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Original Research

Head Trauma not Associated with Long Term Effects on Autonomic Function

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ABSTRACT

International Journal of Exercise Science 14(3): 779-790, 2021. Contact-sports can elicit concussions, which impacts autonomic function, as well as elicit repetitive head trauma, where autonomic function has not yet been assessed. The purpose of this study was to determine if differences in autonomic function exist among three groups (CTRL: healthy non-contact-sport participant, RHT: repetitive head trauma contact-sport participant, CONC: previous concussion). Forty participants (16 men and 24 women), aged 18-37 (22 ± 3), participated in the study. Participants were grouped based on their sport and concussion history (CTRL, RHT, and CONC). Body composition was measured via air displacement plethysmography. Prior to testing, participants were outfitted with equipment to evaluate heart rate, blood pressure, and cerebral-artery blood flow velocity (CBFv). The participant performed against three stimuli: deep breathing, Valsalva maneuver, and a 70° head-up tilt test. Following autonomic function testing, a YMCA submaximal cycle test was performed. All group comparisons were analyzed using a one-way ANOVA and all data are presented as means ± standard deviation. The results of this study indicated that the groups did not differ in respiratory sinus arrhythmia (CTRL: 22 ± 6 bpm, RHT: 21 ± 8 bpm, CONC: 19 ± 7 bpm, p = 0.471), Valsalva ratio (CTRL: 2.19 ± 0.39, RHT: 2.09 ± 0.37, CONC: 2.00 ± 0.47, p = 0.519), CBFv (CTRL: 47.74 ± 25.28 cm/s, RHT: 40.99 ± 10.93 cm/s, CONC: 43.97 ± 17.55 cm/s, p = 0.657), or tilt time (CTRL: 806.09 ± 368.37 sec, RHT: 943.07 ± 339.54 sec, CONC: 978.40 ± 387.98 sec, p = 0.479). However, CONC (113.24 ± 11.64 mmHg) had a significantly higher mean systolic blood pressure during the tilt test than CTRL (102.66 ± 7.79 mmHg, p = 0.026), while RHT (107.9 ± 9.0 mmHg) was not significantly different than CTRL (p = 0.39) or CONC (p = 0.319). The results of this study are the first step in determining if long-lasting deficits to the autonomic nervous system occur following a diagnosis of concussion. However, concussions do not seem to have lasting effects on autonomic function. Overwhelmingly, dysautonomia is not present during chronic recovery from concussions or in individuals with RHT from contact-sports. In the future, sex should be considered as a variable.

KEY WORDS: Mild traumatic brain injury, athletes, dysautonomia, autonomic nervous system

INTRODUCTION

Although concussion return-to-play protocols have been established, diagnosis and management of concussions can be difficult for an athlete (28, 29). While methods have been developed to alleviate this difficulty from athletic trainers, coaches, physicians, and other professionals, there is no universally accepted diagnostic criteria (9, 13). Further complicating this matter is that people sometimes fail to recognize or report symptoms of a concussion (8). If a concussion is not managed well and the athlete returns to play too soon, they are susceptible to another head injury, which requires even more time to recover (4, 10). In addition to repetitive head trauma, often seen in contact-sport athletes, returning to play too soon has been speculated to cause permanent damage in the autonomic nervous system (ANS) (30, 33).

The ANS involuntarily regulates physiological functions like heart rate, blood pressure, and blood flow and has two divisions: sympathetic nervous system (SNS) and parasympathetic nervous system (PNS) (15, 26, 48). Both utilize the vasomotor center to maintain homeostasis by sending and receiving signals from and to target organs (15, 26, 35). These signals are mediated by baroreceptors and the Bainbridge reflex to modulate sympathetic and parasympathetic activity in order to maintain homeostasis (6, 15, 25).

