

Article

The Effects of Concussions on Static Postural Stability

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Abstract: Concussions among the athletic population are extremely common, which could lead to postural instabilities. The purpose of this study was to assess the effect of concussions on postural stability in young healthy adults. The static postural stability of thirty volunteers (age 21.63 ± 2.50 years; height 1.70 ± 0.14 m; weight 75.00 ± 15.58 kg; 17 with a history of concussions) was assessed using a force platform during three tests: baseline stability test, clinical test of sensory interaction and balance test, and unilateral stability test. Postural sway variables during each test were statistically analyzed using an independent *t*-test between the concussion group (CONC) and no concussion (NO CONC) groups. Two secondary analyses were performed with the CONC group: individuals who had one concussion (ONCE) vs. who had multiple concussions (MULTIPLE) and individuals who had their last concussion in 2023–2018 (RECENT) and in 2017–2011 (OLD). The CONC, MULTIPLE, and RECENT groups demonstrated greater postural sway than the NO CONC, SINGLE, and OLD groups. Concussions cause postural decrements in young healthy adults compared to their counterparts with no history of concussions. The results of the study exhibit that concussions could lead to imbalances, which is decisive in athletes' performance and injury risk during play.

Keywords: concussions; static; balance; CTSIB; force plate; mTBI; postural stability



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1. Introduction

Concussions are defined as a complex pathophysiological process affecting the brain, induced by traumatic biomechanical forces [1]. Concussions could be identified as a significant intrinsic factor that could affect an athlete's postural stability. Postural control must happen in order to maintain a myriad of activities and postures [2], and thus, the deficits can result from a sensory, motor, or cognitive impairment [2]. McLeod [3] found that ~67–77% of the people who had a concussion experienced dizziness, which resulted in a risk factor for a longer recovery. Other symptoms of concussions include facial and neck pain, blurred vision, sleep disturbance, headache, memory and concentration [1,2]. However, the non-modifiable and modifiable risk factors of concussions are not well understood [4]. Concussions can affect everyday life, whether that be in sports, recreation, or work [5], and can affect someone's performance and injury risk.

Having a concussion diagnosed immediately after a blow or hit to the head allows for an active management approach, which can result in faster recovery and prevent a secondary injury [5]. In McLeod's [3] literature review, the authors found that 3–10 days post-injury, the concussed individuals had balance impairments. Research shows that most people who have suffered a concussion recover completely, but about 10–15% of individuals who have had a concussion do not recover completely and suffer from post-concussion syndrome (PCS) [6]. More specifically, some research specifies that it can take

up to 3 to 6 months to recover [7]. Roughly 40% of concussed people have impairments that affect their daily life [8–10], while 25% still cannot return to work one-year post-injury [8]. Furthermore, some people have persistent symptoms that require active rehabilitation [5]. The outcome of concussions depends on the severity of the concussion. Clinically, the individuals with concussions are categorized as grade 1, grade 2, and grade 3, depending on their symptoms. In this categorization, amnesia, confusion, and loss of consciousness are the main symptoms to consider. There are different guidelines that exist for this categorization, such as the Colorado Sports Concussion Grading Scale, the American Academy of Neurology Concussion Grading Scale, and the Cantu Sports Concussion Grading Scale. In all grading scales, transient confusion is considered grade 1, and loss of consciousness is considered a grade 3 [3].

Lifetime concussion symptoms lead to an increased risk of falls and motor disturbances [11]. Decreased postural control and neurocognitive function are both side effects of someone who has had a concussion [12]. As well as over 23% of concussed people complain about being dizzy [4]. Dizziness can be a result of either inner ear disorders and central nervous system disorders [4]. Some of these disorders include benign paroxysmal positional vertigo and post traumatic migraine [4]. The central nervous system (CNS) plays a key role in postural equilibrium [13]. For the CNS to maintain equilibrium and execute coordinated and appropriate musculoskeletal responses, it must process and integrate information from the somatosensory (proprioceptive), vestibular, and visual systems [13]. The feedback received from the peripheries must be processed in the CNS to send messages to the muscles in the extremities to contract appropriately for the body to maintain postural stability [13]. Thus far, the results from studies that investigated the effects of concussions on balance are controversial. Lee [14] found that postural stability was not affected by a concussion. Guskiewicz [13] found that when the task became more complex by altering the somatosensory, vestibular, or visual feedback during the trial, the balance impairment increased in the individuals who had a mild traumatic brain injury (mTBI). (The terms concussion mild traumatic brain injury (mTBI) are used interchangeably in this paper, as they are in other research articles such as Junn [1] and Lefevre-Dognin 2020 [5]).

