the recording chamber uses an isolated air conditioning unit and thermostat that was used to keep the room at a stable temperature throughout exercise. Additionally, the electrode gel that is used for recording is highly viscous and has the ability to remain solid under exercise conditions. Finally, very careful attention was taken during the data collection and processing steps. Participants sat in a recumbent bike during both recording sessions. This seated posture provides back support and allows clearance for the EEG electrode wire harness. This position also reduces the sway of the neck, torso, and shoulders. During data processing, a semi-automated procedure was implemented whereby researchers visually inspected continuous and segmented data to ensure movement artifact was kept to a minimum. All remaining data quality standards (e.g., artifact detection settings, blinding of researchers to conditions) were maintained and implemented throughout the data processing procedures.

Conclusion

Together, these results suggest that while behavioral measures of accuracy and reaction time are similar between groups throughout the five time points, functional differences may occur during exercise. However, these functional differences may not be sufficient enough to alter behavioral outcomes during this type of cognitive task. This study adds to the small, but

growing body of literature that examines changes in cognitive performance during steady-state exercise. The results that were found are contrary to many similar studies in the area. With the observed similarities in accuracy and reaction time between conditions, low-intensity exercise may not have as large of an effect as previously thought. The reductions in P3 amplitude during exercise also oppose much of the existing literature, though few of the studies exclusively examine low-intensity exercise.

Table 1

Participant Characteristics (M ± SD) Overall and by Gender

Measure	Male *n* = 17	Female *n* = 10	Total *N* = 27
Age (years)	23.6 ± 3.4	21.6 ± 1.3	22.9 ± 3.0
BMI (kg/m^2)	25.5 ± 3.3	25.2 ± 4.7	25.4 ± 3.8
Depressive Symptoms (BDI)	3.9 ± 3.5	6.0 ± 5.1	4.7 ± 4.2
Anxiety levels (STAI)	47.3 ± 3.7	46.6 ± 2.3	47.0 ± 3.2
Perceived Stress (PSS)	27.7 ± 5.7	31.2 ± 4.0	29.0 ± 5.3

Note. kg = kilogram; m = meter; BDI = Beck's Depression Inventory; STAI = State-Trait Anxiety Inventory; PSS = Perceived Stress Scale. *Significant difference, unpaired Student's *t* test between male and female participants, $p < .05$

