EFFECTS OF WALKING VERSUS COMPLETING A NEUROCOGNITIVE TASK, ON END-TIDAL CARBON DIOXIDE AFTER CONCUSSION – A PILOT STUDY

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This study examined differences between healthy and concussed participants when performing a neuropsychological and physical task on measures of end-tidal carbon dioxide ($ETCO_2$). Twenty-two participants (17 healthy; 5 concussed) completed the Immediate Post-Concussion Assessment and Cognitive Test (ImPACT) battery and walked on a treadmill at two walking speeds. A CapnoTrainer© measured $ETCO_2$ during the tasks. Statistically significant main effects were observed for task ($F(1,20)=5.332$, $p<0.032$; $F(2,38)=52.305$, $p<0.001$) and group ($F(1,20)=14.388$, $p<0.001$; $F(1,19)=8.283$, $p<0.01$) in $ETCO_2$ during the cognitive and physical tasks, respectively. Abnormal $ETCO_2$ levels may occur after concussion, therefore, future investigations are warranted.

KEY WORDS: Physical task, respiration, persistent-concussion symptoms

INTRODUCTION: Approximately 95% of all sport-related head injuries reported in Canada, between 2015 and 2016, were concussion (Canadian Institute for Health Information, 2017). A concussion can be described as a complex pathophysiological process that temporarily disturbs brain function (McCrory et al., 2017). A violent direct or indirect impact to the head can result in linear and/or rotational forces causing neural and/or vascular tissue damage. Although the majority of sport-related concussions spontaneously resolve within 2 weeks, 10% of individuals may still experience persistent symptomatology (Leddy, Sandhu, Sodhi, Baker, & Willer, 2012). In these cases, individuals are diagnosed with persistent-concussion symptoms (PCS). Prescribing treatment for PCS can be challenging as there is no universal treatment for concussion due to the uniqueness of each injury. This makes identifying symptomatology vital, as it allows the selection of the most beneficial treatment for patients.
There are vast signs and symptoms that an individual who has sustained a concussion may experience. Neurocognitive deficits are among the most common and there is no shortage of literature that has observed individuals who sustained a concussion having worse performance in concentration, reaction time, or processing speed, compared with non-concussed individuals (McClincy, Lovell, Pardini, Collins, & Spore, 2006). Other common complaints are physiological deficits, which can include changes to cardiovascular (i.e., increased heart rate), vestibular-ocular (i.e., balance and gait), and cardiorespiratory (i.e., elevated end-tidal carbon dioxide) systems (Clausen, Pendergast, Willer, & Leddy, 2016; Fino, Nussbaum, & Brolinson, 2016; Temme, Onge, & Bleiberg, 2016). Research examining the cardiorespiratory deficits, however, is still novel in concussion research. The link between breathing and concussion may be an important area to examine. Individuals who sustain more severe brain injuries have been observed to spontaneously hyperventilate (rapid breathing; Go & Singh, 2013). Furthermore, altered cerebral blood flow is often accompanied with a concussion (Giza & Hovda, 2001). Thomson, Adams, and Cowans (1997) stated that depressed end-tidal carbon dioxide ($ETCO_2$; the peak carbon dioxide at the end of an exhaled breath), which represents alveolar carbon dioxide, can also reduce blood flow to the brain and negatively affect various physiological and psychological processes. Clausen et al. (2016) reported that female athletes with PCS can have elevated $ETCO_2$ during progressive aerobic exercise on a stationary bike compared with a control group. More interestingly, when $ETCO_2$ returned within a normal range (35-40 mmHg) individuals in the PCS group were able to exercise for longer durations and at higher intensities. This finding suggests that physical performance might be negatively impacted by abnormal $ETCO_2$ levels. Despite recent findings, many gaps still exist within the literature. To the author's knowledge, no other studies have observed $ETCO_2$ throughout an entire neurocognitive task or while walking. Therefore, the purpose of the study was to examine

differences between healthy and concussed individuals when performing a neuropsychological and physical task on measures of $ETCO_2$. The secondary aim of the study was to determine the feasibility of a future study investigating the potential impact respiration might have on other physical activities, such as balance and gait in PCS.

