THE EFFECT OF COMBINED PHYSICAL AND MENTAL EXERTION PRIOR TO USING DETECT, A NOVEL NEUROPSYCHOLOGICAL TEST BATTERY

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THE EFFECT OF COMBINED PHYSICAL AND MENTAL EXERTION PRIOR TO USING DETECT, A NOVEL NEUROPSYCHOLOGICAL TEST BATTERY

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LIST OF SYMBOLS AND ABBREVIATIONS

mTBI	Mild Traumatic Brain Injury
TBI	Traumatic Brain Injury
DETECT	Display Enhanced Testing for Cognitive Impairment and TBI
CPT	Continuous Performance Task
RPE	Rating of Perceived Exertion

ABSTRACT

The purpose of this intervention study is to identify the effect of physical and mental exertion on neuropsychological assessments using the neuropsychological DETECT test in healthy, moderately fit, college-aged students. Four test conditions were completed by each subject: 1) effects of mental exertion (reduced sustained attention) on DETECT scores; 2) effects of physical exertion (submaximal cycling) on DETECT; 3) effects of physical and mental exertion on DETECT; and 4) controlled rest effect on DETECT. Mental exertion was induced by a Continuous Performance Task over the course of 20 minutes, and physical exertion was induced by a stationary bicycle with settings based on a prior submaximal graded exercise of each subject. The goal of this study was to identify the individual and combined effects of mental exertion and physical exertion on neuropsychological performance. Mental exertion produced a significant overall decreased performance on DETECT, physical exertion produced an even higher decrease, and the combined exertion had a decrease in performance comparable to that of mental exertion alone. The finding might be useful in adjusting baseline scores of neuropsychological assessments based on the task done prior to taking the test.

INTRODUCTION

In collision sports such as American football, mild traumatic brain injuries (mTBI) such as concussions are very common; the Center for Disease Control estimates that there are more than 3 million cases in the US every year. (Faul, Xu, Wald, & Coronado, 2010) Despite its frequency, there is no “gold standard” for mTBI assessment, due to a lack of complete understanding on its physiological causes and complexity.

In many cases of sports related mTBI, an assessment test is taken by a player immediately following a suspected concussion is after an intense period of focus and exercise to determine return to play. At the time of the test, the player could be physically fatigued, mentally fatigued, or both. It has been shown that light exercise has a significant negative effect on cognition, while more intense exercise has a small positive effect (Chang, Labban, Gapin, & Etnier, 2012). It has also been shown that mental fatigue has a negative effect on attention (Boksem, Meijman, & Lorist, 2005). However, these factors have never been tested for their combined effects on the scores of mTBI screening tests. Baseline tests, furthermore, are typically taken when a player is rested and not immediately following the excitement and exertion of game play.

The purpose of this study was to analyze the effect of physical and mental exertion on neuropsychological assessments using the Display Enhanced Testing for Cognitive Impairment and Traumatic Brain Injury (DETECT) system. (Barker et al., 2007; Wright et al., 2010; Wright et al., 2011) It is a cognitive test developed to assess cognitive deficits associated with concussion and other neurological problems that may result in cognitive problems. For this study, reaction time and accuracy were evaluated to determine whether or not a significant change will occur in a cognitive test due to physical, mental and combined exertion.

This study can potentially gain insight into factors which might influence the use of DETECT when evaluating athletes on the sideline during practice or game setting. It is necessary to measure the effects of these variables so that deviation from the individual's true baseline can be detected if present. Proper postconcussion procedures can then be followed to limit long term cognitive damage to the player.

