



Original Research

Comparison of Balance Variables Across Active and Retired Athletes and Age Matched Controls

CAITRIONA LEE[†], NEIL FLEMING[‡], and BERNARD DONNE[‡]

Department of Anatomy and Physiology, School of Medicine, Trinity College Dublin, IRELAND.

[†]Denotes postgraduate student author, [‡]Denotes professional author

ABSTRACT

International Journal of Exercise Science 14(3): 76-92, 2021. Postural control is a major falls risk factor, therefore identifying protective mechanisms is essential. Physical activity enhances postural stability but effect duration has been minimally researched. The current study investigated if prolonged early life training exposure protected neuromuscular balance processes later in life. Static and dynamic balance variables were assessed in 77 healthy adults. Two age ranges (18 - 35yr, young; > 50yr, retired) were divided into weight bearing athlete and control groups; young athlete (YA), young control (YC), retired athlete (RA) and retired control (RC). Static balance was quantified using force platform derived sway velocity ($\text{mm}\cdot\text{s}^{-1}$) and C90area (mm^2) data (stable and unstable surfaces, eyes open and closed) Dynamic balance was assessed using the Y balance test (YBT). Results demonstrated significant age effect across groups. However, an athletic effect was evident only assessing dynamic balance and static time to error variables. Mean time to error data (YA, 27.8 ± 5.8 ; YC, 20.5 ± 11.1 ; RA, 9.4 ± 8.5 ; RC, 8.6 ± 9.1 s) recorded significant age and athletic effects for the most challenging condition completed (single leg stance, eyes closed, stable surface). Mean maximum YBT composite score (YA, $90.0 \pm 5.4\%$; YC, $83.6 \pm 6.5\%$; RA, $80.8 \pm 10.7\%$; RC, $72.4 \pm 15.5\%$) demonstrated an age effect, and also identified a group effect in the retired cohorts. The current study supports research highlighting declined balance with ageing. Overall, former athleticism did not significantly enhance static balance in later life. Dynamic balance incorporates muscle strength possibly inferring a protective role in former athletes.

KEY WORDS: Sway velocity, C90 area, balance assessment, balance platform, falls prevention, retired athletes

INTRODUCTION

Good balance is considered the ability to maintain centre of gravity vertically over the base of support despite perturbations (29). Balance incorporates feedback mechanisms from visual, vestibular and somatosensory systems (29). Postural control can improve or decline depending on level of activity. With ageing, neuromuscular processes decline and coordination and postural stability become increasingly challenged during everyday tasks. One third of adults over the age of 65 years fall each year (38) prompting the promotion of fall prevention strategies, in particular identifying protective factors. Researchers have reported that people with one or

more falls per annum have increased postural sway when compared to those with no falls (10). A recent meta-analysis (40) demonstrated improved postural stability and decreased sway area in elderly populations with targeted balance training. Physical activity and balance training in later life reportedly improve postural stability (24, 32, 42). Balance training is commonly practiced by athletes, in particular in those competing in a weight bearing stance (3, 19, 20). However, the temporal duration of balance training has been minimally researched. More specifically, does prolonged exposure to neuromuscular training in early athletic life protect postural stability?

The effect of short- and long-term enhanced balance is reported following vigorous exercise exposure (26). There is evidence of between 20 to 70% risk reductions for hip fracture incidence with past or present activity (21), with weight bearing activity being the most protective (11). One study (35) using a balance walk test demonstrated that former athletes (45 to 68 yr) had superior balance to a control group (27 to 67 yr) and their balance was comparable to a young (24 to 30 yr) population. Perrin et al. (32) documented superior postural stability by tilt perturbation in active older adults, most notably those who recently commenced activity were on par to those who had a long-term exposure to physical activity. It has been reported that football trained elderly adults showed better postural control and lean body mass when compared with untrained elderly adults by measuring number of errors when sustaining single leg stance for one minute (45). Notably, balance did not differ between football trained elderly adults and untrained young adults.

To execute dynamic movements, athletes combine balance with joint range of movement and strength (20). Specifically, balance is an important component in weight-bearing sport. Game sports require an athlete to make postural adjustments according to selective attention, reaction time, movement time and agility. Research has shown that the more proficient the athlete, the better their balance ability (20). Balance control of an athlete is a useful tool to predict injury risk, diagnose and monitor rehabilitation (25). Additionally, several studies have reported an effect of lower extremity musculoskeletal injury altering somatosensory input by damaging proprioceptors (12, 14). However, the long-term effects on these neuromuscular systems in later adult life remains minimally researched.

Contrary, balance assessment tools for the elderly focus on fall screening tests; namely, tandem walk, unilateral stance, sit to stand and the timed up and go tests (8, 40). Some studies objectively measured balance and have reported older participants to have increased sway velocity (2, 28, 44). However, dependence on visual and proprioceptive inputs remained constant across age cohorts (7). Sway velocity has been shown not to be affected by gender in some studies (7, 44), however, a significant correlation between age and the length of sway path has been reported for single leg stance (44).

Shumway-Cook and Horak (42) isolated sensory inputs under six test conditions to identify the defected sense, referred to as the clinical test of sensory interaction and balance (CTSIB). A hard, flat surface ensured accurate orientation information from the somatosensory system and using an unstable surface (foam mat) reduced the accuracy of the orientation. Increased instability

with a foam surface (challenging proprioception) suggested inadequate vestibular and/or vision compensation. The modified CTSIB (without dome) is a condensed tool often used in screening of the elderly. Using the modified CTSIB, a decreased performance time was associated with a concomitant rise in fall risk (1).

Static and dynamic steady-state, proactive and reactive balance tests are the general methods of assessing balance (24). A force platform is frequently used for indirect assessment of static posturography, centre of pressure (COP) data are calculated using ground reaction forces projected from the body (32). The C90area (mm²) represents the area of an ellipse that encompasses 90% of COP points, with increased mean data suggesting decreased postural control (32). Mean sway velocity (mm.s⁻¹) represents displacement across time of COP variable. Safe use of the force platform is necessary. Past studies have used harnesses which may provide sensory input and therefore hinder results (42). Parallel safety rails eliminate this sensory support. No significant difference in COP data comparing dominant and non-dominant limbs has been reported in the scientific literature (18).