Guskiewicz [6] and colleagues attributed their findings to a sensory interaction problem by receiving various combinations of information from the visual, vestibular, and somatosensory systems. Kunker [15] found that when a participant with a history of a concussion relied on visual cues with their eyes open during testing, they had an increased displacement of COP (center of pressure) in the mediolateral direction, increased COP area, and reduced path length when compared to individuals who never had a concussion. Whereas Lee [14] reported no functional deficits of postural stability performances in the individuals with a mTBI while using the force platform to assess balance. With the mixed results of past research, this study aimed to investigate the effect of previous concussions on postural stability in young healthy adults. It was hypothesized that any history of concussions would have a negative effect on postural stability. Additionally, it was hypothesized that multiple concussions and time since the last concussion would cause greater balance decrements compared to single and old concussions.

2. Materials and Methods

A total of thirty healthy collegiate volunteers (age 21.63 ± 2.50 years; height 1.70 ± 0.14 m; weight 75.00 ± 15.58 kg; 9 males; 2 left leg dominants; 17 with a history of concussions) without current or recent history of neurological, visual, vestibular, or musculoskeletal abnormalities were recruited for the study. Participants with a history of lower extremity fractures, surgery, back pain, or joint sprains within the last three months were excluded from the study. The study was approved by the institutional review board (IRB-AY22-23-301). The sample size was calculated using G*Power statistical software (3.1.9.6) with an effect size of 0.25, a desired power of 0.8, and an alpha level of 0.05.

The study consisted of a single session for each participant, conducted over the course of one day. Participants were instructed to refrain from vigorous leg workouts the day

before testing. Upon arrival at the laboratory, informed consent was obtained, followed by completing a Physical Activity Readiness Questionnaire (PARQ+) to inquire about any existing pathology. To get the concussion history, the participants answered an online-based survey, which asked whether they had any concussions, how many concussions they had, how many concussions were diagnosed by a medical professional (e.g., medical doctor, nurse, athletic trainer, etc.), when their last concussion was, and the activity(ies) led to their concussion(s). Then, the participants' demographics and anthropometric data were recorded, and the dominant leg was determined using the ball-kick test (i.e., asking the participants, "If I gave you a ball to kick, which leg you would use") [16]. After recording these, they were familiarized with the study protocols, including standing on the force plate in a standardized body position. During each trial, the participants were advised to stand in the middle of the force plate, feet shoulder-width apart, keeping the arms along the body, looking forward with gaze fixed, without talking. The participants were allowed to practice standing on the force plate during familiarization.

Following familiarization, the testing started. The protocol included three tests: baseline stability test, Clinical Test of Sensory Interaction and Balance (CTSIB) test, and unilateral stability test administered in the same order for every participant. Static postural stability was assessed using an AMTI force platform (Advanced Mechanical Technology, Inc., Watertown, MA, USA) at a rate of 100 Hz and analyzed using bioanalysis software version 2.2 (Watertown, MA, USA) [17]. During the baseline stability test, the participants' static postural stability was assessed while standing on the force plate, on both feet, and with their eyes opened. Three 20-s trials were recorded for this test. The CTSIB test included four conditions: standing on the force plate on both feet and eyes opened (firm BL EO condition), standing on the force plate on both feet and eyes closed (firm BL EC condition), standing on a foam pad placed on the force plate on both feet and eyes opened (foam BL EO condition), and standing on a foam pad placed on the force plate on both feet and eyes closed (foam BL EC condition) (Figure 1). During this test, three trials were recorded for each condition, each 20 s long. The unilateral stability test consisted of four conditions: standing on the force plate on the dominant leg with eyes opened (DOM EO condition), standing on the force plate on the non-dominant leg with eyes opened (ND EO condition), standing on the force plate on the dominant leg with eyes closed (DOM EC condition), and standing on the force plate on the non-dominant leg with eyes closed (ND EC condition) (Figure 1). During this test, three trials were recorded for each condition, each 10 s long.

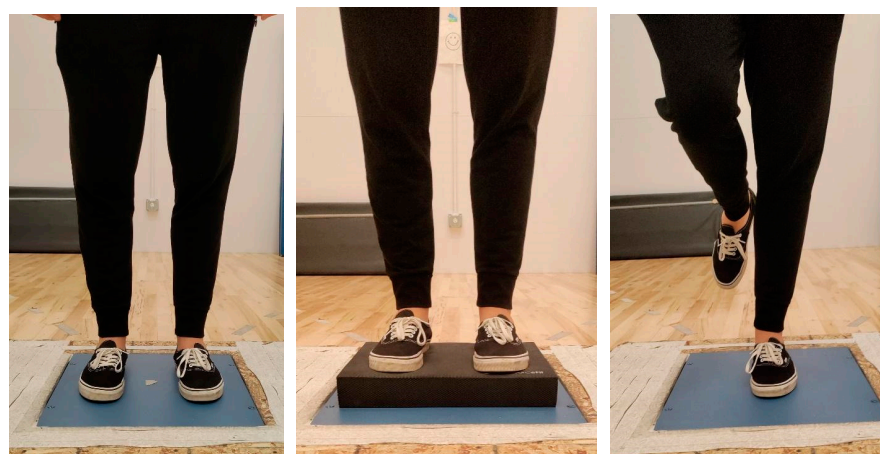


Figure 1. (Left): A participant standing on the force platform on both feet during the clinical test of sensory interaction and balance (CTSIB) test; (Middle): A participant standing on a foam pad placed on the force platform on both feet during CTSIB test; (Right): A participant standing on the force platform on one foot during unilateral stability test.