METHODS: Ethical approval was obtained from the academic institution prior to participant recruitment. Participants were separated into a healthy control group (n=17) and PCS group (n=5) for a total of 22 participants (9 males and 13 females; mean age 22.3 years ±2.5; mean height 173.2 cm ±7.6; mean BMI 25.8 kg/m^2 ±4.4). Participants in the PCS group had to be diagnosed by a health care provider with PCS and have at least one symptom for at least 8 weeks but no longer than 1 year. Inclusion criteria required all participants to be aged 16-35 years, and free of any musculoskeletal injury or neurological disorder. Participants in the control group were also excluded if they had a respiratory disease.
The study's protocol was based off pilot data that was completed by the research team previously. The session was completed in a single, 45-minute period. Participants began by completing a demographic interview and having their weight (kg) and height (cm) measured. General demographic information (i.e., name, age, and brief medical history) was collected during this time. Once completed, a respiratory questionnaire was filled out. The Nijmegen Questionnaire was used to identify the likelihood that the individual had an abnormal breathing pattern. Total scores that fall above 23 are believed to be linked with higher probabilities of abnormal breathing. When the paper work was completed, participants were fitted with a nasal cannula which connected to a CapnoTrainer© breath analyser. Participants were instructed to refrain from talking and to breathe through their nose during the tasks. This allowed the device to accurately collect $ETCO_2$ data throughout the entire test session. During the neurocognitive task, baseline $ETCO_2$ (mmHg) was collected for 40 seconds while the participant was sitting upright in a chair and performing quiet breathing. Next, the Immediate Post-Concussion Assessment and Cognitive Test (ImPACT) battery was completed on a desktop computer to simulate different types of neurocognitive function. A 2-minute recovery period followed the completion of the ImPACT battery to allow $ETCO_2$ to return to baseline values. During the physical task, baseline $ETCO_2$ (mmHg) was measured while the participant was standing erect on top of a treadmill while quiet breathing. There were 3-minute walking trials completed at two different walking speeds with a 0% treadmill incline. The first walking condition was at a slow self-selected walking speed (3-3.5 mph) that most closely resembled the participant's average walking pace. The second walking condition was at a walking speed that was 25% faster than the speed chosen in the first condition. There were also 2-minute recovery periods following each walking condition to minimize the effect of fatigue. Initial data analysis was completed on Microsoft's Excel computerized program before inputting data into IBM SPSS 24 for statistical analysis. Two repeated measures mixed factorial ANOVAs were conducted to examine the interaction effect between task and group differences on mean $ETCO_2$ during each of the tasks (cognitive and physical) with an alpha level of $p<.05$. If no interactions were found, the main effect was examined. A Bonferroni post-hoc analysis was performed if a statistical significance was found to determine where the difference occurred. Nonparametric statistical analyses were also performed due to heterogeneous group sizes.

RESULTS: Participant characteristics did not differ between groups. Nonparametric statistical tests revealed similar findings as the parametric analyses and therefore, the results were discussed based on the parametric statistical analyses. There was no statistically significant interaction effect between group and task for the cognitive tasks on measures of $ETCO_2$ (see Figure 1a). There was a significant main effect for task with a large effect size on measures of $ETCO_2$ during the cognitive task, $F(1, 20)=5.332$, $p<0.032$, $n^2=0.21$. Completing the ImPACT battery decreased $ETCO_2$ in both groups. There was also a significant main effect for group on measures of $ETCO_2$, $F(1, 20)=14.388$, $p<0.001$, $n^2=0.418$, with a large effect size. The PCS group had elevated $ETCO_2$ at baseline and remained higher throughout the cognitive task compared with the control group. No statistically significant interaction effect in $ETCO_2$ levels between group and task for the physical task was found (see Figure 1b). There was a significant main effect of task on measures of $ETCO_2$ during the physical task, $F(2, 38)=52.305$, $p<0.001$, $n^2=0.734$, with a large effect size. A Bonferroni post-hoc analysis further revealed that $ETCO_2$ significantly increased in both slow ($p<0.001$) and fast ($p<0.001$) walking speeds when compared with baseline. Lastly, a significant main effect for group was also observed with a large effect size, $F(1, 19)=8.283$, $p<0.01$, $n^2=0.304$. The PCS group had elevated $ETCO_2$ throughout the entire physical task compared with the control group.

