Wallmann and VanWye, J Athl Enhanc 2016, 5:4
DOI: 10.4172/2324-9080.1000236

Journal of Athletic Enhancement

Research Article

A SCITECHNOL JOURNAL

Balance Assessment Changes in Female Collegiate Soccer Players over a 2-Year Period

Harvey W Wallmann* and William R VanWye

Abstract

Objective: The purpose of this study was to measure the balance changes in female collegiate soccer players over a 2-year period.

Methods: Seven females from a Division I university soccer team (starting mean age, 17.71 years; SD=0.49) completed the 2-year study. Subjects were assessed on the NeuroCom Smart® Balance Master system before their freshman seasons and were re-tested at the beginning of each subsequent fall season for static balance on the Sensory Organization Test (SOT) and for dynamic balance on the Limits of Stability (LOS) Test. Mean differences were analyzed with repeated measures ANOVA.

Results: Players' overall static balance improved as noted by the increase in the composite equilibrium score for the SOT: $F_{2,12}$=12.94, p=0.001. Pairwise comparisons revealed a significant increase from year 1 [79.1 (2.9)] to year 2 [84.7(3.1)] (p=0.009) and year 1 to year 3 [86.4 (2.8)] (p=0.008). Significant improvements in balance were noted for the following SOT conditions: condition 4 ($F_{2,12}$=3.94, p=0.048); condition 5 ($F_{2,12}$=13.77, p=0.001); and condition 6 ($F_{2,12}$=4.44, p=0.036). Pairwise comparisons revealed changes from year 1 [85.8 (5.4)] to year 3 [91.6 (1.6)] for condition 4 (p =0.05) and year 1 [69.2 (6.4)] to year 3 [79.9 (6.0)] for condition 6 (p=0.036). In condition 5, balance improved from year 1 [59.5 (8.9)] to year 2 [76.5 (6.4)] (p=0.006) and from year 1 to year 3 [76.4 (7.1)] (p=0.008). A significant change was observed in LOS for Backward Endpoint Excursion ($F_{2,12}$=5.44, p=0.021) with pairwise comparisons revealing a significant increase from year 1 [51.0 (11.2)] to year 3 [66.5 (10.2)] (p=0.017).

Conclusion: This study showed that female soccer players' performance increased components of static and dynamic balance, which indicates that participating in soccer may not be detrimental to the overall balance performance of a female collegiate soccer player and may actually enhance it.

Keywords

Static balance; Dynamic balance; Soccer; Female; Concussion; Sensory organization test; Limits of stability test

Introduction

Youth soccer has seen substantial growth in U.S. in the past 40 years with just over 100,000 participants in 1974 to over 3 million in 2014 [1]. This increased participation is evident at the collegiate level as well, with women's soccer growing considerably between 1989 and 2003, increasing from under 300 programs to nearly 900 [2]. At one time soccer was touted as a safe alternative to other pediatric sports, especially for females [3]. However participation in any sport has inherent risk and, with increased participation in soccer, injury rates will undoubtedly be increased.

The most common in-game injuries in women's collegiate soccer are ankle ligamentous injuries, internal knee derangements, and concussions with the latter accounting for nearly 9% of all in-game injuries [4]. In 2004, Schulz et al. [5] estimated that for every 100,000 female soccer athlete exposures, one could expect 13.2 concussions. The most common mechanism of a concussion in women's collegiate soccer is contact with another player (68%) followed by contact with the ball (18%) [6]. While a concussion may not be the most frequent injury to female soccer players, there is concern regarding the long-term ramifications given the seriousness of the injury. Some have criticized use of heading the ball, especially since this aspect of the game could be reduced or removed entirely as advocated by researchers and professional athletes [7-10]. Heading does have acute and chronic consequences as there is significant evidence of neurological changes due to sub-concussive impacts. For example, the short and long-term effects of heading and head impacts have been shown to significantly affect cognitive abilities such as IQ, attention, verbal, visual, and working memory, planning and decision making, visuoperceptual processing, concentration and cognitive flexibility [11-20].