As the postural sway variables of interest, the maximum COP excursion in the anterior-posterior direction (COP-X max), minimum COP excursion in the anterior-posterior di-

rection (COP-X min), maximum COP excursion in the medial-lateral direction (COP-Y max), minimum COP excursion in the medial-lateral direction (COP-Y min), average COP displacement in the anterior-posterior direction (Avg. Displacement along X), average COP displacement in the medial-lateral direction (Avg. Displacement along Y), and 95% ellipsoid area (95 EA) were chosen. Lower values for the postural sway variables indicate greater postural stability and vice versa.

Participants who had at least one medically diagnosed concussion were put in the concussions (CONC) group, and the others were placed in the no-concussion (NO CONC) group. Postural sway data from each test [baseline stability test, CTSIB test, and unilateral stability test] were analyzed separately using an independent *t*-test for CONC vs. NO CONC groups. Furthermore, two secondary analyses were performed with the CONC group. In one analysis, the CONC group was divided into two groups: the individuals who had one concussion (ONCE) and the individuals who had multiple (>1) concussions (MULTIPLE). In the other analysis, the participants were divided into two groups: those who had their last concussion in the years 2023–2018 (RECENT) and those who had their last concussion in the years 2017–2011 (OLD). In both these analyses, postural sway variables were analyzed using an independent *t*-test for ONCE vs. MULTIPLE and RECENT vs. OLD groups. Statistical analyses were performed using JASP (Version 0.18.1; Amsterdam, The Netherlands) at an apriori alpha level of 0.05.

3. Results

Out of the 30 participants, 17 had a history of medically-diagnosed concussions, while 13 did not. Eight participants had a history of one concussion, while nine had multiple concussions (five with two concussions, two with three concussions, and two with four concussions). The participants have had their last concussion in the years ranging from 2023–2011. Nine of them had their last concussion in the years 2023–2018 (two in 2018, one in 2019, two in 2020, two in 2021, one in 2022, and one in 2023), while the others had their last concussion in the years 2017–2011 (one in 2011, one in 2013, one in 2014, one in 2015, one in 2016, and three in 2017). As the circumstances lead to concussions, the participants listed sporting events (13 participants), falling/slipping/tripping (3 participants), and heavy objects falling onto the head (1 participant).

3.1. Baseline Stability Test

There was no significant difference in any sway variable between the CONC and NO CONC groups, ONCE and MULTIPLE groups, or RECENT and OLD groups.

3.2. Clinical Test of Sensory Interaction and Balance (CTSIB) Test

The independent *t*-test of CONC vs. NO CONC groups revealed a significant difference in postural sway between groups in COP-X max ($p = 0.036$; $t = 2.21$; $d = 0.81$), Avg. Displacement along X ($p = 0.016$; $t = 2.57$; $d = 0.95$), and 95 EA ($p = 0.043$; $t = 2.12$; $d = 0.78$) sway variables during the foam BL EO condition (Figure 2). The descriptive statistics for all three variables demonstrated higher values for the CONC group than the NO CONC group. No significant differences between CONC vs. NO CONC groups were observed in firm BL EO, firm BL EC, or foam BL EC conditions.

The secondary analysis of ONCE vs. MULTIPLE groups revealed a significant difference in postural sway between groups in COP-Y max ($p = 0.027$; $t = 2.46$; $d = 1.20$) and 95 EA ($p = 0.037$; $t = 2.29$; $d = 1.11$) sway variables during the foam BL EO condition. The descriptive statistics for both variables demonstrated higher values for the ONCE group than the MULTIPLE group. No significant differences between ONCE vs. MULTIPLE groups were observed in firm BL EO, firm BL EC, or foam BL EC conditions. Furthermore, the secondary analysis of RECENT vs. OLD groups revealed a significant difference in postural sway between groups in COP-X max ($p = 0.019$; $t = 2.63$; $d = 1.28$) in the foam BL EC condition with higher values for the RECENT group than the OLD group.