Dynamic balance is the ability to maintain postural control while the person's centre of mass moves outside their base of support (15). Dynamic testing has reportedly been shown to demonstrate greater discrepancy between young and old healthy adults than static testing (2). The Y balance test (YBT) is a useful clinical tool for assessing postural control in single leg stance while reaching in three directions; anterior, posteromedial and posterolateral directions with the opposite leg. Although primarily used in an athletic population for injury risk assessment, the YBT has been reported to be an effective and safe tool to correlate distance achieved with lower limb strength in an older population (13, 22).

Few studies exist comparing postural stability in retired athletes to young athletes and to the author's knowledge there is a gap in the literature using age-matched control groups. The aims of the current study were to compare the ability to maintain upright stance when sensory inputs (visual and platform stability) were altered and to compare dynamic balance in athletic and former athletic population. We hypothesise that retired athletes would have superior balance to non-athletes by demonstrating reduced sway velocity, maintain stability when challenged and enhanced dynamic ability. Findings of increased postural stability could potentially infer reduced injury and falls risk and a protective mechanism across healthy populations. The current study collected normative data in athletic and non-athletic populations, in particular data from the YBT in the elderly population which, currently, is lacking in the literature.

METHODS

An observational study design measured balance variables in healthy adults. Participants completed a modified CTSIB protocol on a force platform and the YBT on a single day. Ethics approval was received from the Faculty of Health Sciences Ethics Committee in Trinity College Dublin. This research was conducted in accordance to the ethical standards of the International Journal of Exercise Science (30).

Table 1: General overview of study design.

Pre-testing evaluation	Questionnaire and anthropometric assessment Falls risk assessment (>50 yr only)
Static balance	Instruction, demonstration and warm-up 4 test conditions (30-s trials: 30-s rest)
Dynamic balance	Instruction, demonstration and warm-up 3 directions; 3 attempts per direction

Participants

Participants were recruited through sport clubs and local advertisement. Both male and female candidates who expressed interest were sent an information leaflet and contacted the lead investigator if he or she satisfied the inclusion and exclusion criteria. Groups were categorized as athletic or control based on their exercise history. The definition of an athlete was an individual who trained vigorously three times a week all year round, as well as competing regularly for a minimum of 5 years (5). A retired athlete (RA) was an athlete who had not trained or competed in a weight-bearing sport (any sport where standing was the predominant position) for a minimum of 5 years; however, RA may continue to exercise recreationally. The control group had a low physical activity lifestyle (< 20 min of daily vigorous-intensity activity < 3 days per week or less than 30 min of daily moderate-intensity activity < 5 days per week) and with no previous history of participation in a competitive weight-bearing activity. Consequently, the four participant categories assessed were YA aged 18 to 35 yr, RA > 50 yr, YC 18 to 35 yr and RC > 50 yr.

Exclusion criteria included recent (< 3 month) or chronic lower limb or trunk injury (musculoskeletal or neurological), recent head injury (< 12 month), neurological disorder potentially affecting balance (vestibular, vision or neuropathy), taking medications or substance which may impair balance (< 24 h before testing) or hyper/hypotension. Athletes were asked to refrain from activities that may induce injury or significant fatigue within 24 h of testing. An informed consent form was completed by all enlisted participants.

Protocol

Participants completed a questionnaire prior to testing in the presence of the investigator to quantify their level of activity and ensure study criteria were met. Measurements of body mass in kilogram (Seca, Hamburg, Germany) and height in metre (Holtain, Dyfed, UK) were performed in barefoot and light clothing. Body mass index (kg.m⁻²) was subsequently calculated. Dominant limb length (chosen by the participant) was measured using a standard 1.5 m flexible measuring tape, barefoot from anterior superior iliac spine to the most distal portion of the medial malleolus (34).

All participants > 50 yr (RA and RC groups) completed a falls risk assessment using the Berg Balance Scale (BBS) and Timed Up and Go (TUG) test. Each manoeuvre was preceded by safety instructions and a demonstration. Time data (s) were collected on an iPhone 7 with inbuilt stopwatch. Two chairs (both equal in height, one chair with arm rests and the other without) were positioned adjacent to each other with chair backs against a solid wall. A 30 cm solid ruler

was used to measure arm reach. Using a 5 m heavy duty measuring tape, the floor was marked out from the front leg of the chair to 3 m perpendicular to it which was used for the TUG test. A 100 g weight was used as the object for picking up from the floor and a wooden step (dimensions 12 cm in height, 30 cm in length and 20 cm in width) was placed against a wall.

All testing was conducted on a solid surface in a quiet room, free from distraction, noise and vibration. Participants had their static balance assessed using a force platform (HURLabs iBalance platform, Tampere, Finland) connected via USB to a laptop computer (Dell Inspiron, Texas, USA). Data were estimated by the associated iBalance software (iBalance premium Ver 2.4, HURLabs, Tampere, Finland). The force platform had four inbuilt force transducers pre-calibrated by the manufacturer. The static balance protocol, based on modified CTSIB (1), was formulated using iBalance software. Supportive barriers and adjacent walls were placed within arm’s reach for safety precautions.

Each participant viewed a standard demonstration of the protocol performed by the lead investigator. The standardised warm-up allowed for familiarisation without inducing fatigue which consisted of a combination of all positions for 10 s each. Participants stood barefoot on markings on the platform (heels touching and big toes at 30°) for double leg stance (DLS). Dominant leg was chosen by the participant based on practice attempts during single leg stance (SLS). For SLS, the dominant foot was placed in the centre of the platform, heel and second toe on a marked line and foot covering the centre point of the platform. The raised leg was positioned as neutral hip and knee flexed to approximately 45° with knees closely aligned. Hands were rested on the abdomen. For (eyes open) conditions, participants were asked to fix their gaze on a point 5 m away. Safety instructions were outlined. A foam cushion of thickness 2.54 cm was used as the unstable surface with foot markings corresponded to the force platform foot markings to ensure similar foot positioning.

Test conditions 1 to 4 (Table 2) were randomly allocated prior to assessment to eliminate any potential learning effect associated with a more challenging condition. Each test condition commenced with DLS followed by SLS.

Table 2: Conditions randomly tested for both double and single leg stance on a force platform.

