

## [ Athletic Training ]

# Examination of Age-Related Differences on Clinical Tests of Postural Stability

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**Background:** The modified Balance Error Scoring System (mBESS) and Y-Balance Test are common clinical measurements of postural control, but little is known about the effect of age on performance of these tasks. The purpose of this study was to examine how healthy child and adolescent athletes perform on 2 common clinical measurements of postural control.

**Hypothesis:** Younger athletes would demonstrate poorer postural control compared with older athletes.

**Study Design:** Cross-sectional study.

**Level of Evidence:** Level 3.

**Methods:** Three hundred eighty-nine athletes between the ages of 10 and 18 years underwent an evaluation of postural control. Each participant completed the mBESS in the double-leg, single-leg, and tandem stances as well as the Y-Balance Test. Postural stability data were analyzed between age groups (10-12, 13-15, and 16-18 years) using univariate analyses of covariance.

**Results:** The youngest athletes (10-12 years) had a greater mean number of errors in the single-leg stance of the mBESS than the 13- to 15-year-old and 16- to 18-year-old athletes (3.8, 3, and 2.5 errors, respectively;  $P < 0.01$ ). They also had greater right to left asymmetry compared with the 16- to 18-year-old athletes on the Y-Balance Test in the posterolateral (6.8 and 3.8 cm, respectively;  $P = 0.006$ ) and posteromedial (5.3 and 3.6 cm, respectively;  $P = 0.014$ ) directions of movement.

**Conclusion:** Athletes between the ages of 10 and 12 years performed worse on the single-leg stance of the mBESS and demonstrated more asymmetry on the Y-Balance Test in the posterolateral and posteromedial directions compared with older athletes.

**Clinical Relevance:** In the absence of a baseline balance test for athletes younger than the age of 13 years, caution should be used in interpreting postural stability assessments, as age may be a modifying factor in performance.

**Keywords:** postural control; balance; development; adolescence

Postural control is the orientation of the body in relation to gravity, whereas balance is the body posture dynamics that prevent falling.<sup>36</sup> Postural control is regulated by the integration of the vestibular, somatosensory, and visual systems.<sup>1</sup> These systems develop at different rates throughout childhood<sup>33</sup>; therefore, performance may change across time on clinical balance tasks commonly used in postinjury evaluations for concussion and ankle sprains. The

vestibular and visual systems develop after the somatosensory system has fully developed,<sup>11</sup> and children experience the greatest development of sensory integration between the ages of 4 and 6 years.<sup>33</sup> The age of full vestibular and visual system maturation varies, as some studies have reported maturation as young as 11 years of age<sup>31</sup> or as late as 16 years of age.<sup>35</sup> Thus, developmental maturity may affect balance control throughout childhood and adolescence.

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In children, balance control tends to decrease as body mass index (BMI) increases.<sup>2,20</sup> Female individuals have better postural control than male individuals in clinically based<sup>7,22</sup> and laboratory-based<sup>23</sup> balance measurements. Sport participation<sup>4,13</sup> and level of play<sup>24,26</sup> also affect balance. Gymnasts have the greatest balance control, followed by soccer players, swimmers, healthy controls, and basketball players.<sup>13</sup> Age is 1 factor that affects balance control; balance tends to get better as age increases during childhood.<sup>1,6,20</sup> For example, Pediatric Balance Scale scores improve throughout childhood, between the ages of 2 and 13 years.<sup>6</sup> During single-limb stance, 8-year-old children had significantly greater postural sway compared with 10-year-olds.<sup>22</sup>

Two different tests of clinical balance have been examined in postinjury assessments or as screening tools to identify the risk of injury in athletes: the Balance Error Scoring System (BESS)<sup>1</sup> and the Y-Balance Test.<sup>32</sup> The BESS identifies alterations in postural control acutely after concussion<sup>1,28</sup> and risk of ankle injury.<sup>21</sup> The Y-Balance Test evaluates motor control patterns and risk of a noncontact injury.<sup>34</sup> Few investigations have examined the differences between child and adolescent-aged athletes on tasks that challenge postural control.<sup>16</sup> The BESS test was used to identify the relationship between postural control and anthropometric characteristics among pediatric athletes, finding that no age-related differences in BESS scores were present among 10- to 17-year-olds.<sup>16</sup>

Few studies have examined the BESS and Y-Balance Test in individuals younger than 18 years.<sup>16</sup> Balance and postural control abilities improve throughout childhood development,<sup>6</sup> so performance may vary throughout adolescence. Thus, the purpose of this study was to assess performance on these 2 commonly used postural control tests among a sample of healthy child and adolescent athletes.