A growing body of evidence suggests that ANS function is affected by short-term concussions (12, 22, 40), long-term concussions (17, 18), and a mix of both (1, 23, 34). However, the effects of repetitive head trauma on autonomic function are largely unknown, especially when a formal concussion diagnosis was absent (44). At the present time, only one published study addresses this issue. This study observed an increased prevalence of initial orthostatic hypotension in individuals exposed to repetitive head trauma (5). Although concussions have become a popular topic of interest over the past decade, there are many areas that should be addressed with future research. Understanding the long-term effects concussions may have on autonomic function should be a priority. Currently, only non-specified individuals (17, 18, 23), professional boxers (5), and a combined sample of contact-sport and noncontact-sport nonprofessional athletes (1, 12, 22, 34, 40) have been assessed. Therefore, further research is needed to determine if autonomic dysfunction is associated with long-term exposure to repeated head trauma that is experienced by contact-sport athletes. Due to the lack of literature in this area, there is much ambiguity with how concussions and repetitive head trauma affect autonomic function.

Thus, the purpose of this study was to explore the long-term effects of head trauma on autonomic function in the following three groups: Control (CTRL) (physically active, but no contact-sport participation nor concussion diagnosis), Repetitive Head Trauma (RHT): (contact-sport (i.e., boxing, football, wrestling) participation, but no concussion diagnosis), and Concussed (CONC) (previously concussed three or more months ago). The information gained could possibly add to the growing body of evidence, regarding the effects of concussions and repetitive head trauma, and aid the medical community, coaches, athletes, and parents in understanding the effects of long-term concussions and contact-sports on autonomic function.

METHODS

All aspects of this study were approved for completion by the local Institutional Review Board at Ball State University and procedures, followed in accordance with the 1964 ethical standards of the Helsinki Declaration, and are in line with ethical issues relating to scientific discovery in exercised science as outlined by the International Journal of Exercise Science (31).

Participants

Sixteen men and 24 women (age: 22 ± 3) from Ball State University and the surrounding community participated in this study. Participants were screened for age, biological sex, current medications, head injury and sport participation history, smoking status, and physical activity ability. Prior to testing, participants were asked to refrain from caffeine, alcohol, and exercise for 24 hours as well as food for 12 hours. Participants were permitted to drink water *ad libitum* during this time. To minimize hormonal differences between sexes, data collection took place during the early follicular phase of the menstrual cycle for women (11, 20). For all participants, data collection occurred in the morning to eliminate differences in circadian rhythm (7). Means ± standard deviation for participant characteristics are presented in Table 1. The exclusion criteria included having known cardiovascular, pulmonary, renal, or metabolic diseases, being under the age of 18 years or over 40 years, taking medications that alter cardiovascular, pulmonary, renal, or metabolic pathways, smoking, lack of physical ability to complete a submaximal cycle test, a concussion less than three months prior to the study, and refusal to give informed consent. Every participant completed the entire data collection process.

Table 1. Participant characteristics.

	CTRL	RHT	CONC	*p*-value
Age (yrs)	21 ± 2	23 ± 2	23 ± 4	P = 0.16
Weight (kg)	66.20 ± 10.06	67.27 ± 12.79	75.43 ±14.50	P = 0.13
Height (cm)	171.7 ± 6.60	167.3 ± 7.80	172.8 ± 9.50	P = 0.18
Body Fat (%)	22.44 ± 8.01	20.38 ± 7.19	20.59 ± 6.89	P = 0.75
Physical Activity Level (kcal/day)	928.40 ± 370.86	1018.15 ± 275.64	1288.22 ± 550.54	P = 0.08
VO_2 max (ml/kg/min)	40.38 ± 11.60	42.21 ± 7.90	37.44 ± 11.33	P = 0.46
Gender (M%/F%)	27%/73%	29%/71%	60%/40%	n/a

Data are presented as means ± standard deviation. CTRL = control group, RHT = repetitive head trauma group, CONC = concussed group, M% = male percentage, F% = female percentage.

Protocol

Data collection took place in Ball State University's Integrative Exercise Physiology Laboratory. Upon arrival to the lab, the participant provided both oral and written informed consent. The participant then completed a Physical Activity Readiness Questionnaire (PAR-Q+) (45), head trauma and sport questionnaire (24, 37, 39), and symptom checklist to determine the participant's history of head injury and sport participation (27). Anthropometrics and body composition were measured next, followed by instrumentation of autonomic function testing equipment. While resting supine, a Seven-Day Physical Activity Recall (PAR) interview was conducted (38). Autonomic function testing took place following 15 minutes of quiet supine rest (32). To finish the laboratory visit, a YMCA submaximal cycle test was performed using an electronically braked cycle ergometer (Sport Excalibur, Lode B.V.