LITERATURE REVIEW

Currently in concussion screening technology, there are many screening tools available such as the Neurobehavioral Cognitive Status Examination (NCSE), the Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT), the King-Devick test, the Sport Concussion Assessment Tool 2 (SCAT2) among others. (Blostein, Jones, Buechler, & Vandongen, 1997; Bruce, Echemendia, Meeuwisse, Comper, & Sisco, 2014; M. S. Galetta et al., 2013) However, all these tests are designed to be taken in a controlled environment with minimal distractions. In sports, this means that players need to be taken out of the game in order to be screened for concussions, making these tests both time consuming and potentially unpopular with players. DETECT is a neuropsychological test that includes a headset to block out both noise and light, which allows usage directly on the sidelines of games. However, this exposes the test to the effects of potential prior physical and mental exertion occurring during sports.

Much of the research to date on mTBI screening methods are validation experiments and test-retest reliability experiments, where the sensitivity of a test or the effect of time between tests on baseline results of an individual are evaluated. (K. M. Galetta et al., 2011) The interval of the test-retest can range from a year to a couple of days. (Bruce et al., 2014; Little et al., 2015) There have been other studies examining different factors such as the effect of age (Blostein et al., 1997), sleep (Sufrinko, Johnson, & Henry, 2015), and medication (Yengo-Kahn & Solomon, 2015) on the baseline score.

The factors most relevant to the current study are physical and mental exertion, which have been looked at separately against cognitive tests. It has been shown that light

exercise has a significant negative effect on cognition, while more intense exercise has a small positive effect (Chang et al., 2012). It has also been shown that mental fatigue has a negative effect on attention (Boksem et al., 2005). Other studies have looked at the impact of mental fatigue on exercise, and cited that the combination produces an altered perception of effort and participants reported higher levels of fatigue.

This study aims to examine the effects of sub maximal physical and mental exertion on the baseline of cognitive testing, both in conjunction to each other and individually.

METHODS AND PROCEDURES

Study Design:

This is an intervention study designed to quantify the effects of mental and physical exertion prior to DETECT, a neuropsychological assessment, both separately and in tandem. A total of 15 healthy and moderately fit Georgia Tech students age 18 or over participated in this study. Each subject undertook the following procedures in this set order: 1) initial consent and self-reported medical screening; 2) submaximal graded exercise; 3) resting protocol; 4) mental exertion protocol; 5) physical exertion protocol; 6) mental and physical exertion protocol. The subjects were scheduled to complete each of the 4 protocols with an interval of 1 week, as shown in Figure 1. They were also asked to maintain a good sleeping pattern while avoiding vigorous physical activity, caffeinated products, and alcohol consumption 24 hours prior to each of the sessions. This study was approved by the Georgia Institute of Technology Institution Review Board.

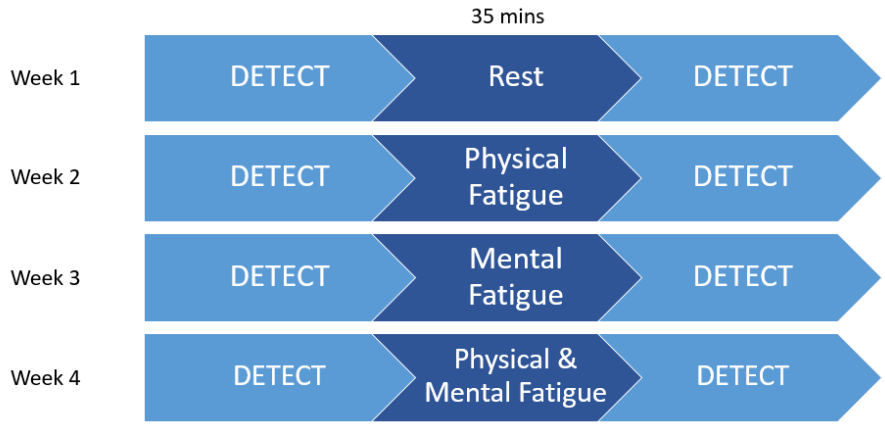

Figure 1: Study Design. Repeated measures study with the 4 treatments of rest, physical exertion, mental exertion, and combined physical and mental exertion. The sessions were scheduled at 1 week intervals and all subjects (n=15) were asked to take DETECT prior to and following each treatment.