## METHODS

### Participants

An institutional review board approved of the study protocol prior to study commencement. A cross-sectional study was conducted of athletes who underwent an injury prevention evaluation at a sports injury prevention center between April 2013 and January 2015. Participants spent several hours at the center where measurements were taken to assess risk factors for sport-related injuries and medical conditions and a prescription for reducing the risk of sustaining sport-related injuries was developed. Measures of risk factors depend on the sport in which the athlete participates. Potential risk factors are based on the medical and scientific literature and include sport(s) participated in, position(s) played, training regimen, past medical history, age, sex, BMI, sleep habits, nutrition, anatomy, biomechanics, endurance, strength, flexibility, balance, and agility, among others. Athletes between the ages of 10 and 18 years were included in this study to examine postural control among 3 specific age groups: 10 to 12 years, 13 to 15 years, and 16 to 18 years of age. Potential participants were excluded from

the study if they had an existing ankle injury that was still painful at the time of testing or an intellectual or developmental disability. Athletes who reported a prior history of concussion were able to participate if they had already been medically cleared to participate in unrestricted physical activity as a part of the injury prevention evaluation and were not experiencing any concussion-related symptoms at the time of testing.

### Experimental Protocol

Postural control was examined using the modified Balance Error Scoring System (mBESS).<sup>10,17</sup> As opposed to the full version of the BESS, which includes trials performed on a foam pad, the mBESS is performed only on a solid surface.<sup>1,29</sup> Participants performed trials with their eyes closed in 3 different stances: double-leg, single-leg, and tandem. Each trial lasted 20 seconds in duration. During the double-leg stance, participants were instructed to stand with their feet placed side by side. In the single-leg stance, participants were instructed to stand on their nondominant leg, determined by the foot with which they report typically kicking a soccer ball. During tandem stance, participants stood with their nondominant foot directly behind their dominant foot, toe-to-heel.

Four experienced personnel rated the mBESS by counting the total number of errors in each stance; possible scores ranged from 0 to 10.<sup>29</sup> An error was defined as opening the eyes, lifting hands off hips, taking a step, falling out of testing position, lifting any portion of the foot from the ground, abducting the hip greater than 30°, or taking more than 5 seconds to return to the testing position.<sup>19,17</sup> A lower score on the mBESS indicates better postural stability. The modified version of the BESS was used consistent with the latest Standardized Concussion Assessment Tool (version 3).<sup>19</sup> The mBESS is a more reliable test than the full version.<sup>14</sup> Interrater reliability for the BESS ranges between 0.78 and 0.96, while intrarater reliability ranges between 0.60 and 0.98.<sup>1</sup>

The Y-Balance Test measures postural stability with good interrater test-retest reliability.<sup>32</sup> It has been used to identify postural control deficits<sup>8</sup> and correlated with an increased risk of sustaining a lower extremity injury.<sup>34</sup> During the assessment, participants stood barefoot with the distal aspect of their right foot on the stance plate and pushed an indicator box with their left foot as far as possible in the anterior, posteromedial, and posterolateral directions, returning to the original standing position without losing balance. Loss of balance is defined as movement off the stance leg, loss of contact with the reach indicator, inability to return to the original starting position after a reach attempt, or placement of the reach foot on top of the indicator box. The protocol is repeated with the left foot on the platform and the right foot reaching in each direction. Total reach length is measured along a pole marking the distance from the stance platform in each direction of reach. Prior to performing the Y-Balance Test, each participant was given specific instructions followed by 6 practice trials in each direction. During the recorded test, 3 trials were performed in each direction. The best score (ie, longest reach) was recorded and used in further analyses.