Medical Technology, Groningen; The Netherlands) (2). A telemetric HR monitor (Polar, Kempele; Finland) tightened around the participant's chest, slightly above the xiphoid process to predict peak oxygen consumption and fitness levels.

Height was measured using a stadiometer (Novel Products Inc., IL, USA) to the nearest mm and without the participant's shoes. Weight was assessed using a beam balance scale and standard methods. Body composition was assessed by air displacement plethysmography (BodPod®, Life Measurement Inc., Concord, CA, USA) per manufacturer's instructions.

Head Trauma and Sport Questionnaire: This questionnaire was adapted from previous studies (24, 37, 39) and provides definitions for a concussion, contact-sport, non-contact-sport, and organized sport (41). The participant recorded the number of previous concussions experienced in their lifetime, along with the month and year the concussion(s) occurred. Length and frequency of sport participation in previous and current organized contact- and non-contact-sports were recorded. This questionnaire was utilized to assign each participant to a group. Group characteristics are displayed in Table 2.

Table 2. Group characteristics.

Group	Male	Female	Previously Concussed (3+ months prior to data collection)	Contact-Sport Experience
CTRL	3	8	0%	0%
RHT	4	10	0%	100%
CONC	9	6	100%	80%

% = percentage of individuals within their respective group.

Autonomic function testing was conducted on a motorized tilt table, which was utilized for the participant to lay supine and tilt to 70°. A 3-lead electrocardiogram (ECG) assessed heart rate. A finger cuff placed on the participant's left middle finger measured beat-to-beat blood pressure through finger photoplethysmography. An automatic blood pressure cuff confirmed changes in blood pressure at rest and during testing in one-minute intervals. Cerebral blood flow velocity (CBFv) was measured using a transcranial-Doppler ultrasound 2 MHz probe. Once in place, the participant's middle cerebral artery was isonated and the probe secured using an adjustable head band. Lastly, a nasal canula and pulse oximeter, connected to a capnography pulse oximeter, were placed in the participant's nose and on their left index or ring finger.

Heart rate variability (HRV) was assessed and analyzed throughout the entire autonomic function testing using the low frequency/high frequency (LF/HF) ratio. The autonomic function protocol utilized was previously described by Novak (32). The first stimulus assessed was deep breathing, which measures cardiac parasympathetic function (32). Respiratory Sinus Arrhythmia (RSA) was calculated as the average of the difference in heart rate at the end of expiration and the heart rate at the end of inspiration for each of the six cycles. The second stimulus was the Valsalva maneuver, which measures baroreceptor function. The Valsalva

Ratio (VR) was calculated from the maximum heart rate during the maneuver divided by the lowest heart rate within 30 seconds of the peak heart rate. The last stimulus was the head-up tilt table test, which assesses orthostatic tolerance and induces blood pooling in the lower extremities via passive standing. The participant was raised to 70° for 20 minutes. If pre-syncopal symptoms (sweating, blurred vision, nausea, or dizziness) and/or the cerebral blood flow indicated cerebral hypoperfusion along with a dramatic increase of heart rate and/or a decrease in systolic blood pressure were experienced, the participant was lowered to the supine position and the test ended early. CBFv, mean systolic blood pressure (SBP), and tilt time were analyzed.

Statistical Analysis

Data are reported as means ± standard deviation. All data was evaluated using a one-way ANOVA. Effect size was calculated for the reported variables by conducting a η^2. When necessary, a Tukey post hoc analysis was performed. Normality was determined by using the Shapiro-Wilkes test, and homogeneity was determined by the Levene test. No variables violated these assumptions. All statistics were calculated using SPSS version 25 and statistical significance was set *a priori* at $a < 0.05$.