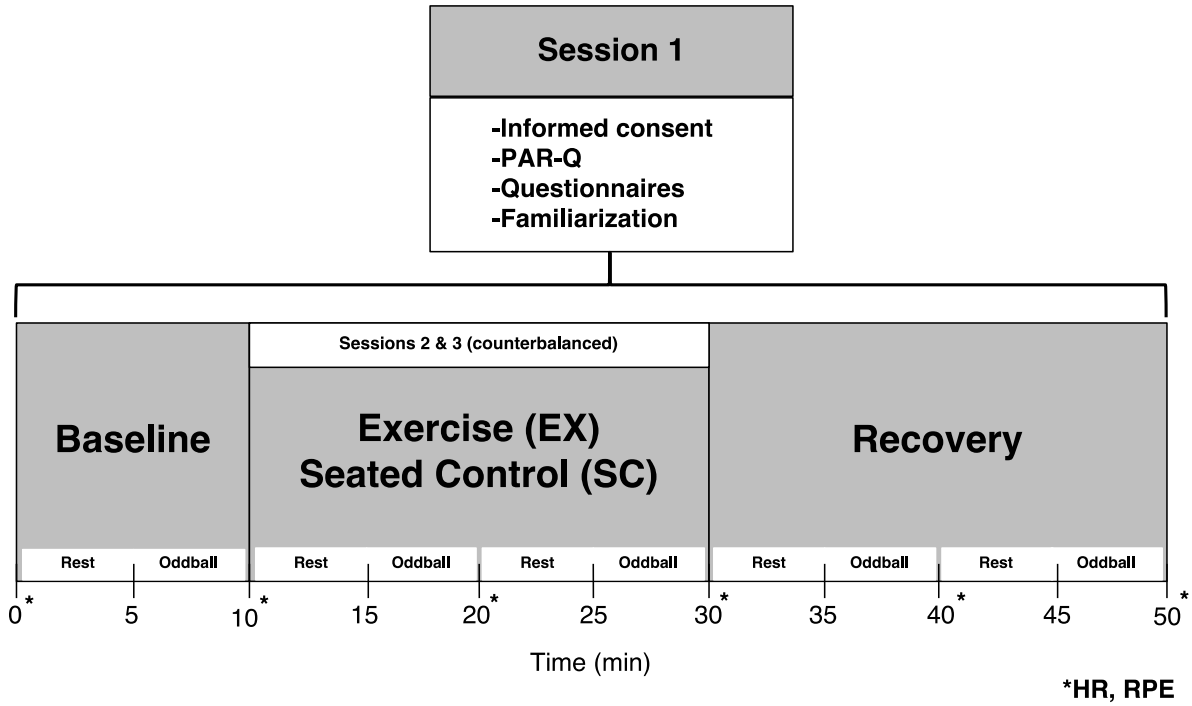

Figure 1. Experimental study design.

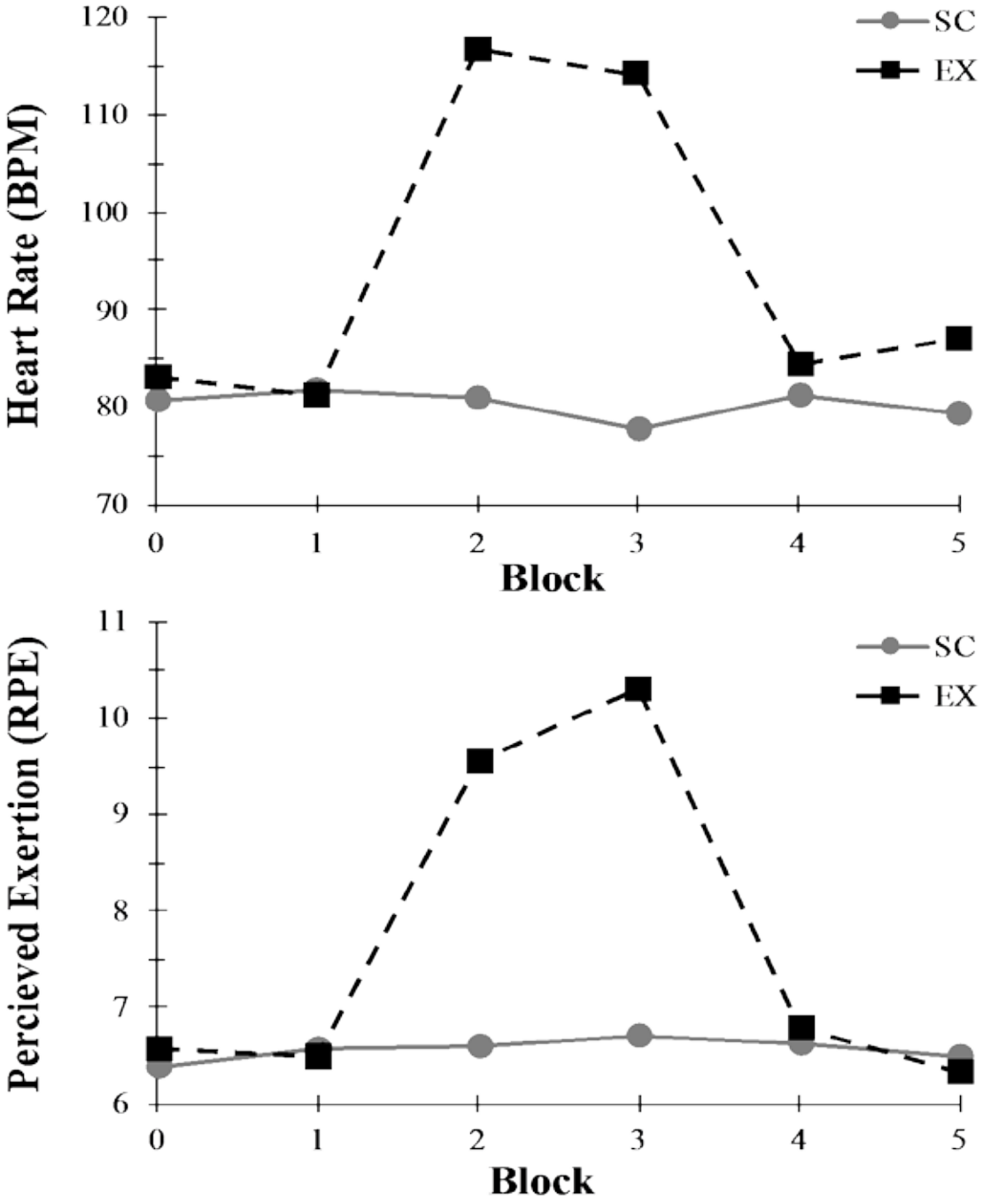

Figure 2. Average heart rate (BPM; top) and perceived exertion (RPE; bottom) measured during blocks 0, 1, 2, 3, 4, and 5 for EX (black line) and SC (grey line) conditions.