It has been suggested that a cumulative effect of multiple concussions may be evident in collegiate athletes [21,22]. College student athletes are playing soccer at a high level on a year-round basis, therefore it is possible, through multiple sub-concussive impacts secondary to heading, that the athlete may exhibit other neurological deficits in addition to cognitive decrements such as alterations in balance. Whereas cognitive deficits in soccer players may take many years post-participation for it to be evident, balance may be adversely affected earlier after a concussion [23,24].

Interestingly, early investigations demonstrated that postural control and balance were not impaired acutely after heading a soccer ball [11,25,26]. More recently however, Haran and colleagues did find postural deficits within one hour of heading, returning to baseline values within 48 hours [27]. The authors hypothesized that these aforementioned studies did not correctly observe acute changes possibly due to methodological flaws such as inadequate control of ball velocity and failing to verify sensitivity of the postural assessment; as such, they may not have been able to ensure that the postural control system was challenged adequately enough to elicit instability or lacked testing for statistical validity threats [27]. Balance has been defined as the ability to maintain the center of gravity (COG) within the body's base of support [28]. This ability involves multiple neurological pathways. Afferent information received from the body's vestibular, visual, and somatosensory systems determine the postural strategies necessary to maintain balance. Balance is often measured using computerized dynamic posturography (CDP). Using a computerized forceplate, CDP is used to measure static or dynamic balance and can assess postural sway (sway) by measuring shifts in

***Corresponding author:** Harvey W Wallmann, Department of Physical Therapy, Western Kentucky University, The Medical Center – WKU Health Sciences Complex, 700 First Avenue Bowling Green, KY 42101, USA, Tel: (270) 745-4070; Fax: (270) 745-3497; E-mail: harvey.wallmann@wku.edu

Received: July 13, 2016 **Accepted:** September 06, 2016 **Published:** September 12, 2016

the COG [29]. An inability to maintain COG over the base of support results in impaired balance.

The purpose of this study was to assess balance changes in female collegiate soccer players over a 2-year period using CDP. If any sub-concussive forces are present and micro-damage occurs each time a player heads the ball, it might logically follow that an increased amount of practice and games may produce a decrement in the female collegiate soccer player's balance over a multiple year period. We hypothesized that female collegiate soccer players would experience a decrement in their balance skills due to lower extremity injuries or the accumulation of subconcussive head injuries.

Methods

Seven females from a Division I university soccer team (starting mean age, 17.71 years; *SD*=0.49) completed the study. Approval was obtained from the university Biomedical IRB to perform baseline balance testing on the women's soccer team before the start of the freshman season and each fall thereafter. We approached the head women's soccer coach and gained approval to conduct the longitudinal testing protocol. In addition, all athletes gave oral and written consent to conduct the testing. In year one, we tested all of the incoming freshmen players with the intent of testing this group during the 4 years of their university soccer career. Each year thereafter we tested the incoming freshmen players and each player who had been tested in a previous year. The number of players tested each year changed due to players electing not to participate on the university soccer team, transferring to a different university, and the number of freshmen players recruited to the soccer team. As such, only 7 freshman players completed a 2-year testing period (3 tests).

Quantitative measurements of balance and postural control through the use of CDP have provided clinicians with the ability to objectively measure the multiple dimensions of the postural components of balance [30-32]. The NeuroCom Smart Balance® Master (Balance Master) system represents this type of technology (NeuroCom International, Inc., Clackamas, OR 97015) and was used to administer the Sensory Organization Test (SOT) and the Limits of Stability (LOS) test. Several studies have been conducted establishing the test-retest reliability, sensitivity, and validity for both the SOT and the LOS test [30-40].

Each player had significant experience playing soccer as is evident by their status as a Division I collegiate soccer player. The authors did not measure hydration status, BMI or VO_{2max}. Although dehydration may be common in soccer players, it appears hypohydration does not affect postural stability [41]. Hypohydration and acute thermal stress affect mood state, but not cognition or dynamic postural balance [42]. There was no account of playing surface or player position. Although some positions in soccer may be more likely to head the ball, there is controversy as to whether position on the soccer field places an athlete at higher risk for head injury over another [16].