Subject Enrollment:

15 students were enrolled to allow for up to 20% attrition. Interested students were enrolled if they consented to study participation, and met subject inclusion criteria: 1) Age 18 or over. 2) Current Georgia Institute of Technology student. 3) Exercise at least twice per week for more than 15 minutes per session. 4) Be able to use a stationary exercise bicycle correctly.

Subject Screening:

Prior to enrollment in this study, potential participants were screened using a screening questionnaire. The exclusion criteria included: 1) Screening positive for 6-month history of concussion, learning disabilities, or use of mind altering medication or other substances. 2) Suffered TBI or head/neck injury that resulted in cognitive abnormalities at some time. 3) Prior and/or current participation in collision sports. 4) Participants with any of the following: asthma, bronchitis, emphysema, pneumonia, sickle cell, HIV, cancer, diabetes, heat stroke/exhaustion, metal implants in body,

multiple sclerosis, heart disease, untreated high/low blood pressure, history of stroke or seizure, heart attack, extra/skipped heart beats, epilepsy, attention deficit disorder, untreated cataracts, untreated glaucoma, muscular degeneration, obesity, sensory deficits in hands or legs, neurological disease, arthritis, cardiovascular disease, any fractures in the hands or legs within the past two years, or pregnant women. 5) Currently under care of doctor for related conditions.

Prior medical history and current medication use were recorded as potential confounders. Those who screened positive for any of these conditions were not eligible to participate in this study. Participants who suffer a concussion or is diagnosed with a cognitive impairment within the time the study is conducted had their data withdrawn from the statistical analysis.

Materials:

DETECT

DETECT is comprised of 8 tests: 1) Simple Choice Reaction Time, in which a solid gray shape is displayed and the subjects must remember the shape and then different shapes are displayed and the correct shape must be selected with 'yes' and incorrect shapes with 'no'. This test serves as an effort test. 2) Complex Choice Reaction Time, in which a colored shape is displayed with crosshatches in a particular orientation, then different colored shapes with different cross hatch directions appear. The subject selects the correct shape with 'yes' and each incorrect shape with 'no'. 3) Arrows, in which either a red or a blue arrow appears. The subject chooses the button on the side the arrow is pointing to for a blue arrow and the button on the opposite side for a red arrow. 4) Initial Word Recall, in which a list of 12 words is displayed one at a time and the subject is

asked to remember the words. Then 24 words are displayed one at a time and the subject selects 'yes' for a word in the original list and 'no' for a word that was not in the original list. 5) N-Back1, in which faces are displayed one at a time and the subject must indicate 'yes' if the face shown is the same as the previous or 'no' if it is not. 6) N-Back2, in which faces are displayed one at a time and the subject must indicate 'yes' if the face shown is the same as two faces previous or 'no' if it is not. 7) Second Word Recall, in which the Initial Word Recall is repeated for the words the subject did not remember. 8) Delayed Word Recall, in which the Initial Word Recall is repeated. This is the last test and is separated from the Initial and Second Word Recall tests by several tests. Each answer is reported by reaction time and percent correct, including incorrect/correct status or true positive/true negative/false positive/false negative status for each entry.

Figure 2. The Display Enhanced Testing for Cognitive Impairment and TBI (DETECT) is a neurophysiological assessment tool with 8 subtests. It is comprised of a headset, headphones and a controller with two main buttons for answering prompts.