Table 1. Characteristics of study participants

	10-12 y (n = 84)	13-15 y (n = 198)	16-18 y (n = 107)
Height, cm, mean (SD)	153.14 (9.17)	166.21 (10.73)	171.63 (9.24)
Weight, kg, mean (SD)	44.92 (10.98)	57.75 (10.77)	69.71 (18.87)
BMI, kg/m <sup>2</sup> , mean (SD)	18.92 (3.12)	20.92 (4.10)	23.49 (4.98)
History of concussion, n (%)	22 (26)	49 (25)	39 (36)
Female sex, n (%)	50 (60)	125 (63)	63 (59)
History of ACL tear, n (%)	1 (1)	7 (4)	11 (10)
History of ankle sprain, n (%)	29 (35)	48 (24)	38 (36)
Sport participation, n (%) <sup>a</sup>			
Baseball	10 (12)	17 (9)	10 (9)
Basketball	34 (41)	65 (33)	25 (23)
Cross country	4 (5)	18 (9)	3 (3)
Dance	6 (7)	21 (11)	12 (11)
Field hockey	3 (4)	12 (6)	7 (7)
Football	6 (7)	16 (8)	13 (12)
Gymnastics	11 (13)	7 (4)	2 (2)
Ice hockey	9 (11)	21 (11)	6 (6)
Lacrosse	27 (32)	47 (24)	23 (21)
Ski/snowboard	15 (18)	24 (12)	7 (7)
Soccer	50 (60)	83 (42)	34 (32)
Softball	6 (7)	14 (7)	6 (6)
Swimming	12 (14)	16 (8)	5 (5)
Tennis	6 (7)	14 (7)	4 (4)
Track and field	3 (4)	35 (18)	32 (30)

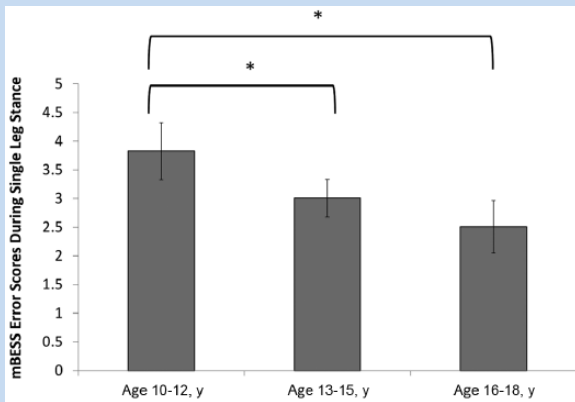
ACL, anterior cruciate ligament; BMI, body mass index.

<sup>a</sup>Values do not add up to 100% as participants could choose multiple sports. Less than 5% of participants responded that they participate in the following sports: crew, cycling, equestrian, figure skating, golf, martial arts, rugby, springboard diving, volleyball, and wrestling.

## Variables

The mBESS outcome variables included the total errors committed in each of the 3 conditions, rated by the observing clinician. Y-Balance Test outcome variables included the best total reach length for the left and right foot in all 3 directions normalized to the respective leg length. Asymmetry was calculated in each direction as the absolute difference between left and right total reach length in the anterior, posteromedial, and posterolateral directions.

As postural control may change throughout the course of adolescent development,<sup>3</sup> we separated participants into 3 age groups: 10 to 12 years, 13 to 15 years, and 16 to 18 years. Current recommendations for postural control testing after sport-related concussion suggest the use of an alternate form of the testing in patients 12 years of age or younger, so participants 10 to 12 years of age comprised 1 group.<sup>19</sup> To better determine the effect of age between younger and older adolescents, those age 13 to 15 and 16 to 18 years comprised separate groups.



**Figure 1.** Mean number of errors on the modified Balance Error Scoring System (mBESS) single-leg stance for each age group (error bars, 95% CIs). Results account for covariates included in the statistical model (sex, sport type, body mass index, history of ankle injury, and history of concussion). \*Significant between group differences. A significant main effect for age group,  $F(2) = 7.59$ ,  $P = 0.001$ , revealed that the 10- to 12-year-old age group committed more errors than the 13- to 15-year-old age group ( $P = 0.007$ ) and the 16- to 18-year-old age group ( $P < 0.001$ ).