Measures

SOT measures

The SOT measures sway and is designed to quantify one's ability to maintain balance in a variety of complex sensory conditions, providing information as to which cues the individual is unable to utilize when attempting to maintain postural control during a specific task. The SOT is sensitive to specific underlying impairments sufficient to distinguish between impairments in postural control and the effective combined use of the vestibular, visual, and somatosensory systems [43]. The conditions of the SOT include various combinations of eyes open, eyes closed, fixed support, sway-referenced support, and sway-referenced visual conditions. Sway referenced conditions involve tilting the support surface and/or the visual surround to follow the person's sway in an anterior-posterior direction and is similar to the postural challenges for activities such as leaning and reaching [29,44].

In order to interpret the SOT results, the composite score must first be examined. The composite score consists of the average of three equilibrium scores for each of the six trial conditions [43]. Equilibrium scores are expressed as a percentage between 0 and 100 with 0 indicating sway that exceeds the limits of stability, resulting in a loss of balance, and 100 indicating perfect stability. Results from the SOT allow researchers to determine the amplitude of postural sway oscillations as each trial progresses.

LOS measures

The LOS test measures volitional control of the COG, while simultaneously assessing speed, direction, and distance of COG movement. The LOS is specific boundaries of space where the body can maintain its position without changing its base of support [45].

Dynamic standing balance refers to how well an individual can lean/weight shift over a stable base of support in a controlled manner. The LOS test quantifies the subject's ability to quickly and accurately move the COG from a centered position to eight peripheral positions in forward, backward, left, right, and diagonal directions toward the LOS boundary and briefly maintain stability at those positions. For each movement direction, measurements include reaction time, average velocity including on-axis and off-axis sway components, path sway, end point excursion, and maximum excursion.

Equipment

The SOT and LOS test protocols are administered using the Balance Master [43], which consists of a movable dual force platform (forceplate), movable monitor, and an overhead safety bar with safety straps. For certain conditions, the forceplate moves forward or backward, depending on the individual's ability to stand still. In addition to the computer-controlled moveable forceplate, there is also a moveable visual surround booth. The force plate and booth move in response to the subject's forward and backward sway, creating a compromised proprioceptive and/or visual input to the brain. A computer analyzes the center of force versus time responses.

Procedures

Subjects stood in their stocking feet where they were placed in a safety harness attached overhead on the Balance Master unit. They were then positioned on the unit forceplate according to the manufacturer's standard protocol for both tests [43] with the medial malleoli being placed over the placement strip imprinted on the platform. The subjects were instructed to stand quietly with their hands on their hips or their arms at their sides for the SOT and LOS tests, respectively, and to keep their feet in the correct position at all times during each trial.

SOT procedures

During the SOT, subjects were exposed to three 20-second trials for each of six conditions (Figure 1). The protocol for the SOT was as follows:

doi: 10.4172/2324-9080.1000236

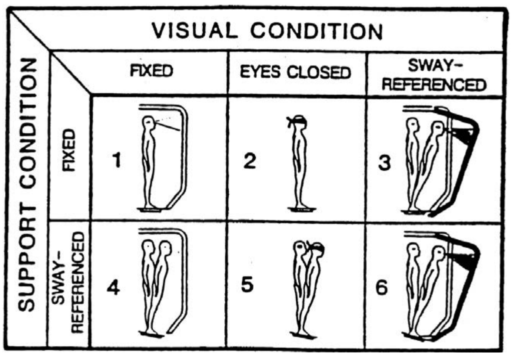

Figure 1: Reproduced by kind permission of NeuroCom® International, Inc.

Eyes open, fixed support surface and surround (visual, vestibular, and somatosensory modalities available)

Eyes closed, fixed support surface and surround (absent visual input)

Eyes open, sway-referenced surround and fixed support surface (visual input inaccurate)

Eyes open, sway-referenced support surface and fixed surround (somatosensory inputs inaccurate)

Eyes closed, sway-referenced support surface and fixed surround (absent visual input and somatosensory input inaccurate)

Eyes open, sway-referenced surround and support surface (inaccurate visual and somatosensory inputs)

The first trial of each condition was performed consecutively with instructions to familiarize the subject with the equipment. However, the next 12 trials were performed in a random order, so as not to bias the subject as to what to expect.