1	2	3	4
Eyes open	Eyes open	Eyes closed	Eyes closed
Stable	Unstable	Stable	Unstable

Each trial for each condition was 30 s in duration. Time to error and number of errors made were also measured. Time measurement (s) was rounded to the nearest second. A test failure was defined as a participant needing to open his or her eyes, breaking hand position, touching down foot, non-dominant hip abduction > 30° approximately, requiring operator intervention or handrail use. The Balance Error Scoring system (BESS) was used to quantify each participant’s test score. The participant was instructed before attempting trials to try and correct their position in the case of an error and continue the test until 30 s elapsed. A trial was abandoned after 10 errors. On initiation of a 30 s trial, the investigator counted ‘3-2-1-and start’. Participants were

asked to be in the correct position by '1' to eliminate any sudden perturbation associated with correcting their position. Neither the participant nor investigator spoke during the 30 s trial to minimise any distraction. For each procedure participants were permitted a maximum of three attempts as recommended (17). A minimum of 30 s rest was allocated between repeat trials and the rest period between test conditions was 90 s. If a participant failed more than one test condition despite repeat attempts, he or she would not be eligible for more challenging conditions; namely, a participant who failed SLS eyes open would not partake in SLS eyes closed if not yet attempted.

As the participant maintains their position, their weight is continuously shifting across the force transducers. The HURLabs software calculated X and Y displacement data (COP data) across the platform and subsequently mean sway velocity (MSV) in mm.s⁻¹ and C90area in mm² were computed. MSV was calculated by dividing the total trace length by the duration of the test (30-s). The trace length summed together successive COP points from real time (X and Y) analysis of the force transducer output sampled at 5 Hz (200 ms intervals). Computed C90 area is the area of the ellipse containing 90% of the assessed COP points sampled at 100 Hz (10-ms intervals). Computed MSV and C90area for participants completing the 30 s test during an attempt were calculated using iBalance software. For those participants who achieved more than 5 s but less than 30 s, data (MSV and C90area) were calculated up to the time of first error using a customised Excel spreadsheet. The customised spreadsheet formula (Equation 1) used in the current study for C90area produced data within 0.1 mm² compared to data produced by HURLabs software when assessing 30 s trials, therefore, this difference was deemed to have minimal significance considering the magnitude for assessed C90area.

Equation 1: $C90area (mm^2) = 4.605 * \Pi * \sum [C_{xx} * C_{yy} - (C_{xy})^2]^{0.5}$

where $C_{xx} = \sum (x_i - x_m)^2 / (n-1)$, $C_{yy} = \sum (y_i - y_m)^2 / (n-1)$ and $C_{xy} = \sum (x_i - x_m) * (y_i - y_m) / (n-1)$

In addition, X and Y coordinates sampled at 20ms (5Hz) intervals were used to calculate the distances between successive time-points using Equation 2.

Equation 2: $[(x_2 - x_1)^2 + (y_2 - y_1)^2]^{0.5}$

Summated distances over the associated time were divided by time to compute sway velocity in mm.s⁻¹. The formula used for MSV produced the exact data as measured by the HURLabs software.

Equation 3: $MSV (mm \cdot s^{-1}) = \sum d / t$, where $d = [(x_i - x_j)^2 + (y_i - y_j)^2]^{0.5}$ and $t = \text{time}$

Dynamic balance was measured using a Y balance test kit consisting of a stance platform and three PVC pipes attached in the anterior, posteromedial, and posterolateral reach directions. Each pipe was marked in 5 mm increments for measurement of reach distance from the centre of the stance platform. Support rails were placed by the anterior pipe and safety precautions were outlined. There was a 10 min rest period between static and dynamic balance assessments.

The YBT was demonstrated by the lead investigator followed by 3 practice trials (36). Participants stood barefoot with their dominant foot on the centre footplate with hands placed on hips. The dominant leg could bend as much as participants could tolerate. Participants started with their non-dominant foot resting on the back of the centre footplate. The participant then pushed the reach indicator in each direction using the non-dominant foot in the order anterior, posteromedial and posterolateral directions.

Failed attempts were discarded and the attempt was repeated with a maximum total of 6 attempts. The first three successful attempts were recorded. A failed attempt was touching down with the non-dominant leg, raising the dominant heel from footplate, loss of contact with the reach indicator while in motion or using a kicking motion, using the reach indicator for stance support or failure to return the free foot to the starting position. The maximal reach distance was measured by reading to the nearest 0.5 cm on the measured pipe. The mean and maximum reach for each direction was used for analysis of the reach distance in each direction. Reach distances were summed to yield a composite score for analysis of overall test performance (34). To express reach distance as a percentage of limb length, the normalised reach distance (%) was calculated as the reach distance divided by limb length and then multiplied by 100 (39). Composite reach distance (%) was the sum of the 3 reach directions divided by 3 times limb length, and then multiplied by 100.

Statistical Analysis

An *a priori* power test was conducted for expected outcomes with a Type 1 error probability of 0.05, a power of 0.85 and a projected effect size 0.4. Effect size was estimated based on age-related normative data for TUG tasks presented by Nolan et al. (31). This analysis indicated that $n = 20$ per group would provide a statistical power of 85% (G*Power v3.0.10 free software; Institute of Experimental Psychology, Heinrich Heine University, Dusseldorf, Germany). Data normality was assessed using Pearson D'Agostino omnibus normality test using Graphpad Software (GraphPad Prism, CA, USA). Mean data for BBS, TUG and age in the retired groups were compared using unpaired Student's T tests. To assess the independent effect of age in either of the retired groups (RA and RC) regression analysis of assessed static and dynamic balance data across age was performed to compute coefficient of determination, standard error of the estimate ($Sy.x$) and significance of the slope of the regression line from zero. As the assessed hypothesis was that an individual's balance would deteriorate with advancing age the alpha level (α) was adjusted to maintain an overall p value of 0.05. Statistical analysis of assessed static and dynamic variables within discrete conditions (SLS, DLS, eyes open, eyes closed, stable platform, unstable platform) was performed using a 2-way ANOVA to compare between and within groups (group \times age). Subsequently, post-hoc Bonferroni tests quantified detected differences. Meaningfulness of the detected differences were examined by computing Cohen's d (mean difference / pooled standard deviation) to quantify the effect size (ES); accepted demarcations are $ES < 0.2$ trivial, from 0.2 to 0.5 poor to moderate, from 0.5 to 0.8 moderate to good and from 0.8 to ≥ 1.0 good to excellent. Descriptive statistics were used to characterize the sample and for all statistical analysis a value of $p < 0.05$ inferred significance.