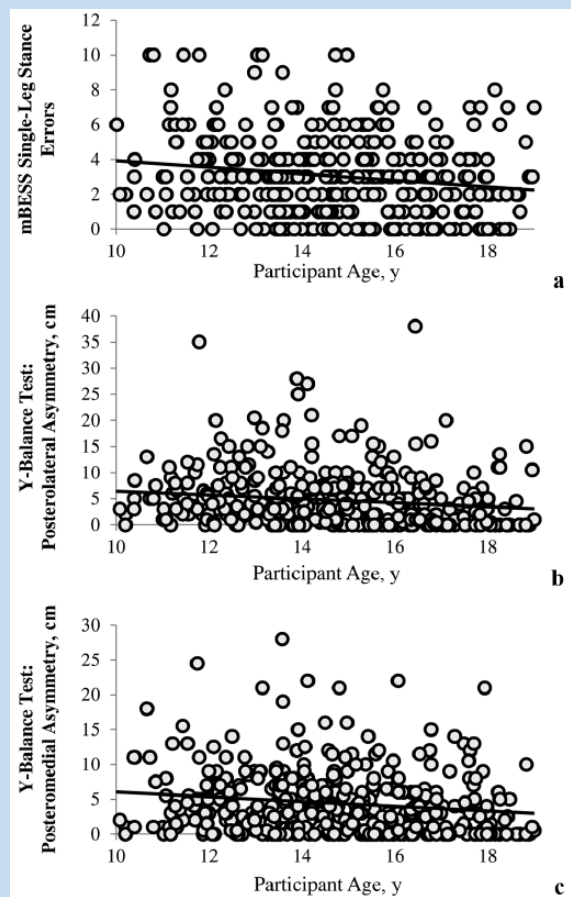
## Statistical Analysis

Age group differences were examined using a 1-way analysis of covariance, with age group as the independent variable. The dependent variables of interest were the mBESS score in each stance, Y-Balance Test asymmetry in each direction, and Y-Balance Test normalized reach length on the left and right sides. The following covariates were included in the analysis: sex,<sup>7,22,23</sup> sport type,<sup>13</sup> BMI,<sup>15,25,27</sup> history of ankle injury,<sup>21,30</sup> and history of concussion.<sup>12,17,18</sup> Individuals were placed into sport-type groups based on their participation in individual, team, or a combination of both individual and team sports.<sup>13</sup> To examine potential postural stability differences between female and male individuals,<sup>5</sup> we compared sexes on each dependent variable using the Student *t* test. Finally, using age as a continuous variable, we examined the correlation between the chronological age of participants (calculated as the difference between the date of testing and date of birth, divided by 365) and postural stability variables using Pearson correlation coefficients (*r*).

For all omnibus tests, statistical significance was set at  $P < 0.05$ . Follow-up pairwise comparisons were conducted using the Bonferroni procedure to control for type I error; statistical significance was adjusted using this procedure and set at  $P < 0.017$  for all follow-up comparisons. Statistical Package for the Social Sciences (version 21; IBM) was used to perform all statistical analyses.

## RESULTS

A total of 389 participants were included in this study. Athletes in the youngest age group were significantly shorter, lighter, and



**Figure 2.** Scatterplot and line of best fit describing the relationship between participant age and (a) modified Balance Error Scoring System (mBESS) single-leg stance errors ( $R = -0.167$ ,  $P = 0.001$ ), (b) Y-Balance Test posterolateral asymmetry ( $R = -0.141$ ,  $P = 0.006$ ), and (c) Y-Balance Test posteromedial asymmetry ( $R = -0.149$ ,  $P = 0.003$ ).

had lower BMI than older athletes (Table 1). The proportions of male and female participants were similar among the age groups (Table 1). A significantly greater proportion of the 16- to 18-year-old athletes had a history of anterior cruciate ligament injury (Table 1). No differences between female and male individuals were found for any mBESS or Y-Balance Test performance variables.

In the single-leg stance of the mBESS, while controlling for sex, sport type, BMI, history of ankle injury, and history of concussion, the youngest athletes (10-12 years) committed more errors than the older 2 age groups (Figure 1). In the double-leg and tandem stances of the mBESS, no significant differences between the 3 age groups were observed. A significant correlation was found between participant age and single-leg stance mBESS errors (Figure 2a).