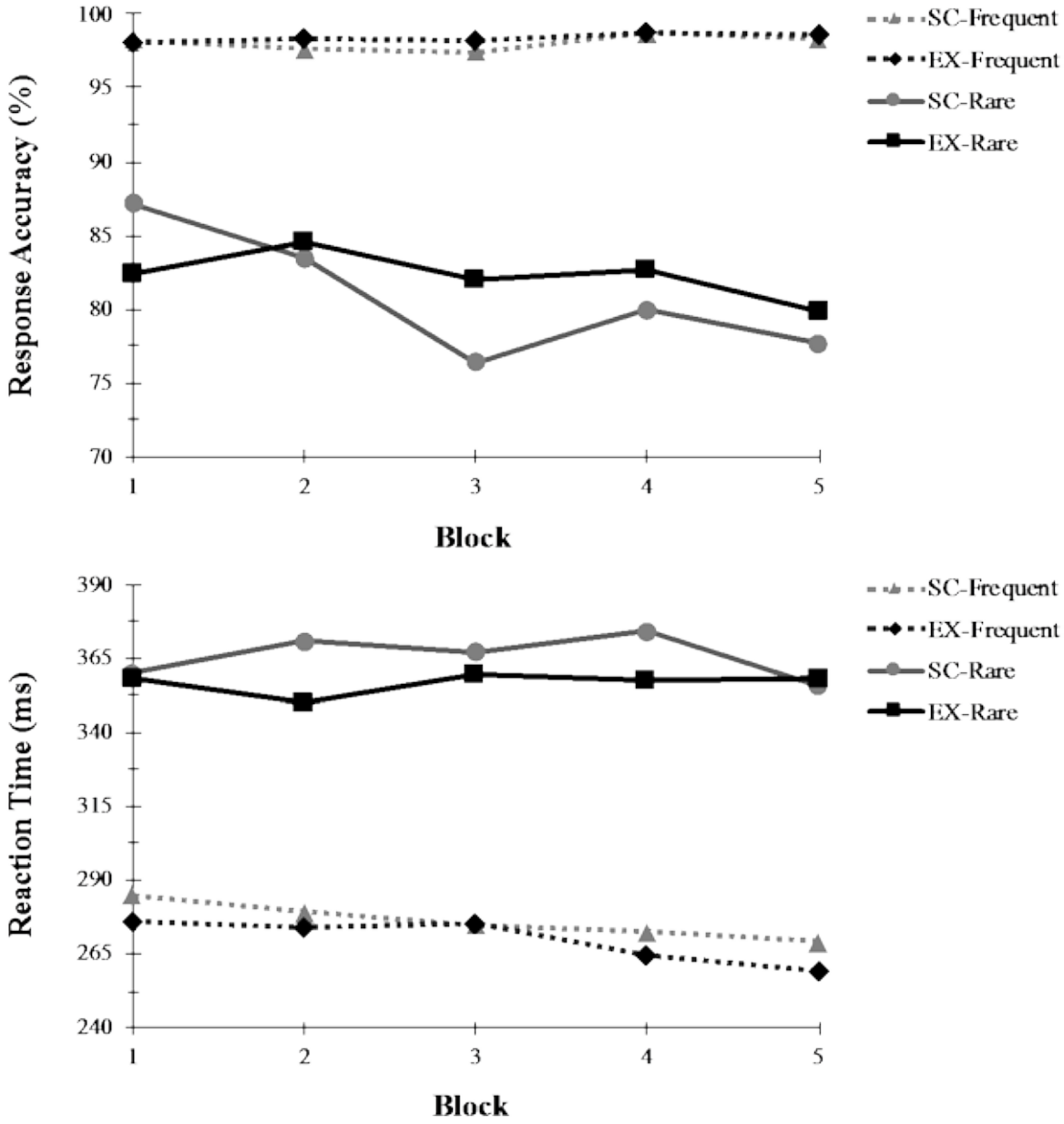

Figure 3. Response accuracy (top) and reaction time (bottom) performance on the oddball paradigm during blocks 1, 2, 3, 5, and 5 for EX (black lines) and SC (grey lines) conditions