CPT

A version of the Continuous Performance Task (CPT) programmed and presented with MATLAB® v2012 (MathWorks, Natick, MA, USA), a cognitive test requiring sustained attention, working memory, response inhibition and error monitoring. (Carter et al., 1998) This task has been used in other studies (Braver et al., 2001; Marcora, Staiano, & Manning, 2009; van der Linden, Massar, Schellekens, Ellenbroek, & Verkes, 2006) to induce mental fatigue with a test-retest reliability of 0.826. (Carter et al., 1998) The CPT is associated with significant activation in the anterior cingulate cortex, an area of the brain that is affected by mental fatigue. (Carter et al., 1998) For the custom programmed CPT in the present study, a series of letters were visually presented in the middle of a computer screen for 0.6 s and participants were instructed to click the mouse upon seeing the target letter 'T'. Participants were specifically instructed to be as accurate as possible in their response and that they would not be judged on speed of their response. The CPT and order of letter presentation was fixed and identical across all trials and the remaining letters of the alphabet served as non-target probes. Attention was required to click on target letters while inhibiting response to non-targets. Letters were 1.5 in. in height and appeared in white capital font on a black background at a rate of 1.67 Hz or 100 letters/min. Each 5 min epoch consisted of 500 letters, 127 target letter 'T's of which 59 were preceded by a bait letter 'S', and 373 non-targets of which 14 were preceded by the bait letter 'S'. (Kumar, Wheaton, Snow, & Millard-Stafford, 2016)

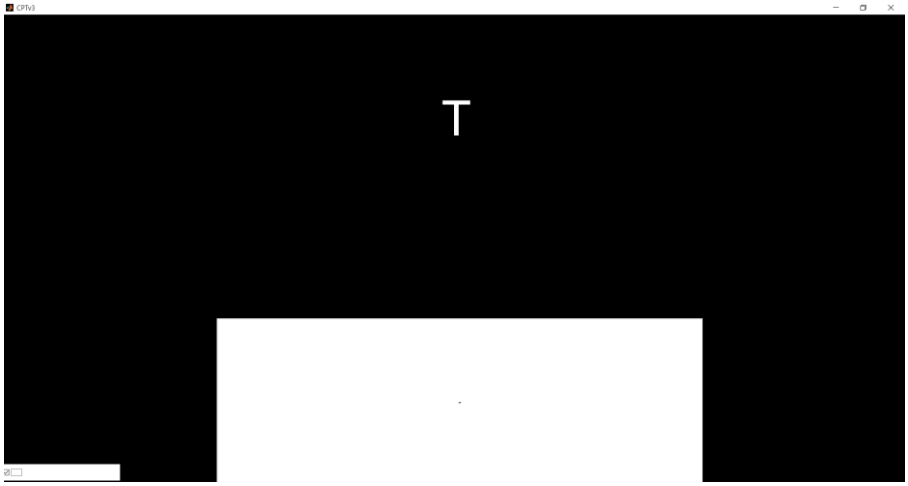

Figure 3. The Continuous Performance Task (CPT) is run using Matlab to stimulate mental exertion.

Protocol:

Submaximal Graded Exercise

During the first session, all subjects signed the consent form and completed the screening questionnaire. Then they were asked to perform the resting protocol to completion before using the ergometer for a submaximal exercise session to match resistance levels on the ergometer to their perceived exertion. The perceived exertion of each subject was self-reported using the Borg RPE Scale every 2 minutes. (Borg, 1990) The low and high perceptual anchors for the Borg's RPE scale were established during the maximal exercise test. A rating of 6 (low anchor, "very, very light, as if lying in bed") was assigned to the lowest exercise intensity, while a rating of 20 (high anchor, "very, very hard, the hardest thing you've ever done") was assigned to the highest exercise intensity. RPE values were recorded during the last 10s of each 2 minute interval. Subjects were asked to keep their speed on the ergometer at a steady 50 RPM in order to keep the watts constant. The test started with 1 kilopond of workload resistance and

increased in intervals of .5 kilopond every 2 minutes until a RPE of 17 or 18 was reached. All tests were performed between 8 to 12 minutes.

Resting Protocol

Subjects were instructed to take DETECT before and after a 35 minute session of rest. For the resting period, subjects remained seated and could either take a nap or do some light reading.