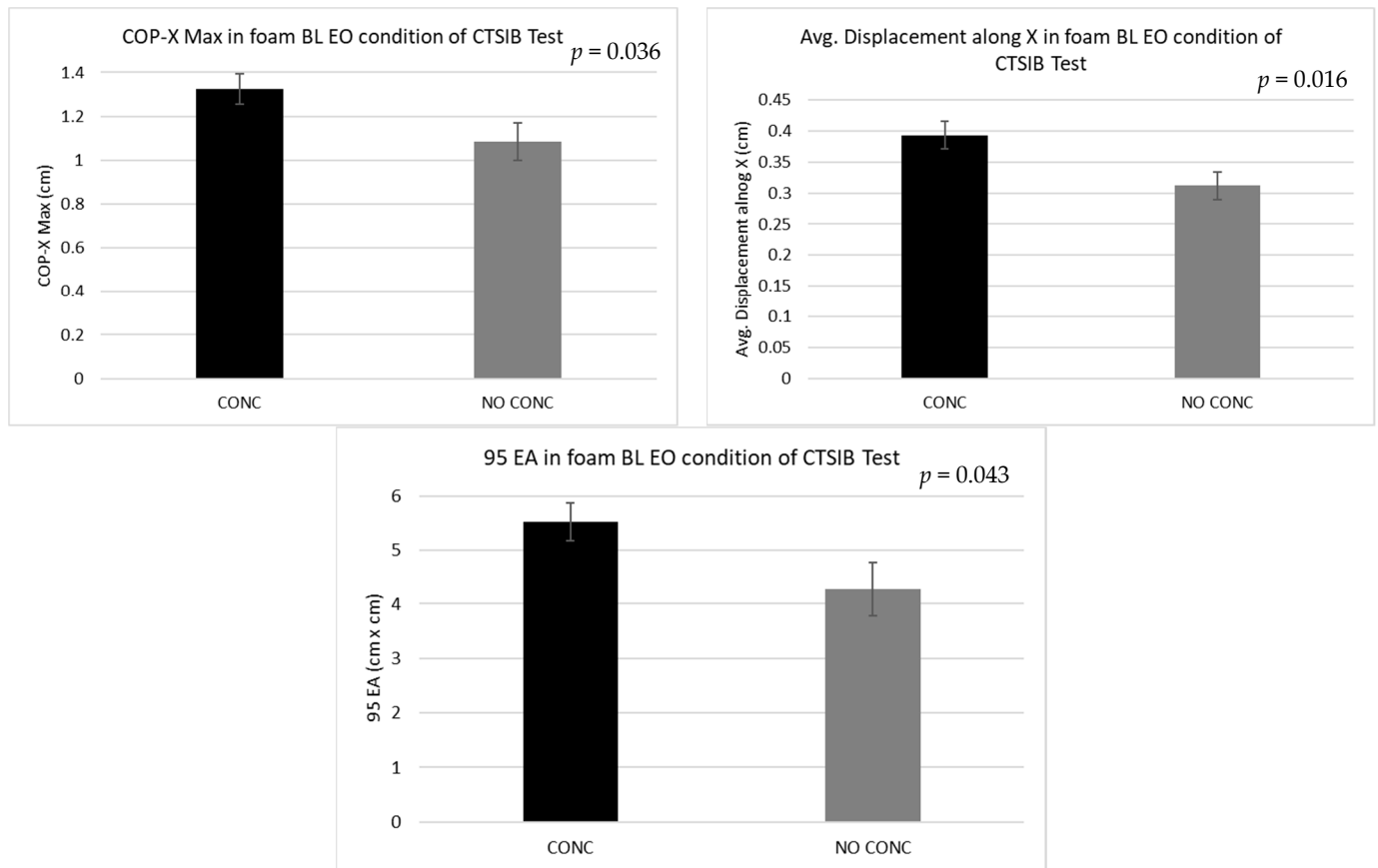


Figure 2. Significant postural sway variables between the individuals with a history of concussion (CONC) and those without concussion (NO CONC) when standing on a foam pad placed on the force platform on both feet with eyes opened (foam BL EO) condition of Clinical Test of Sensory Interaction and Balance (CTSIB) Test. (**Top left**) COP-X max; maximum center of pressure (COP) excursion in the anterior-posterior direction. (**Top right**) Avg. Displacement along X; average COP displacement in the anterior-posterior direction. (**Bottom**) 95 EA; 95% ellipsoid area. Bars represent standard errors.

3.3. Unilateral Stability Test

During this test, significant differences in sway between CONC and NO CONC groups were evident in the DOM EC and ND EC conditions. In DOM EC condition, COP-X max ($p = 0.002$; $t = 3.41$; $d = 1.26$), COP-Y max ($p = 0.045$; $t = 2.09$; $d = 0.77$), Avg. Displacement along X ($p = 0.011$; $t = 2.72$; $d = 1.00$), Avg. Displacement along Y ($p = 0.032$; $t = 2.26$; $d = 0.83$), and 95 EA ($p = 0.024$; $t = 2.38$; $d = 0.88$) demonstrated significant differences with greater postural sway in the CONC group compared to the NO CONC group (Figure 3). Similarly, in ND EC condition, COP-Y max ($p = 0.042$; $t = 2.14$; $d = 0.79$), COP-Y min ($p = 0.046$; $t = 2.09$; $d = 0.77$), Avg. Displacement along Y ($p = 0.009$; $t = 2.80$; $d = 1.03$), and 95 EA ($p = 0.043$; $t = 2.12$; $d = 0.78$) demonstrated significant differences with greater postural sway in the CONC group compared to the NO CONC group (Figure 4). The descriptive statistics for all variables demonstrated higher values for the CONC group than the NO CONC group in both conditions. No significant differences between CONC vs. NO CONC groups were observed in DOM EO or ND EO conditions.