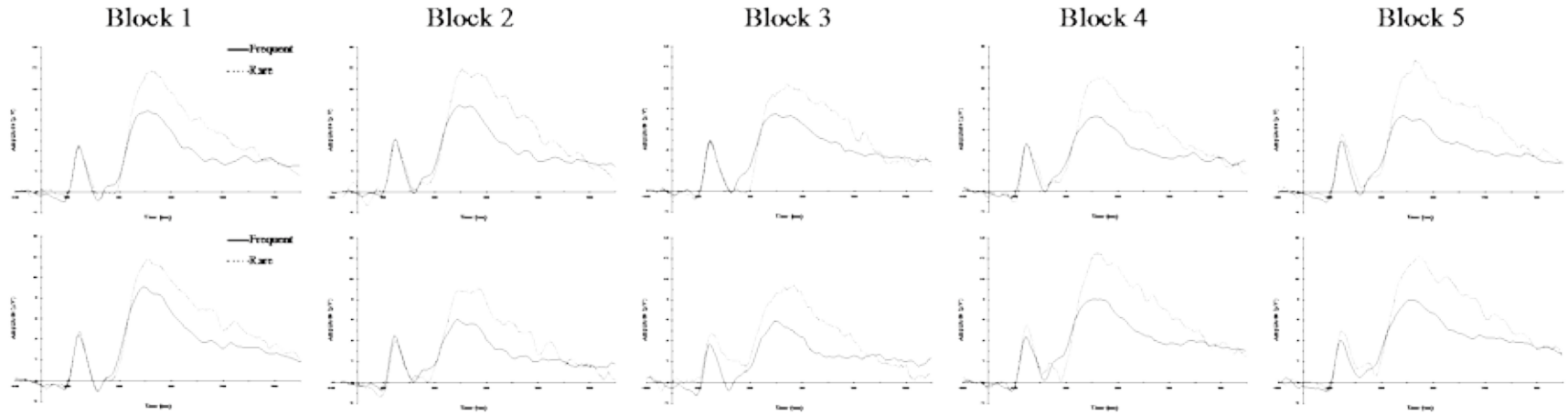

Figure 4. Grand average P3 waveforms averaged across centro-parietal electrode sites (Cz, CP1, CP2, Pz) assessed during blocks 1, 2, 3, 4, and 5 for SC (top) and EX (bottom) conditions.

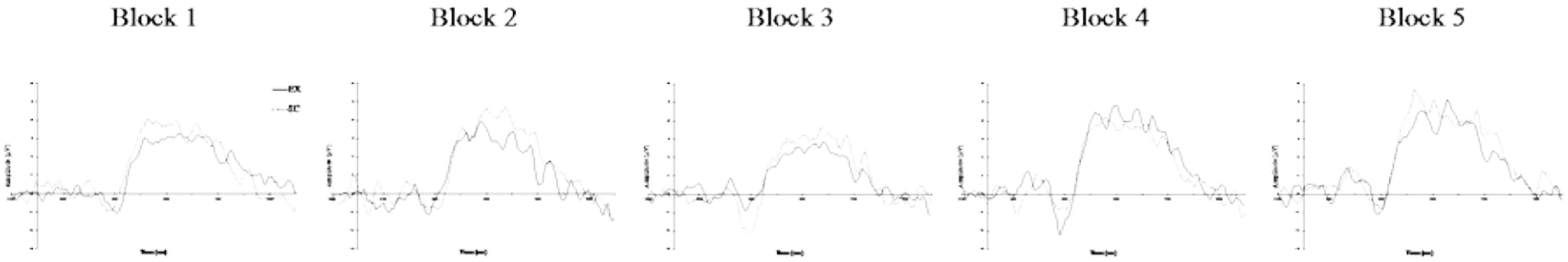

Figure 5. Grand average P3 difference waveforms (rare minus frequent stimuli) averaged across centro-parietal electrode sites (Cz, CP1, CP2, Pz) assessed during blocks 1, 2, 3, 4, and 5 for EX (black line) and SC (grey line) conditions.