During the Y-Balance Test, athletes between 10 and 12 years of age demonstrated significantly greater posterolateral and posteromedial asymmetry than the 16- to 18-year age group

Table 2. Total asymmetry (cm) between right and left legs in the anterior, posterolateral, and posteromedial directions of movement<sup>a</sup>

Y-Balance Test Movement Direction	Age Group, y	Mean Asymmetry, cm	SD
ANT	10-12	3.37	0.47
	13-15	3.24	0.30
	16-18	3.01	0.42
P-L	10-12 <sup>b</sup>	6.27	0.65
	13-15	4.80	0.42
	16-18	3.85	0.58
P-M	10-12 <sup>b</sup>	5.30	0.51
	13-15	4.55	0.33
	16-18	3.58	0.46

ANT, anterior; P-L, posterolateral; P-M, posteromedial.

<sup>a</sup>Results account for covariates included in the statistical model (sex, sport type, body mass index, history of ankle injury, and history of concussion).

<sup>b</sup>Statistically significant main effect of age group. In the posterolateral reach direction,  $F(2) = 3.77$ ,  $P = 0.024$ , the 10- to 12-year-old age group had significantly more posterolateral asymmetry than the 16- to 18-year-old age group ( $P = 0.007$ ). Similarly, asymmetry in the posteromedial direction,  $F(2) = 3.08$ ,  $P = 0.047$ , was significantly greater for participants between 10 and 12 years of age than the 16- to 18-year-old participants ( $P = 0.015$ ).

while controlling for sex, sport type, BMI, history of ankle injury, and history of concussion (Table 2). No significant asymmetry in the anterior reach direction was observed. Y-Balance Test normalized reach lengths were not significantly different among the different age groups on the left or right side in the anterior or posteromedial directions of movement. The normalized posterolateral leg reach length on the right side was not significantly different among age groups, but on the left side,  $F(2) = 3.55$ ,  $P = 0.030$ , athletes 13 to 15 years of age were able to obtain a farther normalized reach length than the 10- to 12-year-old age group ( $P = 0.011$ ). Significant correlations were found between participant age and posterolateral asymmetry (Figure 2b) and posteromedial asymmetry (Figure 2c).

## DISCUSSION

These findings suggest that healthy athletes between the ages of 10 and 12 years may perform worse on clinical tests of postural control than their older counterparts and that the clinical interpretation of performance during postinjury examinations or injury risk screenings for this age group should be considered in light of potential preexisting or developmental factors.

Prior studies have examined how age affects BESS performance, revealing mixed results. One investigation found no association between participant age and total BESS score<sup>16</sup> but was methodologically different from the current study. The mBESS firm testing conditions were examined only in the current study, finding the youngest group of participants made significantly more errors than their older counterparts. Previous work may not have been adequate to detect any age-group

effects ( $n = 100$ ).<sup>16</sup> Therefore, 389 healthy athletes may have been more appropriately powered to detect differences between the youngest participants and the 2 older groups in the single-leg stance. Although the clinical significance of differences in errors between the youngest age group (10-12 years) and older age groups (13-15 and 16-18 years) remains unclear, the results suggest that when testing individuals younger than 12 years on the single-leg stance of the mBESS, interpretation or comparisons of performance to the function of older-aged patients should be done with caution.

Previous studies have reported normative data for individuals 20 to 69 years of age,<sup>15</sup> but few studies have examined mBESS performance in a sample of individuals younger than 18 years.<sup>16</sup> Best-practice recommendations for the postconcussion evaluation of children 12 years and younger, using the Child Standardized Concussion Assessment Tool, suggest that clinicians utilize the mBESS during only double-leg and tandem stances.<sup>19</sup> Our data support such a modification for younger individuals, as this group of healthy athletes 10 to 12 years old demonstrated significantly worse performance than the older 2 age groups in the single-leg stance condition, indicating age may affect performance. These findings demonstrate the importance of baseline testing to make more reliable comparisons postinjury. Furthermore, given the variation of balance by age, it is important to routinely repeat baseline measurements of balance as the athlete matures.

BESS test administration is relatively simple with a low cost, making it a beneficial tool for clinicians to use. Generally, those with functional ankle instability, those who wear ankle braces, and older individuals commit more errors during the test.<sup>1</sup>



Beyond postinjury deficit detection, BESS performance among high school basketball players is associated with sustaining an ankle injury.<sup>21</sup> However, within the context of pediatric and adolescent sport-related concussion, recent evidence suggests that it may be limited in its ability to accurately assess the postural control of younger athletes.<sup>28</sup> The youngest athletes may also have postural control deficits, particularly in single-leg stance, when healthy.