LOS procedures

During the LOS test, subjects were exposed to four predetermined square targets, excluding the center one, which represents the centered COG and starting position. The targets are located on a video screen in front of the individual at eye level. Each target is spaced at 90-degree intervals around an oval representing 100% of the distance from the center position to the theoretical LOS. Subjects were instructed to stand as still as possible while in the center target area and asked to move the cursor in the center target by moving to the designated LOS target, hold that position so that the cursor coincides with the target displayed until the termination of the trial, and then return to the center target. The targets are sequentially highlighted in a clockwise direction during testing. If subjects were not able to reach the target, they were instructed to lean as far as possible in that direction without losing balances. Foot position was checked during and after each test and repositioned if necessary following loss of balance or foot shift during testing. One practice trial to the initial target was allowed in order to familiarize the subject with the test.

Players who experienced lower extremity or head injuries were not excluded from the study. There were reports of lower extremity injuries such as ankle sprains and knee injuries; however, there were no reported head concussions in any of the subjects being tested during the course of this study period, therefore, no subjects were excluded from the study for these reasons. Players were scheduled for an annual balance testing battery when they reported back to school each year. The subjects' results were maintained in a file after the Balance Master Test battery was completed each time.

Data analysis

Mean differences across the course of the 2-year study were analyzed with repeated measures ANOVA using SPSS version 23. The Huynh-Feldt correction was applied in cases where the sphericity assumption was violated. Pairwise comparisons were used to determine the nature of significant F-statistics ($\alpha=0.05$).

Results

The means and standard deviations (SD) for significant SOT composite equilibrium scores, individual SOT condition scores, and LOS scores are presented in Table 1.

Composite equilibrium SOT score

We found that the female soccer players' overall static balance improved as noted by the increase in the composite equilibrium score for the SOT: $F_{2,12}=12.94$, $p=0.001$. Pairwise comparisons revealed a significant increase from year 1 to year 2 ($p= 0.009$) and year 1 to year 3 ($p=0.008$).

Individual SOT conditions

Significant improvements in balance were noted for the following conditions: condition 4($F_{2,12}=3.94$, $p=0.048$); condition 5 ($F_{2,12}=13.77$, $p=0.001$); and condition 6($F_{2,12}=4.44$, $p=0.036$). Pairwise comparisons revealed changes from year 1 to year 3 for condition 4 ($p=0.05$) and condition 6 ($p =0.036$). In condition 5, balance improved from year 1 to year 2 ($p=0.006$) and from year 1 to year 3 ($p=0.008$).

In condition 4, the eyes are open and the force plate may move, but the surround booth does not. This means that subjects were able to improve their ability to overcome inaccurate somatosensory inputs from the ground. In condition 5, the eyes are closed and the force plate may move. In this case, subjects revealed that they overcame absent visual input as well as inaccurate somatosensory input. In condition 6, the eyes are open and the force plate as well as the surround booth may move. Subjects in this condition were able to overcome inaccurate visual and somatosensory inputs.

Individual LOS conditions

A significant change was observed in LOS for Backward Endpoint Excursion ($F_{2,12}=5.44$, $p=0.021$) with pairwise comparisons revealing a significant increase from year 1 to year 3 ($p=0.017$). Essentially, this means that subjects were able to significantly move their COG further straight backward while maintaining their balance.

Discussion

The purpose of this study was to determine if any significant changes in balance occurred to female collegiate soccer players over a 2-year period. Initially, we hypothesized that over successive playing seasons a female collegiate soccer player would experience a decrement in their balance skills due to lower extremity injury or head injury. However, our findings revealed significant improvements in the more challenging conditions (SOT4–SOT6) and the composite equilibrium score (overall balance) across years 1-3, demonstrating that balance improved over the 2 year period in collegiate female soccer players. This may have been due to participation in soccer. However, it is possible that weight training, body conditioning, and/or maturation effects may have played a role in this improvement.

doi: 10.4172/2324-9080.1000236

Table 1: Means and Standard Deviations for years 1 to 3 for SOT Composite Equilibrium Score, Conditions 4-6 and, LOS Backward Endpoint Excursion.