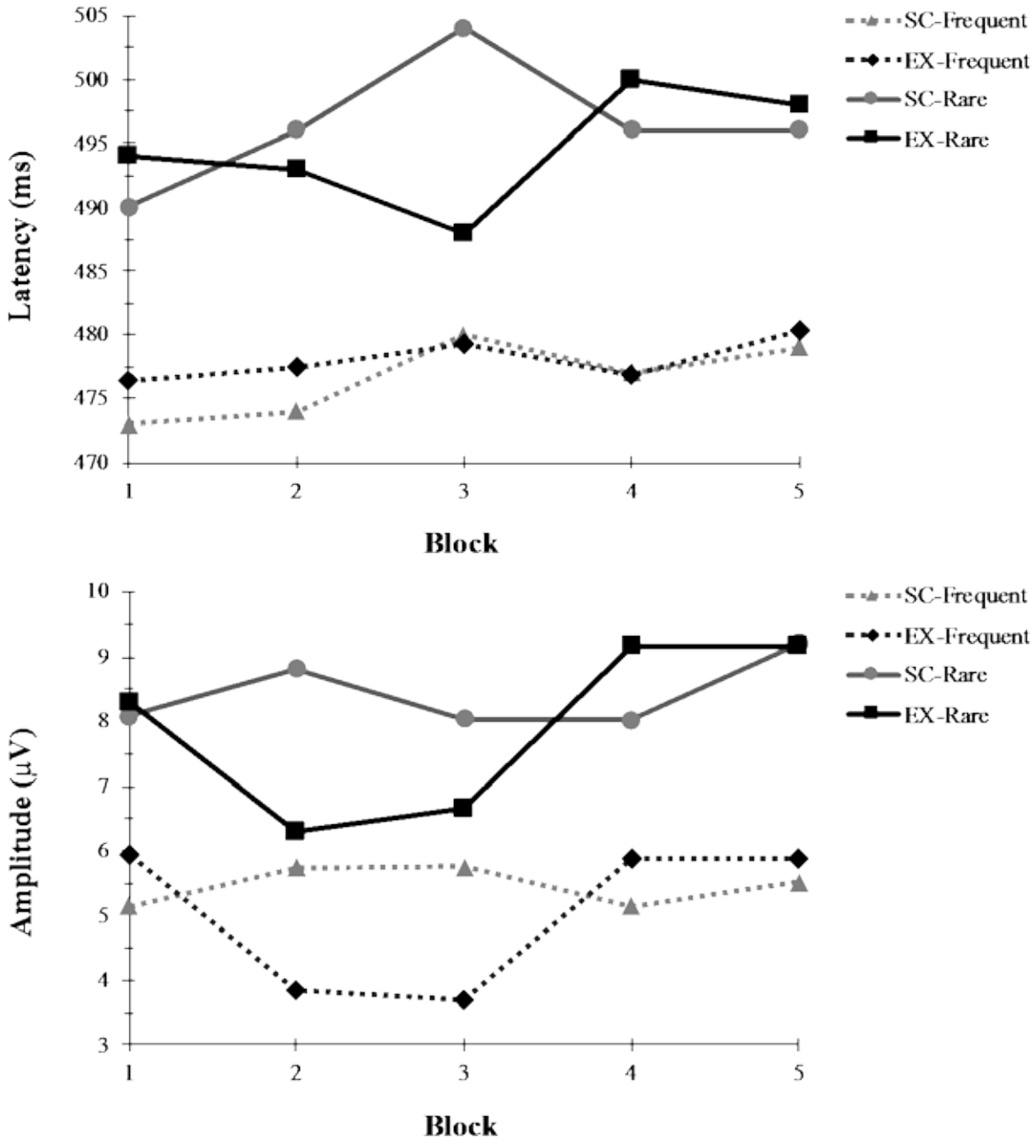

Figure 6. P3 latency (top) and P3 amplitude (bottom) performance on the oddball paradigm during blocks 1, 2, 3, 5, and 5 for EX (black lines) and SC (grey lines) condition

APPENDIX A

INFORMED CONSENT

University of North Texas Institutional Review Board

Informed Consent Form

Before agreeing to participate in this research study, it is important that you read and understand the following explanation of the purpose, benefits and risks of the study, and how it will be conducted. Please read this document carefully and sign the final page if you understand it and agree to participate.

If at any time you have questions regarding any of the information on this form, please ask a member for the research team. When all of your questions have been answered, you will be asked to sign this consent form if you agree to be in the study. A copy of the form will be given to you to keep for your records.

Participation is this study is voluntary and you may withdraw at any time without penalty.