RESULTS

Baseline anthropometric data collected on all participants ($n = 77$) enlisted in the current study are presented in Table 3, participants were categorized according to their age and level of activity. A subsequent post-hoc power analysis indicated that the current study achieved an overall statistical power of 82%.

Table 3: Number of participants (n), mean and standard deviation for age, BMI, weekly duration of vigorous intensity activity and gender distribution of each group.

	<i>n</i>	Male	Female	Age (yr)	BMI (kg.m ²)	Vigorous activity per week (h)
YA	29	15	14	25 (5)	23.9 (2.9)	8.1 (4.2)
YC	13	3	10	27 (4)	22.4 (2.3)	0.7 (1.0)
RA	18	12	6	59 (6)	25.9 (4.1)	3.7 (2.9)
RC	17	6	11	62 (7)	25.2 (3.2)	0.3 (0.8)

Note: (YA)- Young Athlete, (YC)- Young Control, (RA)- Retired Athlete, (RC)- Retired Control, (yr)- Year, (kg.m²)- kilogram divided by metre squared, (h)- hour.

Sporting disciplines were recorded; Gaelic Athletic Association and athletics were the most heavily represented sports across the athletic groups. In total, 60.7% of YA reported a history of formal balance training (single leg exercises, perturbation exercises) compared to 39.3% in RA. In YA, 54% competed at club level, 36% at national level and 11% at international level. In RA, 61% previously competed at club level, 22% at national level and 17% at international level. All participants were deemed low risk by the falls risk assessment. Mean BBS data (maximum score 56) for RA and RC groups were 56 ± 0.4 and 55 ± 1.0 , respectively. Mean TUG data for RA and RC groups were 6.7 ± 1.4 and 7.3 ± 1.4 s, respectively. No significant differences ($p > 0.05$) were identified comparing age, BBS or TUG data between RA and RC groups. Regression analysis of static and dynamic variables indicated weak to moderate association between static and dynamic variables across age (r^2 data varied between 0.0 and < 0.3) in RA and RC groups, slope of regression lines were deemed non-significant ($p > 0.05$) and large $Sy.x$ data were recorded.

Static balance: All participants completed all positions in DLS. The most challenging condition, single leg eyes closed, was only successfully completed by 5 participants (all YA), consequently, single leg eyes closed data were not included for statistical analysis. For any participant who attained > 5 s in their 30 s test, their mean C90area and MSV data up until point of error were recorded.

Table 4: Mean (SEM) data for C90 area (mm²) and MSV (mm.s⁻¹) double leg, eyes open and closed on stable and unstable platforms across group.

Group	Variable	Double leg	Double leg	Double leg	Double leg
		Eyes open Stable	Eyes open Unstable	Eyes closed Stable	Eyes closed Unstable
YA	C90area (mm ²)	234 (39)*	308 (36)**	340 (42)	641 (65)
RA		370 (69)	496 (61)	482 (80)	936 (104)
YA	MSV (mm.s ⁻¹)	9.6 (0.8)**	11.5 (3.9)*	13.7 (3.3)**	22.5 (10.2)**
RA		12.2 (1.0)	15.3 (4.4)	20.7 (9.9)	33.1 (10.0)
YC	C90area (mm ²)	167 (21)	236 (39)*	308 (53)	746 (114)
RC		290 (67)	401 (50)	432 (78)	997 (223)
YC	MSV (mm.s ⁻¹)	8.5 (0.5)**	9.9 (2.9)**	12.6 (3.2)**	20.4 (6.8)*
RC		13.2 (1.4)	15.8 (6.3)	19.7 (8.5)	28.9 (11.9)

Asterisk symbol (*) indicates significant difference across age within group, * infers $p < 0.05$, ** infers $p < 0.01$.

Table 5: Mean (SEM) data for C90 area (mm²) and MSV (mm.s⁻¹) single leg, eyes open on stable and unstable platforms and for eyes closed on a stable platform.

Group	Variable	Single leg Eyes open		Single leg Eyes open		Single leg Eyes closed	
		Stable		Unstable		Stable	
YA	C90area (mm ²)	462 (28)***	$n = 29$	522 (33)**	$n = 29$	1527 (100)***	$n = 29$
RA		813 (102)	$n = 18$	913 (94)	$n = 18$	3647 (807)	$n = 9$
YA	MSV (mm.s ⁻¹)	24.4 (1.2)**	$n = 29$	27.2 (6.2)*	$n = 29$	53.6 (2.1)***	$n = 29$
RA		39.3 (2.7)	$n = 18$	33.8 (8.6)	$n = 18$	89.0 (9.1)	$n = 9$
YC	C90area (mm ²)	323 (30)##	$n = 13$	505 (70)	$n = 13$	1889 (256)	$n = 13$
RC		470 (69)	$n = 16$	799 (125)	$n = 16$	3050 (656)	$n = 9$
YC	MSV (mm.s ⁻¹)	23.4 (2.0)**	$n = 13$	25.7 (7.6)**	$n = 13$	53.1 (3.8)	$n = 13$
RC		33.7 (2.4)	$n = 16$	41.9 (29.9)	$n = 16$	67.5 (7.3)	$n = 9$

Note: Asterisk symbol (*) indicates significant difference across age within group, * infers $p < 0.05$, ** infers $p < 0.01$, *** infers $p < 0.001$, and hash tag symbol (#) indicates a significant difference across groups within age, ## infers $p < 0.01$.