Condition	Year 1	Year 2	Year 3	P	Power
SOT Composite Equilibrium	79.1 (2.9)	84.7 (3.1)	86.4 (2.8)	0.001*	0.98
SOT Condition 4	85.8 (5.4)	89.1 (3.2)	91.6 (1.6)	0.048*	0.59
SOT Condition 5	59.5 (8.9)	76.5 (6.4)	76.4 (7.1)	0.001*	0.99
SOT Condition 6	69.2 (6.4)	76.0 (9.4)	79.9 (6.0)	0.036*	0.65
LOS Backward Endpoint Excursion	51.0 (11.2)	62.9 (13.8)	66.5 (10.2)	0.021*	0.74

* p<.05

SOT – Sensory Organization Test

LOS – Limits of Stability

While these results do not prove cause and effect, they do warrant further research using a more rigorous research design. A systematic review and meta-analysis by Muehlbauer and colleagues found correlations, albeit small-sized, between balance and LE strength and power across the lifespan. Therefore, the athletes' training/strength and conditioning programs could be a possible explanation for the improved balance over time [46].

An accurate comparison of this study to similar studies is difficult secondary to a lack of published literature involving long-term heading and soccer on balance functioning. Those who have examined post-concussion injuries have demonstrated short-term postural stability (balance) deficits in collegiate athletes [47,48]. Studies by Mangus et al. [26] and Broglio et al. [25] involving collegiate soccer players showed that heading a soccer ball multiple times in succession did not result in adverse changes in their balance. However, their studies did not examine the cumulative neurological effects of multiple heading experiences over a longer time period. As such, there is currently no literature to suggest the potential long-term consequences of heading a soccer ball.

Division 1 collegiate soccer teams are generally training year round with the majority of their matches being played in the fall followed by intense training and fewer matches in the spring semester. Although it was not measured in this current study, it was assumed that the soccer players would be heading the ball regularly in practice and competition. On average, soccer players perform 6-16 headers per game, resulting in the possibility of thousands of headings over a player's career [10,18,49-52]. Observations of soccer teams have revealed a great number of headers take place during practices and scrimmages as well [53].

Considering the aforementioned literature regarding the impact of heading on neurocognitive function, we hypothesized the athletes in this study would experience a decrement in their balance skills due to lower extremity injuries or the accumulation of sub concussive head injuries. Therefore, considering the results of this study, it is possible that alterations in static and dynamic balance may not be sensitive enough to detect long-term alterations related to heading.

We monitored head injuries such as concussions (of which there was not a single diagnosed concussion in this subject pool over the 2 year period) and lower extremity injuries. The number of lower extremity injuries over the data collection period was similar to the number of injuries of other Division 1 female soccer teams [4]; however, there were no injuries that prevented a player from completing the balance testing.

Guskiewicz et al. [44] reported balance deficits in athletes experiencing mild head injury for 3 days post-injury using the SOT, while Peterson et al. [48] demonstrated short-term neuropsychological and posturography deficits following injury. Studies by Matser et al. [11,12] examined the effects of sub-concussive events on the neurological system, which they described as "the cumulative long-term neurological consequences of repetitive concussive and sub-concussive blows to the head." Both studies suggested that heading could be dangerous to the mental functioning of the athlete. The current study examined potential long-term sub-concussive events, but showed no indication of any detrimental balance changes to the athletes.

Between the possibilities of a concussion from head-to-head contact to the increased potential for a lower extremity injury, one would be highly swayed to imagine these female athletes would experience a decrement in their balance performance over the 2-year period of the study. However, the female soccer players in this study actually improved in some of their balance capabilities over this time period. Thus, with injuries to the lower extremities and the constant potential of sub-concussive forces being placed on the head from participation, the actual increases in balance practice opportunities seemed to be helpful to these athletes resulting in improvement in their balance capabilities.

Test conditions SOT 1 and SOT 2 represent baseline scores and require only standing in place with eyes open or closed, respectively, with no perturbations. Consequently, they are the easiest to perform. In the present study, no differences were found within the subjects across the 2 years for these conditions. This is to be expected, since very little sway should be apparent with these conditions. However, sway-referencing occurs in test conditions SOT 3 through SOT 6. The individual's ability to balance in place is stressed by introducing perturbations in either the support platform or the surround booth based on their response to the perturbations. With disturbance of the support surface, vision becomes the dominant input and the individual will probably use vision to balance. Disturbing both the support surface and vision results in vestibular inputs becoming dominant to resolve the sensory conflict [54]. In a sway–referenced environment, the healthy individual should perceive that their orientation in space remains the same when in fact it is changing [32].