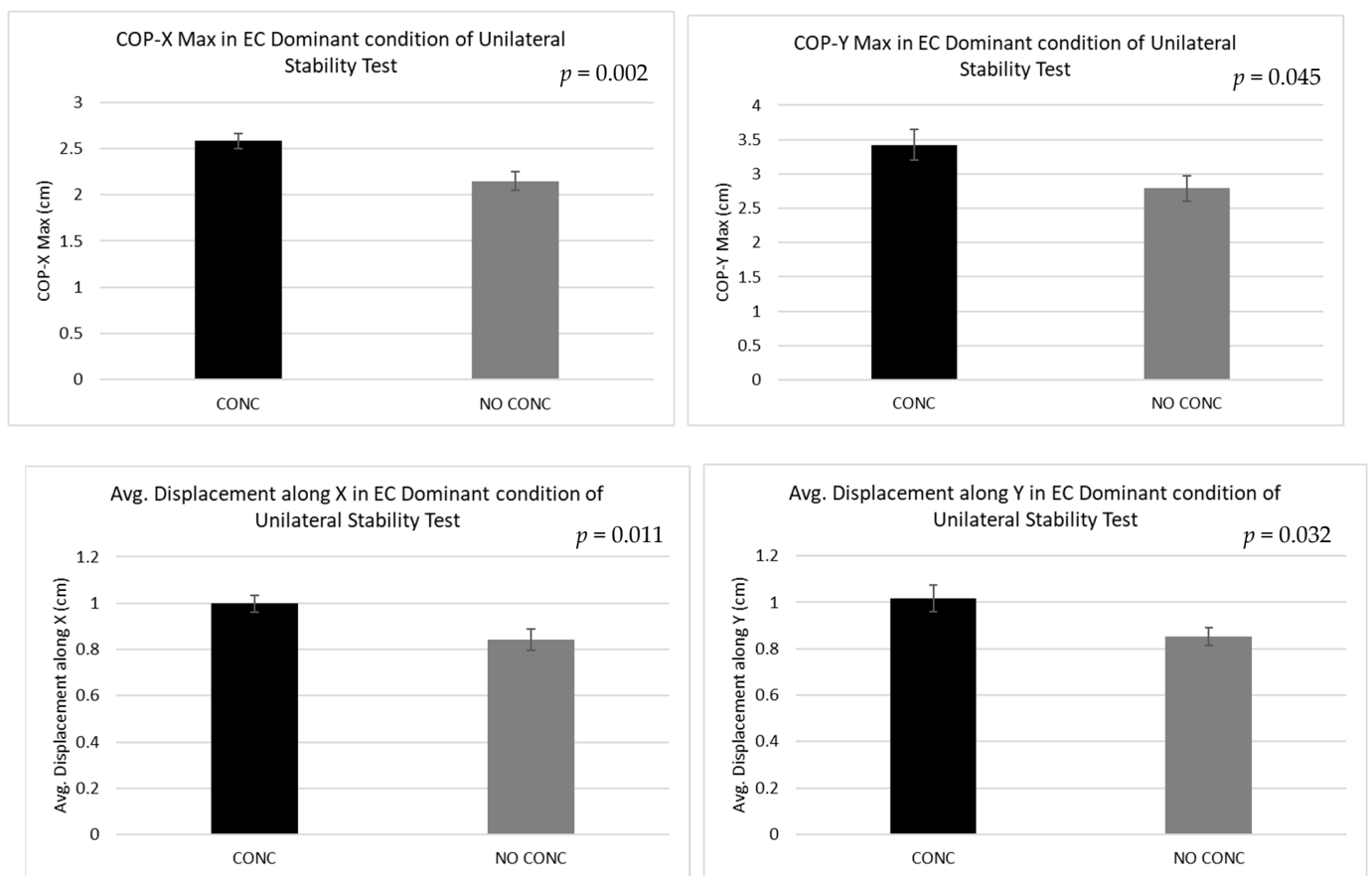


Figure 3. Significant postural sway variables between the individuals with a history of concussion (CONC) and those without concussion (NO CONC) in eyes closed (EC) dominant condition of the unilateral stability test. **(Top left)** COP-X max; maximum center of pressure (COP) excursion in the anterior-posterior direction. **(Top right)** COP-Y max; maximum COP excursion in the medial-lateral direction. **(Bottom left)** Avg. Displacement along X; average COP displacement in the anterior-posterior direction. **(Bottom right)** Avg. Displacement along Y; average COP displacement in the medial-lateral direction. Bars represent standard errors.