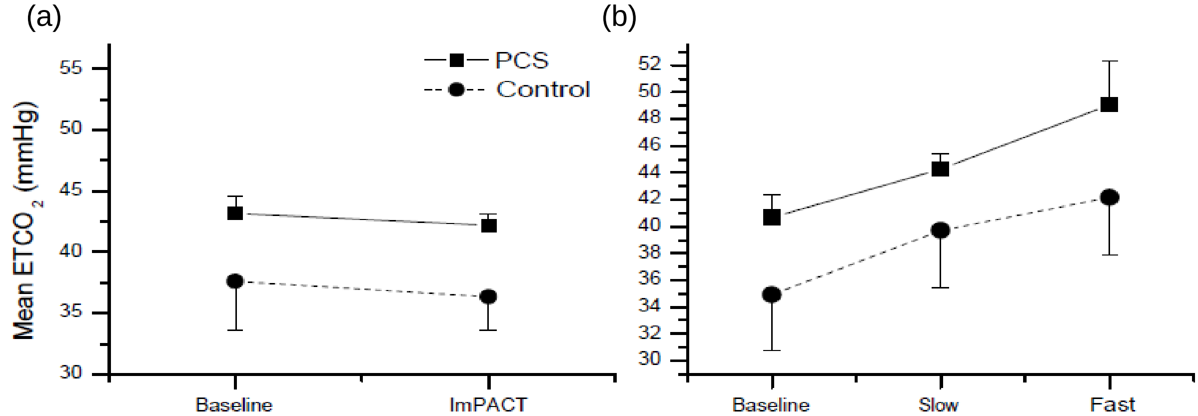

Figure 1. Changes in mean data with standard error bars. (a) Comparison of $ETCO_2$ (mmHg) between control and PCS groups throughout the cognitive task; (b) Comparison of $ETCO_2$ (mmHg) between control and PCS groups throughout the physical tasks.

DISCUSSION: The results showed that $ETCO_2$ significantly decreased in both groups during the neurocognitive task compared with baseline. This is a typical physiological response to cognitive loading found in healthy individuals (Grassmann, Vlemincx, von Leupoldt, Mittelstadt, & Van den Bergh, 2016). Therefore, individuals in the PCS group would also be hypothesized to have had a normal $ETCO_2$ response to cognitive loading during the completion of the ImPACT battery. It was also found that the PCS group had elevated $ETCO_2$ compared with the control group during the entire cognitive task. Resting $ETCO_2$ in both groups may be considered to fall within a conservative normal range (35-45 mmHg; McLaughlin, 2014), however, the PCS group was found near the upper limit of that range (43.2 mmHg). Group differences may be explained by reduced cerebral blood flow observed after concussion while completing the ImPACT battery (Kontos et al., 2014) and may suggest abnormal breathing physiology to accompany physiological changes in the brain. Similar, $ETCO_2$ was found to significantly increase in both groups with walking speed. Our results are similar to those found in studies examining $ETCO_2$ in healthy (Siedlecki, Sanzo, & Zerpa, 2017) and PCS (Clausen et al., 2016) populations. When exercising at a single intensity, such as the walking conditions in our study, $ETCO_2$ increases to meet metabolic demands in muscles and peaks in the first 2 minutes prior to returning to baseline values at 4 minutes (Whipp, 2007). Therefore, it can be hypothesized that the walking trials simulated a mild-to-moderate intense exercise and both groups had a similar response to physical stress. Lastly, the PCS group also had elevated $ETCO_2$ during the entire physical task compared with the control group. There were no group differences in walking speeds as the mean slow walking speed was 3.1 mph in both groups and should not have contributed to the difference observed. Clausen et al. (2016) reported a similar elevation in $ETCO_2$ within female PCS athletes compared with healthy controls. They attributed that difference to altered cerebral blood flow. The continually elevated $ETCO_2$ in the PCS group may also be explained by Whipp (2007), who stated individuals with high resting $ETCO_2$ may still experience difficulty regulating blood gas levels throughout exercise. Therefore, abnormal resting $ETCO_2$ may provoke overbreathing during physical exercise and potentially effect cognitive and physical performance.

CONCLUSION: This study showed the importance that monitoring breathing physiology might be following a concussion. Although all participants had a similar response to cognitive loading and physical stress, individuals in the PCS group had elevated $ETCO_2$ at rest, during the completion of the ImPACT battery, and while walking. Participants in the PCS group were able to successfully complete all aspects of our study without affecting their physical performance. The next stage for this study could be to examine the potential impact abnormal breathing physiology can have on physical performance that is perceived as being more challenging in PCS. Similarly, examining kinetic and kinematic changes during balance and gait activities may also be of interest for future studies. By identifying abnormal breathing as a potential symptom for concussion, introducing treatments that focus on correcting breathing patterns might be beneficial in reducing recovery time or improving athletic and academic performances.

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