In this study, significant improvements were observed in conditions SOT4–SOT6 and the composite equilibrium score (overall balance score) across the 2 years, demonstrating that engaging in collegiate soccer potentially enhances balance as measured by the Balance Master SOT over the 2 year period. This suggests that women soccer players may have improved the ability of the posture control system to effectively use information from the 3 sensory systems to maintain balance over time.

Moreover, the composite equilibrium score revealed significant improvements for each of the 3 time intervals tested. This suggests that overall improvement in balance occurred not just in the early phases of the program, but throughout the entire 2 years.

Soccer training and playing also appear to improve backward balance, as was evidenced by the significant increase in Backward Endpoint Excursion. As was previously mentioned, this means that the athletes were able to move their COG further backward while maintaining their balance. This essentially serves to increase the base of support and allows the athletes to potentially carry out functions requiring backward movements within a more extended area posteriorly without losing balance. In other words, athletes may be able to bend backwards more (shift COG further back), which could allow them to kick and/or head the ball more effectively.

Improvements in this group of individuals may exist for several reasons. Sensory organization involves comparison among the visual, somatosensory, and vestibular systems and between the different body parts [44]. The SOT identifies impairments in these 3 sensory systems that contribute to balance. Soccer emphasizes the utilization of these skills. Therefore, it is possible that soccer taxes all 3 of the sensory systems, thereby resulting in a general improvement of motor and sensory orientation. Feedback obtained from the sensory systems relays commands to the extremity muscles, thereby generating appropriate contractions to maintain postural stability [44,55].

Some limitations do exist with the current study. A learning effect may have been evident, as this was a feasibility study and there was no control group. However, given the fact that there were significant increases from year 1 to 2 as well as year 2 to 3 within the different conditions, in addition to randomization of trials for each condition, we believe that this may not be as likely a factor. The SOT does not provide feedback to the subject and the LOS provides process feedback, but not outcome feedback (i.e., how to do the test, but not how well you did). Therefore, the athletes could not analyze their results in order to make improvements based on this information. Lastly, the small number of subjects and the lack of control group make it difficult to generalize these results to all soccer populations.

However, one cannot completely attribute these improvements in balance to their soccer involvement alone. There were variables that might positively or adversely influence balance which were not controlled during this 2-year period. What is interesting to note is that the female players in this study demonstrated an overall improvement even with the possibility of numerous injury opportunities that would result in a balance decrement over the data collection period.

Conclusion

Initially, we hypothesized that over successive playing seasons a collegiate soccer player would experience a decrement in their balance skills due to extremity or head injury. In this study, components of the soccer player's static and dynamic balance capabilities actually increased indicating that participation in collegiate level soccer may not be detrimental to the balance capabilities of the female soccer player.

Ethical approval: Approval for the study was obtained from the university Biomedical Institutional Review Board.