Each participant was timed for each attempt and time to error data was recorded for each condition to the nearest second. All participants completed each DLS trial without error across the four test conditions. Global analysis of time to error (s) data for SLS with eyes open on a stable surface identified no significant age, group or interaction effects (Figure 1a). However, global analysis for SLS, eyes opened on an unstable surface identified a significant age effect ($F = 21.13, p < 0.001$). There were significant post-hoc age effects detected in the athlete and control group (30 ± 0 vs. 25.3 ± 8.0 s ($p < 0.05$) and 29.9 ± 0.3 vs. 19.6 ± 12.2 s ($p < 0.001$), respectively). Computed effect size for the athletic group was 0.84 and for the control group was 1.18 (Figure 1b). Global analysis of time to error (s) for single leg stance, eyes closed on a stable surface identified significant age (24.2 ± 8.9 vs. 9.0 ± 8.8 s; $F = 59.21, p < 0.001$) and group effects (18.5 ± 7.3 vs. 14.6 ± 10.2 s; $F = 4.30, p < 0.05$). Post-hoc Bonferroni analysis identified a significant age effect in athletic and control groups (27.8 ± 5.8 vs. 9.4 ± 8.5 s ($p < 0.001$) and 20.5 ± 11.1 vs. 8.6 ± 9.1 s ($p < 0.001$), respectively). Post-hoc analysis also identified a significant group effect in the

young cohort (27.8 ± 5.8 vs. 20.5 ± 11.1 s; $p < 0.05$). Computed age effect sizes for athletic and control groups were 2.69 and 1.09, respectively, on a stable surface with eyes closed. The computed group effect size was 0.90 in the young cohort; see Figure 1c.

Dynamic balance: Dynamic balance was assessed using the YBT. Each participant had three successful attempts in each direction recorded. The maximum and mean composite score (%) from the measurements in each direction were subsequently calculated.

Global analysis of maximum composite score (%) on dominant leg on the YBT identified significant age (86.8 ± 6.0 vs. $76.6 \pm 13.3\%$; $F = 24.38$, $p < 0.001$) and group effects (85.4 ± 8.5 vs. $78.0 \pm 11.8\%$; $F = 14.41$, $p < 0.001$). Post-hoc Bonferroni analysis identified a significant age effect in both athletic and control groups (90.0 ± 5.4 vs. $80.8 \pm 10.7\%$; $p < 0.01$ and 83.6 ± 6.5 vs. $72.4 \pm 15.4\%$; $p < 0.001$). Post-hoc analysis also identified a significant group effect (80.8 ± 10.7 vs. $72.4 \pm 15.4\%$; $p < 0.01$) comparing retired cohorts only. Computed effect sizes for maximum composite score data across age in athlete and control groups were 1.08 and 0.94, respectively, and for the retired cohorts across group the computed effect size was 0.62.

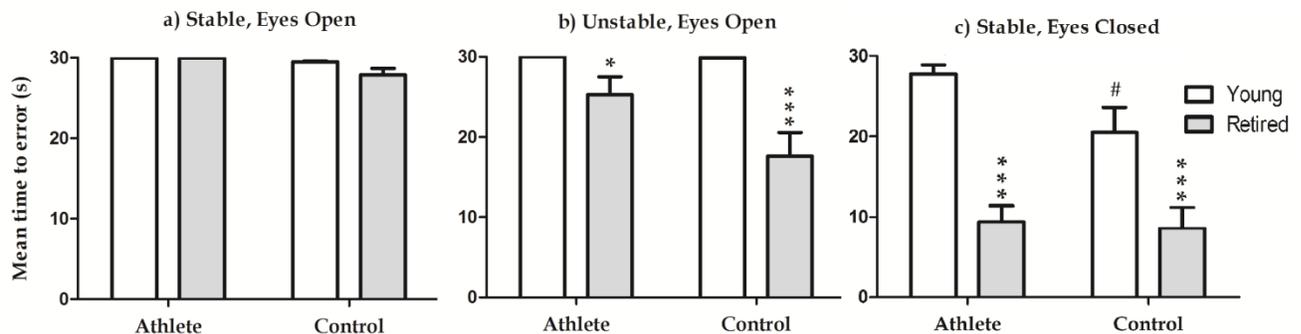


Figure 1: Mean time to error (s) for single leg stance on (a) stable surface eyes opened, (b) unstable surface, eyes open and (c) stable surface eyes closed across groups, error bars denote SEM, n as indicated in Table 3. Asterisk symbol (*) indicates significant difference across age within group, *** infers $p < 0.001$. Hash tag symbol (#) indicates significant across groups within age, # infers $p < 0.05$.

Global analysis of mean composite score (%) also identified significant age (84.3 ± 6.4 vs. $73.5 \pm 13.3\%$; $F = 23.79$, $p < 0.001$) and group effects (82.6 ± 8.7 vs. $75.1 \pm 11.9\%$; $F = 14.04$, $p < 0.001$). Post-hoc Bonferroni analysis identified significant age effect in athletic (87.7 ± 5.4 vs. $77.5 \pm 11.1\%$; $p < 0.01$) and control groups (80.8 ± 7.2 vs. $69.4 \pm 15.2\%$; $p < 0.001$). Post-hoc analysis also identified a significant group effect (77.5 ± 11.1 vs. $69.4 \pm 15.2\%$; $p < 0.01$) comparing retired cohorts. Computed effect sizes for maximum composite score data across age in athletic and control groups were 1.32 and 0.96, respectively, for the retired cohorts across group the computed effect size was 0.61, see Figure 2.

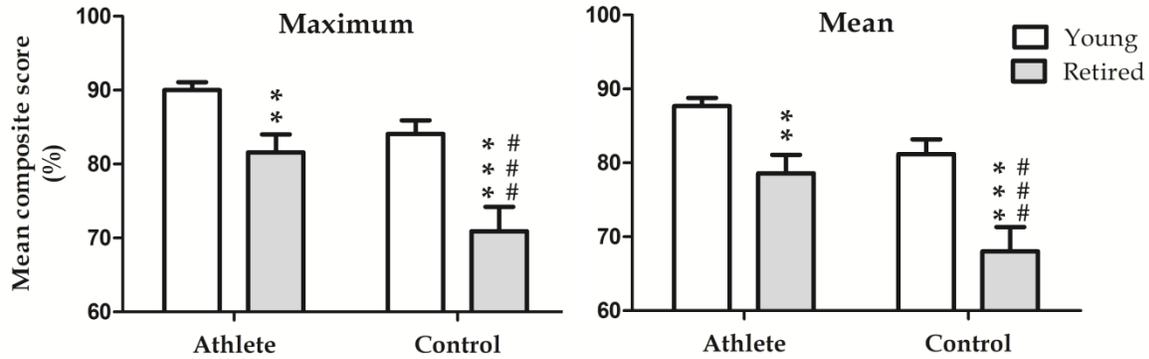


Figure 2: Bar chart representing the maximum and mean composite score (%) for the YBT across groups, error bars denote SEM, n as indicated in Table 3. Asterisk symbol (*) indicates significant difference across age within group, ** infers $p < 0.01$, *** infers $p < 0.001$, and hash tag (#) symbol indicates a significant difference across groups within age, ## infers $p < 0.01$.