Anterior asymmetry during the Y-Balance Test is associated with an increased risk of musculoskeletal injury among collegiate athletes. Asymmetry between left and right total reach length may be an important injury risk screening variable.<sup>34</sup> In comparison, our data indicate that greater asymmetry exists for younger athletes in both posterior directions performed during the Y-Balance Test rather than in the anterior direction. This suggests that motor control strategies differ throughout child development. Poor balance, measured by increased postural sway during a standing task, may be a risk factor for injury in high school athletes.<sup>21</sup> Thus, children 12 years of age and younger may be at increased risk of injury. Postural instability on postural control tests by healthy athletes 12 years and younger should be interpreted with caution when compared with normative data obtained from older individuals.<sup>15</sup>

Interpretation of the findings from this study must be viewed in light of several limitations. All participants reported for testing as a part of an injury prevention evaluation and prescription for mitigating such risk. Therefore, these athletes likely characterize a unique cohort, limiting the generalizability of our results. We also did not record how many times the athletes had previously completed mBESS, BESS, or Y-Balance Tests; previous exposure to these paradigms may have affected performance. Also, the lack of significant findings in several areas of this study may be due to inadequate sample size.

## CONCLUSION

Athletes between the ages of 10 and 12 years made more errors on the single-leg stance of the mBESS and displayed greater asymmetry for the posterolateral and posteromedial directions of the Y-Balance Test compared with their older counterparts. Thus, these tests in children 12 years of age and younger should be used with caution in preseason screening or postinjury physical examinations.