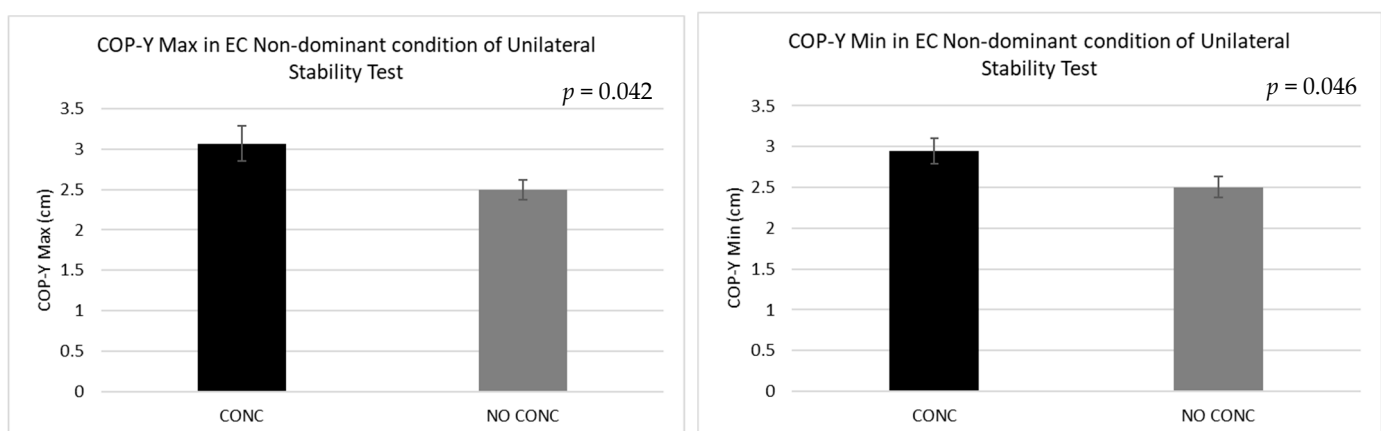


Figure 4. Cont.

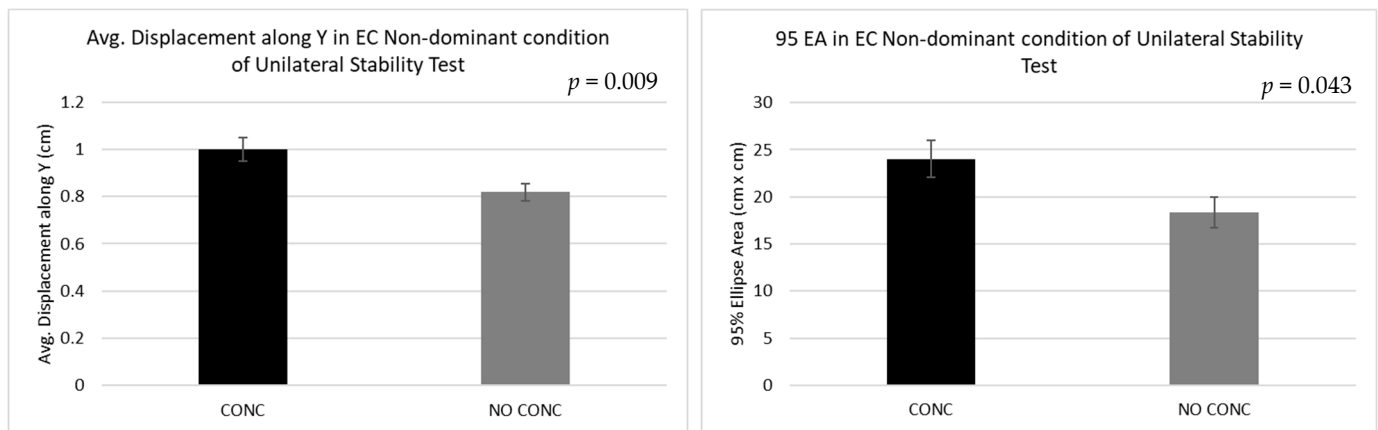


Figure 4. Significant postural sway variables between the individuals with a history of concussion (CONC) and those without concussion (NO CONC) in eyes closed (EC) non-dominant condition of the unilateral stability test. **(Top left)** COP-Y max; maximum center of pressure (COP) excursion in the medial-lateral direction. **(Top right)** COP-Y min; minimum COP excursion in the medial-lateral direction. **(Bottom left)** Avg. Displacement along Y; average COP displacement in the medial-lateral direction. **(Bottom right)** 95 EA; 95% ellipsoid area. Bars represent standard errors.

The secondary analysis of ONCE vs. MULTIPLE groups revealed a significant difference in postural sway between groups in the COP-Y average ($p = 0.019$; $t = 2.62$; $d = 1.27$) during the ND EO condition. The descriptive statistics demonstrated higher values for the ONCE group than the MULTIPLE group. No significant differences between ONCE vs. MULTIPLE groups were observed in the DOM EO, DOM EC, and ND EC conditions.

4. Discussion

The purpose of this study was to assess the effect of concussions on postural stability in young healthy adults. It was hypothesized that a history of concussions would have a negative effect on postural stability. Additionally, it was hypothesized that experiencing multiple concussions and recent concussions would cause greater balance decrements compared to single and old concussions. Overall, the results demonstrated poor postural stability in the group with a concussion history compared to the group that does not have a concussion history.