References

1. Key Statistics US Youth Soccer.
2. National Federation of State High School Associations. 2014-15 High School Athletics Participation Survey.
3. Fields SK (2005) Female gladiators: gender, law, and contact sport in America. Urbana, University of Illinois Press, USA.
4. Dick R, Putukian M, Agel J, Evans TA, Marshall SW (2007) Descriptive epidemiology of collegiate women's soccer injuries: National Collegiate Athletic Association Injury Surveillance System, 1988-1989 through 2002-2003. J Athl Train 42: 278-285.
5. Schulz MR, Marshall SW, Mueller FO, Yang J, Weaver NL, et al. (2004) Incidence and risk factors for concussion in high school athletes, North Carolina, 1996-1999. Am J Epidemiol 160: 937-944.
6. Gessel LM, Fields SK, Collins CL, Dick RW, Comstock RD (2007) Concussions among United States high school and collegiate athletes. J Athl Train 42: 495-503.
7. Sports Legacy Institute Safer soccer initiative.
8. Baroff GS (1998) Is heading a soccer ball injurious to brain function? J Head Trauma Rehabil 13: 45-52.
9. Putukian M (2004) Heading in soccer: is it safe? Curr Sports Med Rep 3: 9-14.
10. Spiotta AM, Bartsch AJ, Benzel EC (2012) Heading in soccer: dangerous play? Neurosurg 70: 1-11.
11. Matser EJ, Kessels AG, Lezak MD, Jordan BD, Troost J (1999) Neuropsychological impairment in amateur soccer players. J Am Med Assoc 282: 971-973.
12. Matser JT, Kessels AG, Jordan BD, Lezak MD, Troost J (1998) Chronic traumatic brain injury in professional soccer players. Neurol 51: 791-796.
13. Matser JT, Kessels AG, Lezak MD, Troost J (2001) A dose-response relation of headers and concussions with cognitive impairment in professional soccer players. J Clin Exp Neuropsychol 23: 770-774.
14. Downs DS, Abwender D (2002) Neuropsychological impairment in soccer athletes. J Sports Med Phys Fitness 42: 103-107.
15. Tysvaer AT, Lochen EA (1991) Soccer injuries to the brain. A neuropsychologic study of former soccer players. Am J Sports Med 19: 56-60.
16. Witol AD, Webbe FM (2003) Soccer heading frequency predicts neuropsychological deficits. Arch Clin Neuropsychol 18: 397-417.
17. Rutherford A, Stephens R, Potter D, Fernie G (2005) Neuropsychological impairment as a consequence of football (soccer) play and football heading: preliminary analyses and report on university footballers. J Clin Exp Neuropsychol 27: 299-319.
18. Rutherford A, Stephens R, Fernie G, Potter D (2009) Do UK university football club players suffer neuropsychological impairment as a consequence of their football (soccer) play? J Clin Exp Neuropsychol 31: 664-681.
19. Straume-Naesheim TM, Andersen TE, IM KH, McIntosh AS, Dvorak J, et al. (2009) Do minor head impacts in soccer cause concussive injury? A prospective case-control study. Neurosurg 64: 719-725.
20. Webbe FM, Ochs SR (2003) Recency and frequency of soccer heading interact to decrease neurocognitive performance. Appl Neuropsychol 10: 31-41.
21. Collins MW, Lovell MR, Iverson GL, Cantu RC, Maroon JC, et al. (2002) Cumulative effects of concussion in high school athletes. Neurosurg 51(5): 1175-1179.
22. Iverson GL, Gaetz M, Lovell MR, Collins MW (2004) Cumulative effects of concussion in amateur athletes. Brain Inj 18: 433-443.
23. Catena RD, van Donkelaar P, Chou LS (2007) Altered balance control following concussion is better detected with an attention test during gait. Gait Posture 25: 406-411.
24. Cavanaugh JT, Guskiewicz KM, Giuliani C, Marshall S, Mercer VS, et al. (2006) Recovery of postural control after cerebral concussion: new insights using approximate entropy. J Athl Train 41: 305-313.
25. Broglio SP, Guskiewicz KM, Sell TC, Lephart SM (2004) No acute changes in postural control after soccer heading. Br J Sports Med 38: 561-567.
26. Mangus BC, Wallmann HW, Ledford M (2004) Analysis of postural stability in collegiate soccer players before and after an acute bout of heading multiple soccer balls. Sports Biomech 3: 209-220.
27. Haran FJ, Tierney R, Wright WG, Keshner E, Silter M (2013) Acute changes in postural control after soccer heading. Int J Sports Med 34: 350-354.
28. Nashner LM, Peters JF (1990) Dynamic posturography in the diagnosis and management of dizziness and balance disorders. Neurologic Clinics 8: 331-349.

doi: 10.4172/2324-9080.1000236

29. Judge JO, King MB, Whipple R, Clive J, Wolfson LI (1995) Dynamic balance in older persons: effects of reduced visual and proprioceptive input. J Gerontol A Biol Sci Med Sci 50: M263-270.

30. Clark S, Rose DJ, Fujimoto K (1997) Generalizability of the limits of stability test in the evaluation of dynamic balance among older adults. Arch Phys Med Rehabil 78: 1078-1084.

31. Hageman PA, Leibowitz JM, Blanke D (1995) Age and gender effects on postural control measures. Arch Phys Med Rehabil 76: 961-965.

32. Monsell EM, Furman JM, Herdman SJ, Konrad HR, Shepard NT (1997) Computerized dynamic platform posturography. Otolaryngol Head Neck Surg 117: 394-398.

33. Blaszczyk J, Lowe D, Hanson P (1994) Ranges of postural stability and their changes in the elderly. Gait Posture 2: 11-17.