DISCUSSION

Despite identifying significant age effects within discrete conditions for postural control, a finding consistent with previous reports (2, 4, 23, 43), group effects attributable to regular participation in sport was demonstrated only with dynamic balance assessment and timed SLS. Static balance variables, in general, failed to attain statistical significance.

In the current study, the YBT data demonstrated a strong age effect across groups while also identifying the effect of former athleticism when compared to sedentary adults. The YBT test assesses an individual’s limits of stability by incorporating strength and flexibility (13). Within the retired group, there were significant differences detected between athletic and control groups, see Figure 2. To the author’s knowledge, there have been few studies measuring dynamic balance using the YBT in older sporting population groups despite this test being reported as an effective tool in an older healthy population (13, 22).

Previous studies have examined YBT data by dividing older adults according to age categories (13, 22). Freud (13) reported an age effect within decades using maximum normalized composite score data in healthy female adults; middle age group (mean \pm SD: 56 \pm 3 yr, 91 \pm 7%); older age group (64 \pm 3 yr, 83 \pm 10%) compared to mixed gender RC data in the current study (mean 62 \pm 7 yr, 71 \pm 14%). The RC scored lower maximum composite score given the RC group ranged three decades. Such scores were also lower compared to another study also (72.4 vs. 85.0%) (22). The wider age group tested makes comparing controls to previous studies more difficult. In the current study, normalized reach distances lacked a group effect in the younger cohort, a finding previously reported in the literature (37). The current athletes who participated have varying sport specific abilities in terms of balance positions and lower extremity strength and flexibility. Although not investigated in this study, we may speculate that no difference was revealed because of one or a combination of training differences. However, the maximum composite score of YA was similar to a study (3) assessing elite level athletes (90 vs. 89%).

Lower extremity strength plays a role in YBT performance in the older healthy population (22). Strength may have a lasting effect among retired athletes although this too declines with age (27). Former athletes reportedly have a superior ability to retain velocity of weight transfer with sit to stand assessment; however, no difference in sway variables was inferred (9). There was no statistical difference between BBS and TUG among the retired group in this study but this could be explained by a younger cohort (mean 60 vs. > 65 yr). Indeed those that played sport may maintain a physically active lifestyle promoting lower limb and truncal strength in their activities of daily living. Future studies could potentially compare lower limb strength with YBT data in former athletes using sedentary adults as controls.

The weekly level of physical activity ranged from inactive to active in both RA and RC. Current activity status of older adults is reported to be a predictor of both static and dynamic balance regardless of previous sport participation (6). Bulbulian (6) assessed static balance using timed SLS, and dynamic balance was assessed using step width and length. Motor coordination and muscle strength while maintaining SLS during YBT may provide a more challenging stance to distinguish athleticism. It is unclear whether the benefit to dynamic balance is attributed to by current level of physical activity or from prolonged participation in sport in earlier life.

YBT data may allow for an objective falls risk assessment in a healthy functioning adult as it emulates a reaching task. The use of sway velocity to predict falls has been controversial but measurement of sway while performing dynamic maneuvers may be more helpful than a static position (2). Similar functioning tests such as TUG and BBS have a ceiling effect and may be more suitable for less active or frail adults. Although the YBT is physically challenging, it requires the participant to force themselves to reach beyond their normal stability boundaries. Speculatively, from a psychological perspective, it is possible that retired athletes may be less apprehensive due to past exposure to multiple physical challenges and therefore were able to push themselves to attain higher reach composite scores. However, the current study did not assess psychological variables and the lack of any significant difference in the younger groups potentially contradicts this argument.

As with the current study, performance of static and dynamic balance have not correlated in an athletic population (19). Athletic performance did not demonstrate an effect between groups when measuring sway. Across all groups, sway increased with surface instability and visual feedback removed for both C90 and MSV. Observing static balance in relation to level of activity, one study concluded that recent practice of physical activity was as beneficial as practice in the past, or permanent practice (33). In contrast to the current study, they concluded past exposure to physical activity was associated with decreased sway velocity and area of displacement during static balance assessment when compared to those who were always inactive. Additionally, the authors reported that physical activity resulted in less dependency upon visual input, which again differs to the current study where there were no differences detected between controls and athletes in conditions where eyes are closed. This may suggest exercise does not provide long-term benefits to proprioception and vestibular systems. As mentioned, evidence from the current study suggest the neuromuscular adaptations of sport diminishes with time. In fact, the higher C90 area and MSV data of RA suggest that longterm weight-bearing

sport may impact on the sensory systems detrimentally whether from chronic over-stimulation or long-term effect of minor lower limb injuries.

Comparable to the current study, researchers (23) measuring sway in master athletes have previously documented no statistically significant difference between master athletes and controls despite being currently active for SLS with and without visual feedback. Data for C90area in RA and RC increased by 4- and 6-fold, respectively, when eyes were closed. Very wide standard deviations for C90area data were evident with all challenging conditions, a finding previously reported (2). Across all groups, MSV increased by a maximum of 2-fold when eyes were closed. For all positions with DLS including tandem stance, master athletes recorded less sway relative to controls (23), unlike the findings reported in the current study where there was no discernible difference between groups using sway in DLS. Baloh *et al.* (2) also reported that sway velocity was not a predictor of falls and fear of falling and there was no detected significant difference between sway velocity measurements when comparing fallers and non-fallers. Our findings of healthy very low falls risk adults would concur with Baloh *et al.* (2).