RESULTS

CONC had a significantly higher mean SBP (113.24 ± 11.64 mm Hg) during the tilt test than CTRL (102.66 ± 7.79 mm Hg, $p = 0.03$, $\eta^2 = 0.14$), while RHT (107.9 0 ± 9.00 mm Hg) was not different than CTRL (p = 0.39) or CONC ($p = 0.32$). There were no differences among the groups for LF/HF (CTRL: 1.13 ± 0.53, RHT: 1.19 ± 0.49, CONC: 1.20 ± 0.45, $p = 0.93$, $\eta^2 = 0.03$), RSA (CTRL: 22 ± 6 bpm, RHT: 21 ± 8 bpm, CONC: 19 ± 7 bpm, $p = 0.47$, $\eta^2 = 0.4$), VR (CTRL: 2.19 ± 0.39, RHT: 2.09 ± 0.37, CONC: 2.00 ± 0.47, $p = 0.52$, $\eta^2 = 0.03$), CBFv (CTRL: 47.74 ± 25.28 cm/s, RHT: 40.99 ± 10.93 cm/s, CONC: 43.97 ± 17.55 cm/s, $p = 0.66$, $\eta^2 = 0.02$), or tilt time (CTRL: 806.09 ± 368.37 sec, RHT: 943.07 ± 339.54 sec, CONC: 978.40 ± 387.98 sec, $p = 0.48$, $\eta^2 = 0.04$). A visual representation of selected results can be found in Figure 1. See Table 3 for concussion symptom recall.