34. Camicioli R, Panzer VP, Kaye J (1997) Balance in the healthy elderly: Posturography and clinical assessment. Arch Neurol 54: 976-981.

35. Goebel JA, Sataloff RT, Hanson JM, Nashner LM, Hirshout DS, et al. (1997) Posturographic evidence of nonorganic sway patterns in normal subjects, patients, and suspected malingerers. Otolaryngol Head Neck Surg 117: 293-302.

36. Paloski WH, Black FO, Reschke MF, Calkins DS, Shupert C (1993) Vestibular ataxia following shuttle flights: effects of microgravity on otolith-mediated sensorimotor control of posture. Am J Otol 14: 9-17.

37. Shepard NT, Telian SA (1996) Practical management of the balance disorder patient. San Diego: Singular Pub. Group.

38. Topp R, Mikesky A, Thompson K (1998) Determinants of four functional tasks among older adults: an exploratory regression analysis. J Orthop Sports Phys Ther 27: 144-153.

39. Whipple R, Wolfson L, Derby C, Singh D, Tobin J (1993) Altered sensory function and balance in older persons. J Gerontol 48: 71-76.

40. Wolfson L, Whipple R, Derby CA, Amerman P, Murphy T, et al. (1992) A dynamic posturography study of balance in healthy elderly. Neurol 42: 2069-2075.

41. Castro-Sepulveda M, Astudillo J, Letelier P, Zbinden-Foncea H (2016) Prevalence of Dehydration Before Training Sessions, Friendly and Official Matches in Elite Female Soccer Players. J Hum Kinet 50: 79-84.

42. Ely BR, Sollanek KJ, Cheuvront SN, Lieberman HR, Kenefick RW (2013) Hypohydration and acute thermal stress affect mood state but not cognition or dynamic postural balance. Eur J Appl Physiol 113: 1027-1034.

43. NeuroCom International (2001) Balance Master's Operator's Manual. Clackamas, OR: NeuroCom International, 2001.

44. Guskiewicz KM, Perrin DH, Gansneder BM (1996) Effect of Mild Head Injury on Postural Stability in Athletes. J Athl Train 31: 300-306.

45. Shumway-Cook A, Woollacott M (1995) Control of posture and balance. In: Motor Control: Theory and Practical Applications. Baltimore: Williams and Wilkins; USA.

46. Muehlbauer T, Gollhofer A, Granacher U (2015) Associations between measures of balance and lower-extremity muscle strength/power in healthy individuals across the lifespan: A systematic review and meta-analysis. Sports Med 45: 1671-1692.

47. Guskiewicz KM, Ross SE, Marshall SW (2001) Postural Stability and Neuropsychological Deficits After Concussion in Collegiate Athletes. J Athl Train 36: 263-273.

48. Peterson CL, Ferrara MS, Mrazik M, Piland S, Elliott R (2003) Evaluation of neuropsychological domain scores and postural stability following cerebral concussion in sports. Clin J Sport Med 13: 230-237.

49. Ekblom B (1986) Applied physiology of soccer. Sports Med 3: 50-60.

50. Straume-Naesheim TM, Andersen TE, Dvorak J, Bahr R (2005) Effects of heading exposure and previous concussions on neuropsychological performance among Norwegian elite footballers. Br J Sports Med 39: i70-77.

51. Tysvaer A, Storli O (1981) Association football injuries to the brain. A preliminary report. Br J Sports Med 15: 163-166.

52. Koerte IK, Mayinger M, Muehlmann M, Kaufmann D, Lin AP, et al. (2015) Cortical thinning in former professional soccer players. Brain Imaging Behav 10: 792-798.

53. Kaminski TW, Wikstrom AM, Gutierrez GM, Glutting JJ (2007) Purposeful heading during a season does not influence cognitive function or balance in female soccer players. J Clin Exp Neuropsychol 29: 742-751.

54. O'Sullivan SB, Schmitz TJ (2001) Physical Rehabilitation: Assessment and treatment. (4th edn), Philadelphia, USA.

55. Shumway-Cook A, Horak FB (1986) Assessing the influence of sensory interaction of balance. Phys Ther 66: 1548-1550.

Author Affiliation

Top

Department of Physical Therapy, Western Kentucky University, USA