Title of Study: Effects of Acute Aerobic Exercise on Neurocognitive Function

Investigators: Ryan L Olson, PhD and David J. Cleveland; University of North Texas (UNT) Department of Kinesiology, Health Promotion, and Recreation (KHPR).

Purpose of the Study: To examine the effects of acute low-intensity cycling on neurocognitive function in college-aged students.

Study Procedures: The total anticipated time commitment for this study is approximately 3 hours over 3 sessions (180 minutes). There will be a screening and familiarization session (30 minutes) followed by two follow-up experimental sessions (75 minutes each). Each session will occur at approximately the same time of day separated by 48 hours.

Screening, Questionnaires, and Familiarization (Session 1): You will be asked to read and sign this informed consent form. Upon the completion of this form, you will be asked to complete several questionnaires related to your physical and mental health. These questionnaires are given to ensure that you have no pre-existing medical conditions that may prevent you from participating in exercise. The screening and questionnaires will take approximately 15 minutes to complete. You will then be fitted with an electroencephalography (EEG) cap and familiarized with the recumbent bike, EEG recording chamber, and cognitive tasks. The cap fitting and familiarization will last approximately 15 minutes.

Exercise and Seated Rest (Sessions 2 and 3): Following session 1, you will be randomly assigned to complete both an exercise and seated rest session. Each session will last approximately 75 minutes with 15 minutes for preparation, 50 minutes of testing,

and 10 minutes for cleanup. After confirming eligibility via a daily screening questionnaire, you will be fitted with a Polar heart rate (HR) monitor and EEG cap. You will then be moved to the recumbent bike located in the EEG recording chamber. Following a 10-minute rest period, you will be asked to complete 20 minutes of low-intensity exercise or 20 minutes of seated rest, followed by a 20-minute recovery period. During the exercise session, you will be pedaling at a self-selected pace while resistance is adjusted to maintain low-intensity based on HR responses and individual ratings of perceived exertion (RPE). Throughout the 50-minute test period, you will be completing several blocks of cognitive testing while EEG data is being recorded. You will then be debriefed on the purpose of the study upon completion of both sessions.

Foreseeable Risks: Trained personnel with appropriate supervision will perform all test procedures, and all attempts will be made to minimize any risks associated with your participation in this study.

SCREENING AND QUESTIONNAIRES: The assessment questionnaires may be stressful for some people. A small portion of individuals may experience increased emotional discomfort as they discuss or think about past or present problems during the assessments. A trained professional will be available for consultation should discomfort become too difficult (see resources below).

- UNT Student Health and Wellness Center: 940-565-2333
- UNT Counseling Center: 940-565-2741
- Denton County MHMR Crisis Line: 1-800-762-0157 (open 24 hours a day)
- National Suicide Prevention Hotline: 1-800-273-8255 (open 24 hours a day)

ELECTROENCEPHALOGRAPHY (EEG): Brain activity will be monitored during cognitive testing using non-invasive electrodes attached to a fitted cap. You will be asked to remain still and relaxed throughout the full testing period. This technique is not known to be harmful; however, the rare and minor risks associated with participating in this research include possible skin irritation from the electrolyte paste or the adhesive discs used to place electrodes on the skin, discomfort associated from sitting still in one position, and discomfort due to having electrolyte gel in the hair. You will be allowed to remove the electrodes and adhesive discs, change sitting position, or terminate the experiment and remove gel from your hair if any discomfort is reported. Additionally, in rare cases (<1%), specific diagnostic testing where EEG is recorded has been shown to cause epileptic seizures; however, this is not expected to occur with the cognitive tasks you will be completing as a part of your participation in this study.

EXERCISE: Risks associated with exercise or fitness testing may include increased heart and breathing rate, elevated blood pressure, muscle fatigue, dizziness, musculoskeletal injuries, and possible muscle soreness lasting 24-48 hours post exercise. Trained investigators will take all precautions necessary to minimize any adverse side effects. The PI will oversee these procedures and ensure that investigators are adequately trained. If at any time during the testing procedure

abnormal heart rate is observed, testing will be terminated immediately. In the event of an emergency, trained personnel will use CPR or AED and 911 will be contacted.

Benefits to the Subjects or Others: This study is not expected to be of any direct benefit to you; however, indirect benefits may include: 1) information regarding your physical and mental health based on questionnaire responses and 2) data may improve our current understanding of the relationship between exercise and cognition.