Mental Exertion Protocol

Subjects were instructed to take DETECT before and after a 35 minute session of CPT while sitting on the ergometer. This version of the continuous performance test was programmed and presented in Matlab. A monitor screen and a wireless controller were used for the 35 minutes test.

Physical Exertion Protocol

Subjects were instructed to take DETECT before and after a 35 minute session of using the Monark 828E Ergometer Test Cycle. The perceived exertion of each subject was again self-reported using the Borg RPE Scale, however this time at 1 minute intervals. Again, the low and high perceptual anchors for the Borg's RPE scale were established prior to the protocol. Heart rate was also monitored using the Polar T31 T34 Non-Coded Chest Transmitter and Elastic Strap with the Polar FT2 Activity Tracker, and recorded at 1 minute intervals as well. Each subject began the exercise session with a 5 minute warmup at 1 kilopond. For the following 25 minutes, the resistance on the

ergometer alternated every 5 minutes between the resistances corresponding to the subject's self-reported RPE scores of 10 and 15, starting with the 10 RPE resistance level. 30 minutes into the study, the resistance is again lowered to 1 kilopond for a 5 minute cool down period.

Mental and Physical Exertion Protocol

Subjects were instructed to take DETECT before and after a 35 minute session of using the CPT in conjunction with the ergometer. While the subject was performing the physical exertion protocol with the 5 minutes of warmup, 25 minutes of alternating resistances, and 5 minutes of cool down, they were also performing the mental exertion protocol at the same time. The low and high perceptual anchors for the Borg's RPE scale were established before reading the entire scale was read aloud to the subject. Borg's scale was read aloud every time the subject requested during the protocol to not distract from the CPT. The subject's RPM was also closely monitored and a verbal reminder to speed up or slow down was given.

Statistical Methods:

A Bayesian repeated measures ANOVA was performed to look at the differences between the differences of the after treatment and before treatment DETECT scores. The repeated measures ANOVA was performed as a two way additive without interaction ANOVA with the independent variables being the 4 different treatments and the 13 subjects, and the dependent variables being the accuracy and response time from the DETECT score. The model is additive without interaction because of the assumption that the subjects and treatments are independent from one another. All analyses were

conducted using Winbugs with a burn-in of 1000 and 10000 simulations for the posteriors. (Lunn, Thomas, Best, & Spiegelhalter) Sum-to-zero constraints were used along with noninformative priors on the effect size for both the treatments and the subjects.

RESULTS

Accuracy:

From the analysis of the accuracy portion of the DETECT scores, all the treatments decreased the accuracy of scores significantly when compared to the control. Physical exertion produced the biggest difference on DETECT scores when compared to the scores of the control. Mental exertion and combined exertion both produced smaller differences on the DETECT scores following treatments.

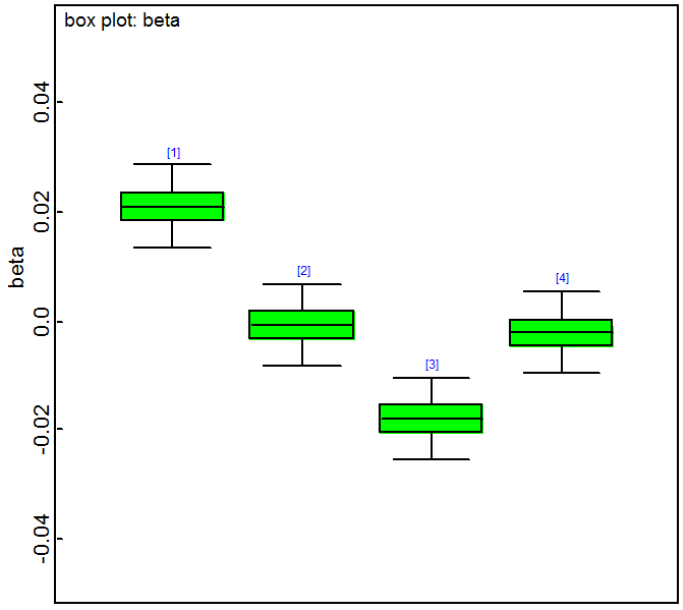

Figure 4. Effect sizes of accuracy for treatments. The effect size of the different treatments when compared to the control: [1] is the control, [2] is mental exertion with a mean effect size of 0.0217 compared to the control, [3] is physical exertion with a mean effect size of 0.0390 compared to the control, and [4] is the combined exertion with a mean effect size of 0.0232.