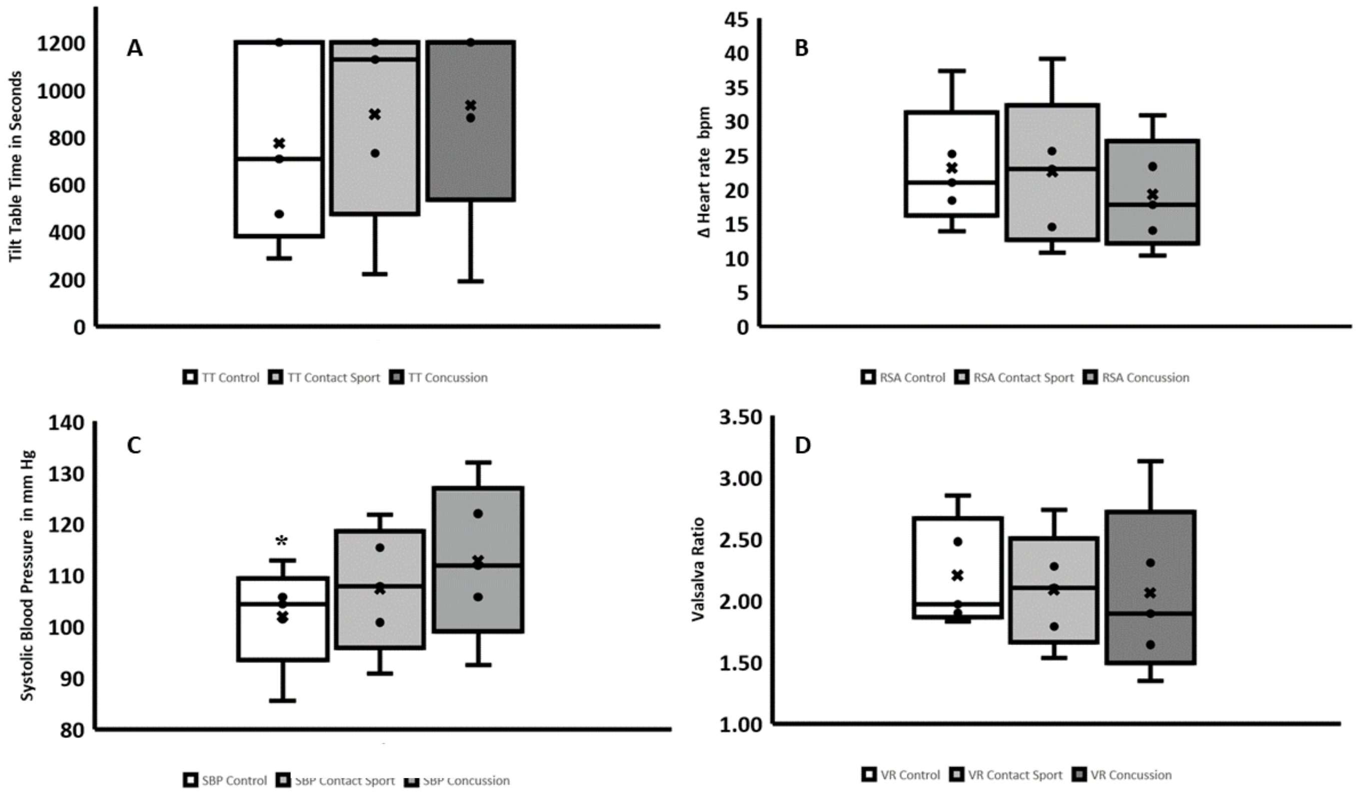

Figure 1. Tilt table times for all three groups: (A) Respiratory Sinus Arrythmia (RSA) for the three groups, (B) Δ in Heart Rate, (C) Mean Systolic Blood Pressure (SBP), and (D) Valsalva Ratio (VR). * indicates p < 0.05 for comparison against CONC group.

Table 3. Symptom recalls for most recent concussion.

Symptoms	48hrs post-Concussion	3-14 days post-Concussion	15 days through 1-month post-Concussion	2-3 months post-Concussion	Persisting symptoms
Nausea	None: 20% Mild: 40% Mod: 27% Sev: 13%	None: 40% Mild: 53% Mod: 7% Sev: 0%	None: 87% Mild: 13% Mod: 0% Sev: 0%	None: 100% Mild: 0% Mod: 0% Sev: 0%	None:100% Mild: 0% Mod: 0% Sev: 0%
Vomiting	None: 80% Mild: 13% Mod: 7% Sev: 0%	None: 93% Mild: 7% Mod: 0% Sev: 0%	None: 100% Mild: 0% Mod: 0% Sev: 0%	None: 100% Mild: 0% Mod: 0% Sev: 0%	None: 100% Mild: 0% Mod: 0% Sev: 0%
Appetite Changes	None: 27% Mild: 27% Mod: 33% Sev: 13%	None: 53% Mild: 27% Mod: 20% Sev: 0%	None: 87% Mild: 7% Mod: 7% Sev: 0%	None: 87% Mild: 13% Mod: 0% Sev: 0%	None: 100% Mild: 0% Mod: 0% Sev: 0%
Unplanned Weight Loss	None: 93% Mild: 7% Mod: 0% Sev: 0%	None: 93% Mild: 7% Mod: 0% Sev: 0%	None: 93% Mild: 7% Mod: 0% Sev: 0%	None: 100% Mild: 0% Mod: 0% Sev: 0%	None: 100% Mild: 0% Mod: 0% Sev: 0%

Data displayed as a percentage of participants that experienced the symptom during that specific time frame. Hrs = hours, mod = moderate, sev = severe.

DISCUSSION

The purpose of this study was to examine the effects repetitive head trauma and concussions have on the ANS. To our knowledge, this was the first study to assess how autonomic function of individuals with exposure to repetitive head trauma compares to individuals who have experienced concussion a minimum of three months prior to data collection. We found that mean SBP was higher in CONC when compared with CTRL. However, our hypotheses that all three groups would significantly differ in RSA, VR, CBFv, and tilt time were not supported by the data.

We found that mean SBP during the tilt test was significantly different between CONC and CTRL. CONC had a significantly higher mean SBP during the tilt test than CTRL, while RHT was not different than CTRL or CONC. Additionally, the effect size as determined by an η^2 was large (0.14). Therefore, in previously concussed adult men and women, mean SBP seems to be affected upon orthostatic change. Previously it has been noted that SBP increases in individuals with previous concussions upon orthostatic change, which agrees with our findings (19). As well, concussed individuals have been found to have an increased sympathetic drive at rest, while healthy controls do not and could help explain our results (19). However, the results from our HRV as a ratio of LF/HF does not support the notion that there is an increased sympathetic drive following concussion. The increased in SBP noted in this study could potentially be a function of sex and it should be noted that others have suggested that SBP is higher in males than females over 24 hours (36). Therefore, sex distribution in this study should be considered because 60% of CONC were males, while only 27% of CTRL and 29% of RHT were males.