4.1. Effects of Concussion History on Postural Stability

In the analyses of postural sway variables between the participants with a concussion history (CONC) and without a concussion history (NO CONC), the results revealed that the CONC group had higher postural sway than the NO CONC group, indicating greater postural decrements. More specifically, the CONC group demonstrated greater COP-X max, avg. displacement along X, and 95 EA in the foam BL EO condition of CTSIB. The CONC group also demonstrated greater COP-X max, COP-Y max, avg. displacement along X, avg. displacement along Y, and 95 EA in DOM EC condition, as well as COP-Y max, COP-Y min, avg. displacement along Y, and 95 EA in ND EC condition of unilateral stability test. In essence, the CONC group showed a greater postural sway in both anterior-posterior and medial-lateral directions compared to the NO CONC group. These findings agree with the researchers' original hypothesis that concussions would have a negative effect on postural stability, as well as with the previous studies [3,15,18].

Postural stability decrements following concussions can occur due to multiple reasons. Postural stability in humans is mainly maintained by three main systems: the afferent system, the CNS, and the efferent system. The afferent system consists of the three visual, vestibular, and somatosensory systems, with healthy individuals' somatosensory system contributing to 70% of the postural control in a well-lit room on a firm surface [19]. The CNS

consists of higher brain centers, while the efferent system consists of the musculoskeletal system [20]. Coordination between these systems is required for balance, and any effect on these three systems can affect someone's postural stability. Concussions (and the majority of other traumatic brain injuries) are well-known to affect the vestibular system [21,22]. The vestibular organ located in the inner ear is mainly comprised of three semi-circular canals that detect angular acceleration of the head and the two maculae (sacculae and utricle) that detect linear movement as well as the effects of gravitational force on the body. Moreover, endolymph and hair cells in semicircular canals, along with the hair cells in maculae, detect the direction of body movements [23]. Thus, any disruption to the anatomy of this highly sensitive vestibular system (especially endolymph, hair cells, and natural orientation of the structures) affects the person's postural stability. As concussions result following a severe collision of the head against another surface, it interferes with the vestibular system, which explains the headache, dizziness, lightheadedness, nausea/vomiting, and tinnitus following concussions. Furthermore, the symptoms of photophobia and blurred vision could suggest a disturbance to the individual's visual system, affecting the contribution of their visual system in postural control. The visual system, consisting of eyes, optical tracks, and optic nerves gathers information on the surrounding environment to maintain balance and is considered the fastest sensory system out of the three and hence capable of reacting to acute perturbations [24]. Thus, interruptions to the function of visual systems affect someone's ability in postural stability [25].

In the present study, there were no significant differences in balance between CONC vs. NO CONC groups during the baseline stability test. This was not unexpected since the participants were young healthy adults (age 21.63 ± 2.50 years) who have excellent postural control mechanisms and were shown to recover soon after concussions [26]. Moreover, in the baseline stability test, the participants were standing on a firm surface (force plate), on both feet, with their eyes open, which is not a challenging condition for balance maintenance. The significant differences in balance between CONC vs. NO CONC groups were only observed in foam BL EO condition, and no differences were observed in firm BL EO, firm BL EC, and foam BL EC conditions of CTSIB. In "foam" conditions of CTSIB, the individuals stand on a foam pad placed on the force plate, which is an unstable surface for the participants. In EO conditions, the participants were advised to keep their gaze fixed at a specific point. Thus, the participants sway due to the unstable surface, but the gaze is fixed, leading to conflicting feedback from somatosensory and visual systems, causing postural instability. In healthy individuals, their vestibular system continues to provide correct information even when erroneous or conflicting information is received via other sensory systems [27]. Previous research suggests that the impact of concussions appears to be most prominent on the vestibular system [20,21]. Therefore, the vestibular system of the participants in the CONC group could be already negatively affected by past concussions, leading to compromised corrections made by their vestibular system. This is also supported by the results that the CONC group performed poorly when the tasks required a greater reliance on the vestibular system. During the unilateral stability test, declined performance was observed only when visual input was prevented (in ND EC and DOM EC conditions, but not in DOM EO and ND EO conditions). Further, when there was a significant reduction in their base of support (the unilateral stability test), a greater contribution of the vestibular feedback was required to maintain balance, which could have led to significant findings in UL EC conditions.

4.2. Effects of Multiple Concussions on Postural Stability

In the analyses of postural sway variables between the participants who had a single concussion (ONCE) and multiple concussions (MULTIPLE), the results revealed that the ONCE group had higher postural sway compared to the MULTIPLE group, indicating greater postural decrements. More specifically, the ONCE group demonstrated greater COP-Y max and 95 EA in foam BL EO condition of CTSIB, as well as average displacement along Y in ND EO condition of unilateral stability test. This finding that the participants

with a history of one concussion (ONCE) had a greater postural sway in both anterior-posterior and medial-lateral directions compared to the group who had a history of multiple concussions (MULTIPLE) contradicts the researchers' original hypothesis that multiple concussions would have a greater negative effect on postural stability compared to a single concussion.