Time to error did not detect an athletic or age effect for SLS with eyes open on a stable surface (Figure 1a), however, an age effect was detected when participants were on an unstable surface (Figure 1b). Time to error during SLS trials detected significant age and athletic effects for the most difficult condition completed (eyes closed, stable surface, Figure 1c). Like the YBT, an athlete's muscle endurance and strength may allow for greater stability by maintaining SLS for longer when balance mechanisms are challenged (vision and proprioception). A high sway velocity may not reflect an inability to maintain limits of base of support but rather frequent postural corrections for sustained postural stability. The time to error data detected more significant differences with task difficulty. This suggests that although athletic populations sway more with more challenging conditions, their ability to maintain composure without errors was greater than the control group, especially for those who are currently training regularly. A previous study has reported similar mean time results across age (4).

One limitation of this current study was the current level of physical activity of the older adults enlisted as this was not a factor when categorizing the groups. Within both retired groups, there was a diverse range of current regular physical activity. Notably, within the groups there were those who were former athletes but now led a sedentary lifestyle. Likewise with the control group, despite never competing in sport some enlisted participants now led an active lifestyle which potentially may contribute to preserved balance control. Another limitation is possible selection bias as the sample was not stratified based on age group or gender.

The range of sporting disciplines was also a potentially a limiting factor as balance varies according to activity. This could be resultant from integration of sensory systems internally (vestibular and proprioception) with external visual cues due to the contact nature of the sport and required rapid change in direction.

Another area of concern for the design of the current study was that volunteers may be biased if they selectively enrolled believing they already have apprehension regarding their balance. However, this bias would potentially result in overall poorer postural control across both

groups, and, therefore not necessarily weaken the current study's findings. Additionally, the level and intensity of training of the retired athlete group (circa 1955 to 1965) most likely was not as stringent in comparison to current training regimens. Therefore the skill that an athlete would develop presently would likely be more advantageous to postural control than previously. With this said, control participants in the current study displayed very good balance, despite sample size limitations. Analyzing postural stability when balance is disturbed by perturbations is an important component of falls risk assessment. The current study lacks controlled perturbation and cognitive challenges, unfortunately such challenges were outside our remit currently. Additionally, reaction time to regain balance after perturbations is also important in relation to falls.

Furthermore the current study did not assess joint flexibility or strength. Enhanced muscle mass and range of joint movement in athletes may be more determinant for superior balance during dynamic maneuvers compared to sedentary people. Consequently, we were unable to interpret the degree of contribution of balance sensory systems with regard the YBT. Future studies should use more specific sporting groups, in particular targeting athletes according to their specific sporting discipline and level of training. Ideally studies should be a cohort study to follow athletes over time in order to identify everyday lifestyle factors that may contribute to protected postural stability and minimize falls in later life.

Assessment tools and protocols vary across the literature resulting in difficulty interpreting and applying results on a large scale. Future studies should use advancing technologies to draw quantitative measurements of the varying sensory components and the effect of sport has on them across the age divide.

In conclusion, the findings of the current study demonstrate previous athletic exposure does not have a lasting effect on vision, proprioception and vestibular systems. We may speculate from the positive findings of dynamic testing and timed SLS that muscle strength and joint flexibility has a protective role in postural stability as we age. Determining the extent to which strength and muscle endurance of athletes influence balance should continue to be investigated. Our current data does not support the concept that years of competing in weight-bearing sport accrues a major benefit to athletic individuals in terms of balance control mechanisms. However, the current study reiterates the published literature that there is a significant decline in balance control systems with the ageing process. Future research should investigate the effect of balance perturbation in former athletes compared to non-athletes using a force platform and future studies should include the YBT in the older population.

ACKNOWLEDGEMENTS

The authors disclose no conflicts of interest or financial arrangements related to this research. We would like to thank all athletic and control volunteers for their gracious participation in this research.

REFERENCES

1. Agrawal Y, Carey J, Hoffman H, Sklare D, Schubert M. The modified Romberg balance test: Normative data in US adults. *Otol Neurotol* 32: 1309-1311, 2011.
2. Baloh R, Fife T, Zwerling L, Socotch T, Jacobson K, Bell T, Beykirch K. Comparison of static and dynamic posturography in young and older normal people. *J Am Geriatr Soc* 42: 405-412, 1994.
3. Benis R, Bonato M, La Torre A. Elite female basketball players' body-weight neuromuscular training and performance on the Y-balance test. *J Athl Train* 51: 688-695, 2016.
4. Bohannon R, Larkin P, Cook A, Gear J, Singer J. Decrease in timed balance test scores with aging. *Phys Ther* 64: 1067-1070, 1984.
5. Brauer S, Neros C, Woollacott M. Balance control in the elderly: Do masters athletes show more efficient balance responses than healthy older adults? *Aging Clin Exp Res* 20: 406-411, 2008.
6. Bulbulian R, Hargan M. The effect of activity history and current activity on static and dynamic postural balance in older adults. *Physiol Behav* 70: 319-335, 2000.
7. Colledge N, Cantley P, Peaston I, Brash H, Lewis S, Wilson J. Ageing and balance: The measurement of spontaneous sway by posturography. *Gerontology* 40: 273-278, 1994.
8. Cwikel J, Fried A, Biderman A, Galinsky D. Validation of a fall-risk screening test, the Elderly Fall Screening Test (EFST), for community-dwelling elderly. *Disabil Rehabil* 20: 161-167, 1998.
9. Feland J, Hager R, Merrill R. Sit to stand transfer: Performance in rising power, transfer time and sway by age and sex in senior athletes. *Br J Sports Med* 39: e39, 2005. doi: 10.1136/bjism.2005.018564.
10. Fernie G, Gryfe C, Holliday P, Llewellyn A. The relationship of postural sway in standing to the incidence of falls in geriatric subjects. *Age Ageing* 11: 11-16, 1982.
11. Feskanich D, Willett W, Colditz G. Walking and leisure-time activity and risk of hip fracture in postmenopausal women. *JAMA* 288: 2300-2306, 2002.
12. Freeman M, Dean M, Hanham I. The aetiology and prevention of functional instability of the foot. *J Bone Joint Surg Br* 47: 678-685, 1965.
13. Freund J, Stetts D, Oostindie A, Shepherd J, Vallabhajosula S. Lower quarter Y-balance test in healthy women 50-79 years old. *J Women Aging*. 31: 475-491, 2019.
14. Gauffin H, Tropp H. Altered movement and muscular-activation patterns during the one-legged jump in patients with an old anterior cruciate ligament rupture. *Am J Sports Med* 20: 182-192, 1992.
15. Goldie P, Bach T & Evans O. Force platform measures for evaluating postural control: reliability and validity. *Arch Phys Med Rehabil* 70: 510-517, 1989.
16. Hammami R, Behm D, Chtara M, Othman A, Chaouachi A. comparison of static balance and the role of vision in elite athletes. *J Hum Kinet* 41: 33-41, 2014.
17. Heitmann D, Gossman M, Shaddeau S, Jackson J. Balance performance and step-width in non-institutionalized, elderly, female fallers and non-fallers. *Phys Ther* 69: 923-931, 1989.
18. Hoffman M, Schrader J, Applegate T, Koceja D. Unilateral postural control of the functionally dominant and non-dominant extremities of healthy subjects. *J Athl Train* 33: 319-322, 1998.
19. Hrysomallis C, McLaughlin P, Goodman C. Relationship between static and dynamic balance tests among elite Australian Footballers. *J Sci Med Sport* 9: 288-91, 2006.
20. Hrysomallis C. Balance ability and athletic performance. *Sports Med* 41: 221-232, 2011.
21. Kannus P, Sievänen H, Palvanen M, Järvinen T, Parkkari J. Prevention of falls and consequent injuries in elderly people. *Lancet* 366: 1885-1893, 2005.