## REFERENCES

- Bell DR, Guskiewicz KM, Clark MA, Padua DA. Systematic review of the Balance Error Scoring System. *Sports Health*. 2011;3:287-295.
- Bernard PL, Geraci M, Hue O, Amato M, Seynnes O, Lantieri D. Influence of obesity on postural capacities of teenagers. Preliminary study [in French]. *Ann Readapt Med Phys*. 2003;46:184-190.
- Branta C, Haubenstricker J, Seefeldt V. Age changes in motor skills during childhood and adolescence. *Exerc Sport Sci Rev*. 1984;12:467-520.
- Bressel E, Yonker JC, Kras J, Heath EM. Comparison of static and dynamic balance in female collegiate soccer, basketball, and gymnastics athletes. *J Athl Train*. 2007;42:42-46.
- Covassin T, Elbin R, Harris W, Parker T, Kontos A. The role of age and sex in symptoms, neurocognitive performance, and postural stability in athletes after concussion. *Am J Sports Med*. 2012;40:1303-1312.
- Cumberworth VL, Patel NN, Rogers W, Kenyon GS. The maturation of balance in children. *J Laryngol Otol*. 2007;121:449-454.
- Franjoine MR, Darr N, Held SL, Kott K, Young BL. The performance of children developing typically on the pediatric balance scale. *Pediatr Phys Ther*. 2010;22:350-359.
- Gribble PA, Hertel J, Plisky P. Using the Star Excursion Balance Test to assess dynamic postural-control deficits and outcomes in lower extremity injury: a literature and systematic review. *J Athl Train*. 2012;47:339-357.
- Guskiewicz KM. Assessment of postural stability following sport-related concussion. *Curr Sports Med Rep*. 2003;2:24-30.
- Guskiewicz KM, Register-Mihalik J, McCrory P, et al. Evidence-based approach to revising the SCAT2: introducing the SCAT3. *Br J Sports Med*. 2013;47:289-293.
- Hirabayashi S, Iwasaki Y. Developmental perspective of sensory organization on postural control. *Brain Dev*. 1995;17:111-113.
- Howell DR, Osternig LR, Chou LS. Dual-task effect on gait balance control in adolescents with concussion. *Arch Phys Med Rehabil*. 2013;94:1513-1520.
- Hrysomallis C. Balance ability and athletic performance. *Sports Med*. 2011;41:221-232.
- Hunt TN, Ferrara MS, Bornstein RA, Baumgartner TA. The reliability of the modified Balance Error Scoring System. *Clin J Sport Med*. 2009;19:471-475.
- Iverson GL, Koehle MS. Normative data for the modified Balance Error Scoring System in adults. *Brain Inj*. 2013;27:596-599.
- Khanna NK, Baumgartner K, LaBella CR. Balance Error Scoring System performance in children and adolescents with no history of concussion. *Sports Health*. 2015;7:341-345.
- King LA, Horak FB, Mancini M, et al. Instrumenting the Balance Error Scoring System for use with patients reporting persistent balance problems after mild traumatic brain injury. *Arch Phys Med Rehabil*. 2014;95:353-359.
- Martini DN, Sabin MJ, DePesa SA, et al. The chronic effects of concussion on gait. *Arch Phys Med Rehabil*. 2011;92:585-589.
- McCrory P, Meeuwisse WH, Aubry M, et al. Consensus statement on concussion in sport: the 4th International Conference on Concussion in Sport, Zurich, November 2012. *J Athl Train*. 2013;48:554-575.
- McGraw B, McClenaghan BA, Williams HG, Dickerson J, Ward DS. Gait and postural stability in obese and nonobese prepubertal boys. *Arch Phys Med Rehabil*. 2000;81:484-489.
- McGuine TA, Greene JJ, Best T, Levenson G. Balance as a predictor of ankle injuries in high school basketball players. *Clin J Sport Med*. 2000;10:239-244.
- Mickle KJ, Munro BJ, Steele JR. Gender and age affect balance performance in primary school-aged children. *J Sci Med Sport*. 2011;14:243-248.
- Nolan L, Grigorenko A, Thorstenson A. Balance control: sex and age differences in 9- to 16-year-olds. *Dev Med Child Neurol*. 2005;47:449-454.
- Paillard T, Noe F, Riviere T, Marion V, Montoya R, Dupui P. Postural performance and strategy in the unipedal stance of soccer players at different levels of competition. *J Athl Train*. 2006;41:172-176.
- Pataky Z, Armand S, Muller-Pinget S, Golay A, Allet L. Effects of obesity on functional capacity. *Obesity*. 2014;22:56-62.
- Pau M, Arippa F, Leban B, et al. Relationship between static and dynamic balance abilities in Italian professional and youth league soccer players. *Phys Ther Sport*. 2015;16:236-241.
- Ponta ML, Gozza M, Giacinto J, Gradacchi R, Adami GF. Effects of obesity on posture and walking: study prior to and following surgically induced weight loss. *Obes Surg*. 2014;24:1915-1920.
- Quatman-Yates C, Hugentobler J, Ammon R, Mwase N, Kurowski B, Myer GD. The utility of the Balance Error Scoring System for mild brain injury assessments in children and adolescents. *Phys Sportsmed*. 2014;42(3):32-38.
- Rahn C, Munkasy BA, Barry Joyner A, Buckley TA. Sideline performance of the Balance Error Scoring System during a live sporting event. *Clin J Sport Med*. 2015;25:248-253.
- Sabin MJ, Ebersole KT, Martindale AR, Price JW, Broglio SP. Balance performance in male and female collegiate basketball athletes: influence of testing surface. *J Strength Cond Res*. 2010;24:2073-2078.
- Schmid M, Conforto S, Lopez L, Renzi P, D'Alessio T. The development of postural strategies in children: a factorial design study. *J Neuroeng Rehabil*. 2005;2:29.
- Shaffer SW, Teyhen DS, Lorensen CL, et al. Y-balance test: a reliability study involving multiple raters. *Mil Med*. 2013;178:1264-1270.
- Shumway-Cook A, Woollacott MH. The growth of stability: postural control from a development perspective. *J Motor Behav*. 1985;17:131-147.
- Smith CA, Chimera NJ, Warren M. Association of y balance test reach asymmetry and injury in division I athletes. *Med Sci Sports Exerc*. 2015;47:136-141.
- Steindl R, Kunz K, Schrott-Fischer A, Scholtz AW. Effect of age and sex on maturation of sensory systems and balance control. *Dev Med Child Neurol*. 2006;48:477-482.
- Winter DA. Human balance and posture control during standing and walking. *Gait Posture*. 1995;3:193-214.