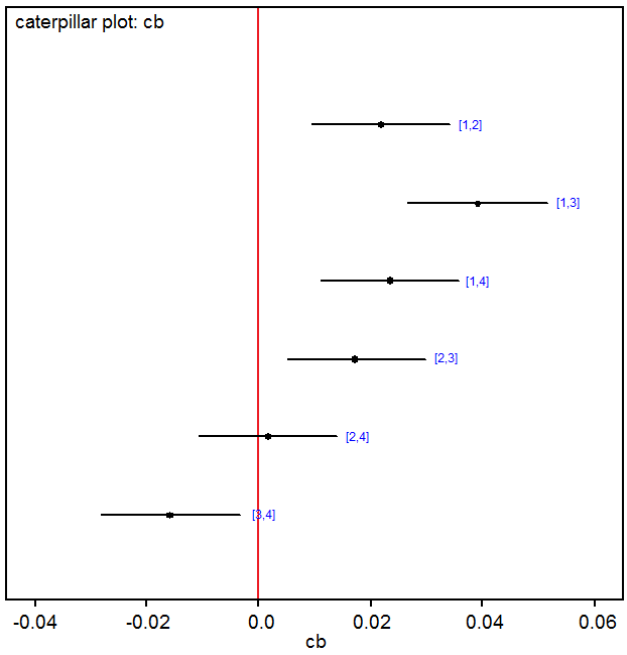

Figure 5. 95% credible sets of comparisons between treatments for accuracy. The caterpillar plot shows the 95% credible sets of the comparison between the accuracies of different treatments. [1] denotes the control treatment, [2] is the mental exertion treatment, [3] is the physical exertion treatment and [4] is the combination treatment. The first 3 bars show the credible sets of the comparisons between the control and the rest of the treatments. Since the bars are not intersected by 0, they are considered significantly different. The only comparison that was not significantly different was between mental exertion and combined exertion.

Response Time:

From the analysis of the response time portion of the DETECT scores measured in milliseconds, all the treatments significantly increased the response time when compared to the control. Physical exertion produced the biggest difference on DETECT scores when compared to the scores of the control again. Mental exertion produced the next biggest difference and combined exertion produced smaller differences on the DETECT scores following treatments.

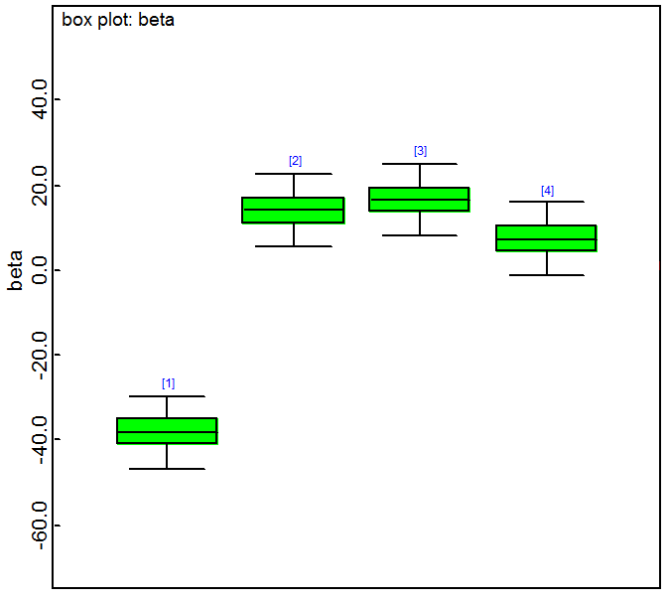

Figure 6. Effect sizes of reaction time for treatments. The effect size of reaction time of the different treatments when compared to the control: [1] is the control, [2] is mental exertion with a mean effect size of 51.95 compared to the control, [3] is physical exertion with a mean effect size of 54.73 compared to the control, and [4] is the combined exertion with a mean effect size of 45.56.