Compensation for Participants: Upon successful completion of the study, participants will be entered into a raffle to win a $50 gift card (2 winners). The raffle will take place on the day following the final test session or at the end of the spring semester (whichever comes first). The gift card winner will be notified via email within 48 hours of the raffle. You will not be entered into the raffle if you choose to withdraw before study completion. Additionally, extra credit will be offered in select classes. A non-research alternative that is equal to the time and duration of this study will be offered to those students who do not wish to participate.

Procedures for Maintaining Confidentiality of Research Records: This research is confidential. The research records will include some information about you, which will be stored in such a manner that some linkage between your identity and the response in the research exists. Some of the information collected about you includes psychological and physiological data. Please note that we will keep this information confidential by assigning you an ID code, limiting individual's access to the research data, and keeping all data in a secure location.

The research team and the Institutional Review Board at UNT (a committee that reviews research studies in order to protect research participants) are the only parties that will be allowed to see your data, except as may be required by law. If a report of this study is published, or the results are presented at a professional conference, only group results will be stated. All study data will be kept in a secure location for at least five years, at which point any files that link your ID code to your name will be destroyed.

Additionally, we may ask you to provide names or contact information of other potential research subjects. You may decline to provide this information; however, confidentiality will be maintained if you choose to provide research staff with this information.

Questions about the Study: If you have any questions about the study, you may contact Dr. Ryan L. Olson at Ryan.Olson@unt.edu or (940) 565-3417.

Review for the Protection of Participants: This research study has been reviewed and approved by the UNT Institutional Review Board (IRB). The UNT IRB can be contacted at (940) 565-4643 with any questions regarding the rights of research subjects.

Research Participants' Rights: Your signature below indicates that you have read or have had read to you all of the above and that you confirm all of the following:

- Ryan L. Olson, PhD or another trained member of the research team has explained the study to you and answered all of your questions.
- You have been informed of the possible benefits and the potential risks and/or discomforts of the study.
- You understand that participation is voluntary, and your refusal to participate or your decision to withdraw will involve no penalty or loss of rights or benefits.
- The study personnel may choose to stop your participation at any time.
- You understand why the study is being conducted and how it will be performed.
- You understand your rights as a research participant and you voluntarily consent to participate in this study.
- You have been told you will receive a copy of this form.

_____	_____	_____
Printed Name of Participant	Signature of Participant	Date

For the Investigator or Designee: I certify that I have reviewed the contents of this form with the subject signing above. I have explained the possible benefits and the potential risks and/or discomforts of the study. It is my opinion that the participant understood the explanation.

_____	_____
Signature of Investigator or Designee	Date

APPENDIX B

RECRUITMENT EMAIL AND FLYER

Hello,

You are receiving this email because you signed a form saying you are interested in more information regarding the Effects of acute low-intensity exercise on neurocognitive function study. This study will be looking at the effects of acute low-intensity exercise on neurocognitive function. We will be using EEG and questionnaires to look at these effects. There will be 3 sessions you will need to come in for. The first will be a familiarization session where we will give you an informed consent and some other questionnaires, as well as get you fitted for an EEG cap and where you seat will be on the recumbent bike. At the end of this, we will administer a maximal aerobic fitness test on a bike. The next two sessions will be counterbalanced between a control and exercise trial. You will be on the recumbent bike for 40 minutes in both sessions. In both sessions, you will have a 10-minute rest and 10-minute recovery period at the beginning and end of the session. In the exercise trial, you will be peddling at a self-selected pace, while resistance is adjusted to stay in a low-intensity range based off of HR and rating of perceived exertion (RPE), for the middle 20 minutes, while in the control trial you will be just sitting on the bike. Throughout the rest, exercise/control, and recovery periods you will be completing a block of neurocognitive testing every 5 minutes.

There is little risk to this study as we will be using a low-intensity exercise protocol and you will be filling out a physical activity readiness questionnaire during the familiarization trial. Upon successful completion of the study, participants will be entered into a raffle to win a $50 gift card (2 winners). The raffle will take place on the day following the final test session. The gift card winner will be notified via email within 48 hours of the raffle. All of your records will be kept confidential using participant numbers.

Below is a link to sign up for the study.
(LINK)
Please feel free to respond with any questions.

Best regards,

David

David Cleveland
Kinesiology M.S. Student
UNT Psychophysiology Lab

This project has been reviewed and approved by the UNT Institutional Review Board (IRB)

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