These findings could have occurred due to multiple reasons. One reason could be testing the young healthy individuals who are shown to recover from concussions faster and better [26]. Additionally, in the present study, the severity of the concussion(s) and post-concussion management/therapy that the study participants underwent were not taken into consideration, which could have affected the results. For example, an individual who sustained a grade 3 concussion once could potentially have higher balance decrements compared to an individual who had two grade 1 concussions. Recent evidence indicates that early initiation of clinical interventions, including vestibular therapy following concussion, positively impacted the recovery time [28,29] and functional outcomes [30]. Moreover, in the current study, the timing of concussion(s) was not taken into consideration. Therefore, a participant who had a single concussion recently will have more effects on postural stability compared to someone who had multiple concussions a few years ago. The authors assume the results would differ if the severity and timing of concussions were taken into consideration when categorizing participants into ONCE and MULTIPLE groups. In addition to these, the individual participants' activity level, training history, and type of footwear worn could have contributed to the findings.

4.3. Effects of Timing of Concussions on Postural Stability

In the analyses of postural sway variables between the participants who had their last concussion in the years 2023–2018 (RECENT) and those who had their last concussion in the years 2017–2011 (OLD), the results revealed that the RECENT group had higher postural sway compared to the OLD group, indicating greater postural decrements. More specifically, the RECENT group demonstrated greater COP-X max in foam BL EC condition of CTSIB, showing greater postural sway in the anterior-posterior direction compared to the OLD group. This finding agrees with the researchers' original hypothesis that recent concussions would have a greater negative effect on postural stability compared to old concussions. This finding also agrees with the previous research that showed the persisting effects of concussions [3,31,32].

As mentioned above, concussions disrupt the anatomy and physiology of vestibular and visual systems, leading to postural instability. This disruption is pronounced during the immediate three weeks after concussion and is considered to resolve by three months post-concussion [31]. However, this recovery depends on the person and multiple other factors, such as age, activity level, previous history of concussions, the severity of the concussion, co-existing neurological disorders, stress, and pre-mature return to work/play, where some individuals were shown to have lingering effects until a few years post-concussion [31]. As such, they could have postural decrements lasting from immediately after the concussion to a few years until the vestibular system returns to normal. Additionally, concussions cause post traumatic vestibular migraines, positional vertigo, and spatial disorientation, which can have a significant effect on someone's postural stability [21].

The findings of this study have a few practical implications. Since it is evident that concussions cause postural instabilities, it would be a decisive factor when determining an athlete's return to play following a concussion. Premature return to play after a concussion is known to increase their risk of PCS and possibly fatal second impact syndrome, it is crucial to determine the appropriate time to return [33]. As the timing of full recovery is still unclear, balance and gait assessment should be a part of the concussion assessment. Moreover, since disruption of the vestibular structure and function is the major reason for the postural issues following concussions, vestibular rehabilitation therapy (VRT) could improve the recovery time [28,29]. Additionally, it has been shown that when VRT is

combined with cervical therapy, it allows the athletes to be able to return to play within eight weeks of their concussion [29].

This study is not without limitations. Not considering the severity and timing of each concussion was a limitation, which narrowed the possibility of further assessing the effects of multiple concussions on postural stability. As the sample size of the present study was small ($n = 30$; 17 had a history of concussions), the participants were not categorized according to the severity or the timing of the concussion. Thus, having a smaller sample in the CONC group could also have affected the secondary analyses (MULTIPLE vs. ONCE and RECENT vs. OLD comparisons). Hence, future studies could be focused on recruiting a larger sample with a concussion history and considering potential confounding factors, including the severity and timing of concussions and clinical interventions such as VRT in analyses. Furthermore, this study recruited young healthy adults, who are known to have a rapid and excellent recovery; geriatric and clinical populations would yield different results. Additionally, future studies could focus on investigating the timing of full recovery following concussions.

5. Conclusions

In conclusion, the present study demonstrated concussions cause postural decrements in young healthy adults compared to their counterparts who did not have a history of concussions. The secondary analyses showed greater instability among the individuals who had recent concussions compared to the old concussions, as well as in the individuals who had one concussion compared to their counterparts who had multiple concussions. The results of the present study demonstrate that concussions could lead to impaired balance, which is decisive in athletes' performance and injury risk during play. Moreover, the results show that the postural effects of concussion could last for years, and therefore, it is mandatory to perform a balance and gait assessment before returning to play. As the timing of full recovery is yet debatable, further studies are warranted to ascertain the perfect time to return.

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Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki and approved by the Institutional Review Board (or Ethics Committee) of Weber State University (protocol code IRB-AY22-23-301 and 5 February 2023).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data presented in this study are available on request from the corresponding author due to privacy reasons.

Conflicts of Interest: Author Paul Brewer is employed by the company Diverge Neurovision. The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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