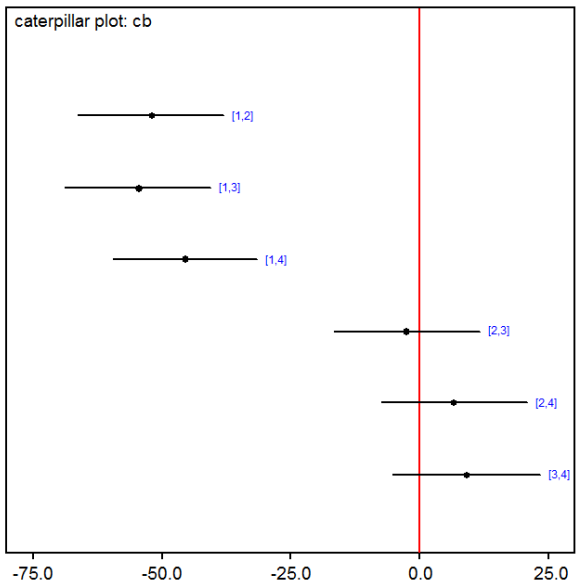

Figure 7. 95% credible sets of comparisons between treatments for response time. The caterpillar plot shows the 95% credible sets of the response time comparison between the different treatments. [1] denotes the control treatment, [2] is the mental exertion treatment, [3] is the physical exertion treatment and [4] is the combination treatment. The first 3 bars show the credible sets of the comparisons between the control and the rest of the treatments. Since the bars are not intersected by 0, they are considered significantly different. None of the other comparisons of reaction time between the exertion treatments were significantly different.

DISCUSSION

The results from this experiment did not match what was expected from prior literature. In prior literature, physical exertion caused a small increase in cognitive task scores. (Chang et al., 2012) Mental exertion was shown to have the oppose effect, causing a small decrease in cognitive task scores. (Boksem et al., 2005) Due to these it was hypothesized that with the combination exertion, effects of each exertion would cancel the other out and would produce no effect overall.

From the results, mental exertion did produce an overall decreased performance on DETECT: there was a decrease in accuracy and increase in reaction time when compared to the control. However, in the experiment conducted, the results showed that physical exertion actually lead to an even larger overall decreased performance on DETECT: there was a larger decrease in the accuracy of DETECT scores and higher increase on the reaction time. This was surprising since physical exertion was supposed to lead to slightly better accuracy. A possible reason for the low scores on DETECT is that the subjects were exhausted during the bout of exercise. (Fery, Ferry, Vom Hofe, & Rieu, 1997)

Finally, the combined mental and physical exertion produced a similar decrease in performance on DETECT comparable to that of the mental exertion alone. This was surprising since it indicated that the combined effects of physical and mental exertion were not just a simple combination of the effects of each. The results showed that when physical and mental exertion are combined, the accuracy of DETECT was decreased to the same level as mental exertion alone. The reaction time was impacted at a comparable degree to that of either mental or physical exertion alone.

CONCLUSION

In conclusion, this study led to some interesting results that can help determine adjustment scores for the baseline of DETECT based on the presence of mental and/or physical exertion prior to taking the test. Future work include examining if there was a learning effect through the study that might have made scores better as the experiment went on. The impact of the individual subtests within DETECT should also be looked at since it is likely that not all subtests were impacted equally by each treatment. If a follow up experiment could be conducted, it would be interesting to have varying levels of mental and physical exertion instead of one level for each.

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