22. Lee D, Kang M, Lee T, Oh J. Relationships among the Y balance test, Berg balance scale, and lower limb strength in middle-aged and older females. *Braz J Phys Ther* 19: 227-234, 2015.
23. Leightley D, Yap M, Coulson J, Piasecki M, Cameron J, Barnouin Y, McPhee J. Postural stability during standing balance and sit-to-stand in master athlete runners compared with non-athletic old and young adults. *J Aging Phys Act* 25: 345-350, 2017.
24. Lesinski M, Hortobagyi T, Muehlbauer T, Gollhofer A, Granacher U. Effects of balance training on balance performance in healthy older adults: A systematic review and meta-analysis. *Sports Med* 45: 1721-1738, 2015.
25. McGuine T, Greene J, Best T, Levenson G. Balance as a predictor of ankle injuries in high school basketball players. *Clin J Sport Med* 10: 239-244, 2000.
26. Messier S, Royer T, Craven T, O'Toole M, Burns R, Ettinger W. Long-term exercise and its effect on balance in older, osteoarthritic adults: Results from the Fitness, Arthritis, and Seniors Trial (FAST). *J Am Geriatr Soc* 48: 131-138, 2000.
27. Morley J. The aging athlete. *J Gerontol A Biol Sci Med Sci* 55: 627-629, 2000.
28. Murray M, Seireg A, Sepic S. Normal postural stability and steadiness: Quantitative assessment. *J Bone Joint Surg Am* 57: 510-516, 1975.
29. Nashner L. Practical biomechanics and physiology of balance. In: *Handbook of balance function testing*. Jacobson G, Newman C, Kartush J, ed. San Diego (CA): Singular Publishing Group; pp. 261-279, 1997.
30. Navatala J, Stone W, Scott Lyons T. Ethical issues relating to scientific discovery in exercise science. *Int J Exerc Sci* 12: 1-8, 2019.
31. Nolan M, Nitz J, Choy N, Illing S. Age-related changes in musculoskeletal function, balance and mobility measures in men aged 30-80 years. *Aging Male* 13: 194-201, 2010.
32. Palmieri R, Ingersoll C, Stone M, Krause B. Centre-of-pressure parameters used in the assessment of postural control. *J Sport Rehabil* 11: 51-66, 2002.
33. Perrin P, Gauchard G, Perrot C, Jeandel C. Effects of physical and sporting activities on balance control in elderly people. *Br J Sports Med* 33: 121-126, 1999.
34. Plisky P, Gorman P, Butler R, Kiesel K, Underwood F, Elkins B. The reliability of an instrumented device for measuring components of the star excursion balance test. *N Am J Sports Phys Ther* 4: 92-99, 2009.
35. Rätty H, Impivaara O, Karppi S. Dynamic balance in former elite male athletes and in community control subjects. *Scand J Med Sci Sports* 12: 111-116, 2002.
36. Robinson R, Gribble P. Support for a reduction in the number of trials needed for the star excursion balance test. *Arch Phys Med Rehabil* 89: 364-370, 2008.
37. Sabin M, Ebersole K, Martindale A, Price J, Broglio S. Balance performance in male and female collegiate basketball athletes: Influence of testing surface. *J Strength Cond Res* 24: 2073-2078, 2010.
38. Sattin R. Falls among older persons: A public health perspective. *Ann Rev Pub Health* 13: 489-508, 1992.
39. Shaffer S, Teyhen D, Lorenson C, Warren R, Koreerat C, Straseske C, Childs J. Y balance test: A reliability study involving multiple raters. *Military Med* 178: 1264-1270, 2013.
40. Sherrington C, Whitney J, Lord S, Herbert R, Cumming R, Close J. Effective exercise for the prevention of falls: A systematic review and meta-analysis. *J Am Geriatr Soc* 56: 2234-2243, 2008.
41. Shumway-Cook A, Brauer S, Woollacott M. Predicting the probability for falls in community-dwelling older adults using the timed up and go test. *Phys Ther* 80: 896-903, 2000.
42. Shumway-Cook A, Horak F. Assessing the influence of sensory interaction of balance. Suggestion from the field. *Phys Ther* 66: 1548-1550, 1986.

43. Stribley R, Albers J, Tourtellotte W, Cockrell J. A quantitative study of stance in normal subjects. *Arch Phys Med Rehabil* 55: 74-80, 1974.
44. Sugano H, Takeya T. Measurement of body movement and its clinical application. *Jap J Physiol* 20: 296-308, 1970.
45. Sundstrup E, Jakobsen M, Andersen J, Randers M, Petersen J, Suetta C, Aagaard P, Krstrup P. Muscle function and postural balance in lifelong trained male footballers compared with sedentary elderly men and youngsters. *Scand J Med Sci Sports* 20: 90-97, 2010.

