

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

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The purpose of this study was to examine differences between healthy and concussed participants when performing a neuropsychological and physical task on measures of end-tidal carbon dioxide (ETCO₂). 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 ETCO₂ during the tasks. Statistically significant main effects were observed for time ($F(1,20)=5.332$, $p=.032$; $F(2,38)=52.305$, $p=.001$) and group ($F(1,20)=14.388$, $p=.001$; $F(1,19)=8.283$, $p=.01$) in ETCO₂ during the cognitive and physical tasks respectively. Therefore, abnormal ETCO₂ levels may occur after concussion and 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 (McCroly et al., 2017). A violent direct or indirect impact to the head can cause linear and/or rotational forces to cause neural and vascular tissue damage. In 20% of the concussed population, the injury can leave individuals suffering from psychological and physiological symptomatology that persists for years post-injury (McCroly et al., 2017). 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 a vast amount of 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 to non-concussed individuals (McClincy, Lovell, Pardini, Collins, & Spore, 2006). Another common complaint in concussion 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.

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 (ETCO₂), the peak carbon dioxide at the end of an exhaled breath, can also reduce blood flow to the brain and negatively affect various physiological and psychological processes. Finally, Clausen et al. (2016) reported that female athletes with PCS can have elevated ETCO₂ during progressive aerobic exercise on a stationary bike compared to a control group. More interestingly, when ETCO₂ 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 ETCO₂ levels.

Despite recent findings, many gaps still exist within the literature. To the author's knowledge, no other studies have observed ETCO₂ 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 ETCO₂. The secondary aim of the study was to determine the feasibility of a future study investigating the potential impact ETCO₂ might have on other physical activities, such as balance and gait in patients suffering from 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 \pm 2.5; mean BMI 25.8 kg/m² \pm 4.4). To be in the PCS group, participants must have been 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 between the ages of 16-35 years, and absent of any musculoskeletal injury and neurological disorder. Participants in the control group were also excluded if they had a respiratory disease. Exclusion criteria minimized the effect that health problems, other than the concussion, could have on influencing breathing patterns.

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 would allow the device to accurately collect ETCO₂ data throughout the entire test session.

During the neurocognitive task, baseline ETCO₂ (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 ETCO₂ to return to baseline values.

During the physical task, baseline ETCO₂ (mmHg) was also collected for 40 seconds 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 on subsequent trials.

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 time and group differences on mean ETCO₂ 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 because of the heterogeneous group sizes.

RESULTS: Nonparametric statistical tests revealed similar findings as the parametric analyses and therefore, the results were discussed only on the parametric statistical analyses. There was no statistically significant interaction effect between group and time for

the cognitive tasks on measures of ETCO_2 (see Figure 1a). There was a significant main effect for time with a large effect size on measures of ETCO_2 during the cognitive task, $F(1, 20) = 5.332, p = .032, \eta^2 = .21$. Baseline ETCO_2 decreased when participants were completing the ImPACT battery. There was also a significant main effect for group on measures of ETCO_2 , $F(1, 20) = 14.388, p = .001, \eta^2 = .418$, with a large effect size. The PCS group had elevated ETCO_2 throughout the cognitive task compared to the control group. No statistically significant interaction effect in ETCO_2 levels between group and time for the physical task in relation to the baseline; slow and fast walking speeds was found (see Figure 1b). There was a significant main effect of time on measures of ETCO_2 during the physical task, $F(2, 38) = 52.305, p = .001, \eta^2 = .734$, with a large effect size. A Bonferroni post-hoc analysis further revealed that ETCO_2 significantly increased in both slow ($p = .001$) and fast ($p = .001$) walking speeds when compared to baseline. Lastly, a significant main effect for group was also observed with a large effect size, $F(1, 19) = 8.283, p = .01, \eta^2 = .304$. The PCS group had elevated ETCO_2 throughout the entire physical task compared to the control group.

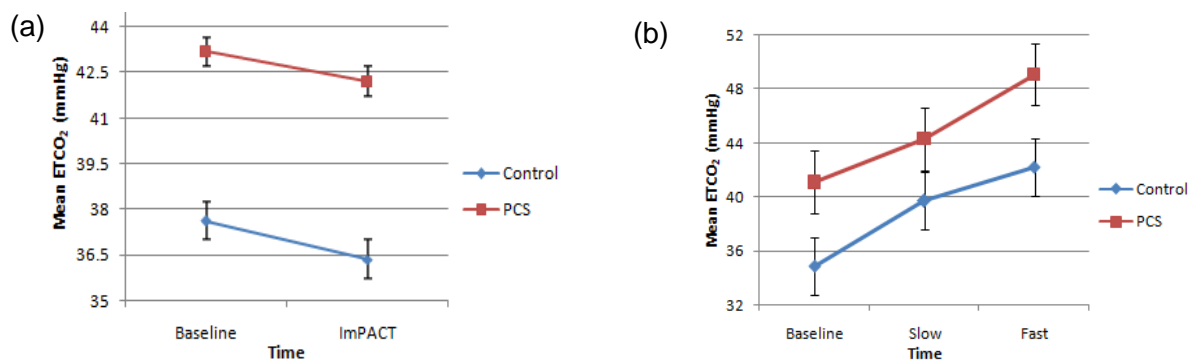


Figure 1. Changes in mean data. (a) Comparison of ETCO_2 (mmHg) between control and PCS groups throughout the cognitive task; (b) Comparison of ETCO_2 (mmHg) between control and PCS groups throughout the physical tasks.

DISCUSSION: The results showed that ETCO_2 significantly decreased in both groups during the neurocognitive task compared to 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 to 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 concussions 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 to 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 to a healthy control group. 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 affect 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 subtle 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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