Our study also found that individuals with repetitive head trauma did not have a different mean SBP than CTRL and CONC. Initial orthostatic hypotension, without reports of presyncope symptoms, have been previously recognized in individuals with exposure to contact-sports and repetitive head trauma (5). However, there is no evidence that hypotension continues into the steady-state phase of standing (5). Therefore, the findings from our study further support the previous literature looking at repetitive head trauma.

The results of the deep breathing protocol support the notion that there is no difference in cardiac parasympathetic function among the groups. Literature shows that individuals recovering from a traumatic brain injury display a significantly lower parasympathetic activity and RSA, and significantly higher sympathetic domain than the healthy controls (47). Therefore, as the recovery phase moves to chronic (three or more months after a concussion), our data is suggesting that concussed individuals may regain autonomic function. In addition, contact-sport experienced individuals do not have negatively affected cardiac parasympathetic function.

The results from the Valsalva maneuver suggests there is no difference in parasympathetic function based on heart rate among the groups. To our knowledge, there is no literature that assesses heart rate during this maneuver in CONC or RHT. However, literature does show that in previously concussed individuals (4–98 months post-injury) the Valsalva maneuver induces a delayed decrease in blood pressure, indicating sympathetic dominance (18). CONC contained a much wider chronic recovery range (3–261 months post-injury), which could have been a reason we did not get similar results. Additionally, the VR displays that contact-sport experienced individuals do not have negatively affected parasympathetic function.

Our CBFv findings align with a recent study that found CBFv does not differ between healthy and previously concussed adults (16). This similarity is supported by the concept of cerebral autoregulation, which states that CBFv generally remains stable regardless of alterations in prefusion and/or blood pressure due to the adjustability of vascular resistance (42) and aortic compliance (43). Additionally, our results suggest that contact-sport experienced individuals do not have negatively affected CBFv upon or during an orthostatic stressor.

The limitations in the study are as follows. Although the participant was asked and reminded to stand still during the tilt test, some did have movement. Two of the 11 (18%) CTRL participants, one of the 14 (7%) RHT participants, and 7 of the 15 (47%) CONC participants had involuntary movements during the orthostatic challenge. The movement from almost half of CONC during the tilt could play a major factor as to why the group lasted the absolute longest (increased muscle pump activity and potentially also a confounder of SBP) Therefore, small voluntary and/or involuntary movements during the tilt test may be a limitation and should be controlled in future studies (21).

As well, we did not control for the amount of fluid intake in the morning before data collection, as participants were allowed water ad libitum. However, upon survey, only 21 participants partook in 1-16 ounces of fluids (4.71 ± 3.47 oz), which has shown to impose limited effects on autonomic function (3, 14, 46). An additional limitation is that most participants were females, and as previously mentioned sex differences may be present. However, all females were tested in the early follicular phase of the menstrual cycle (one to three days following the cessation of bleeding) to minimize hormonal differences between males and females (11, 20). Future studies should address sex differences, specifically assessing SBP during an orthostatic challenge.

Additionally, future studies should control for the number of concussions and the time frame at which the concussions occurred. In the present study, number of concussions ranged from 1-9 (3 ± 2 concussions) and data collection took place 3 to 261 (71 ± 61 months) months after their most recent concussion. To our knowledge, this study was the first to assess long-term effects of concussions and repetitive head trauma on autonomic function, as the participants were accepted as long as a concussion occurred at least three months prior to data collection. Concussion severity should also be considered in the future. Concussions in the present study were self-reported, so we could not accurately assign severity. However, the symptom checklist did confirm that none of the previously concussed participants were still experiencing symptoms at the time of data collection. Future studies should require documentation from the diagnosing physician or athletic trainer.

In conclusion, when exposed to an orthostatic challenge, previously concussed individuals experienced higher mean SBP than healthy adults with no contact-sport experience, while there was no difference when looking at repetitive head trauma from contact-sports. When the individual tests are looked at the overall results suggest to us that concussions, once in the chronic recovery phase, and repetitive head trauma from contact-sports do not lead to lasting deficits in autonomic function. Further studies should control for time since concussion, fluid intake, movement during orthostatic challenges, and sex differences.

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