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INVESTIGATING FEMALE ATHLETES' BALANCE USING CENTER-OF-PRESSURE (COP) DERIVED DISPLACEMENT AND VELOCITY PARAMETERS

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ABSTRACT

A realization of how specific exercises relate to balance performance is important for a wide demographic of individuals. Maintaining active and healthy living is particularly important for balance-impaired individuals (e.g., otherwise healthy individuals recovering from injury, fall-prone elderly, and stroke survivors) whom are interested in improving their balance for function in daily life. However, balance performance is also important for persons that are unimpaired (e.g., athletes). How balance performance may be improved as a result of, and in relation to, various athletic activities and exercises is a common question. Further, how certain activities can be used to prevent injury is an ultimate goal. Our objective was to compare standing balance in 3 unimpaired groups (i.e., female track & female tennis collegiate athletes and female non-athletes).

To assess static balance, participants performed stance variations increasing in difficulty-level, utilizing a wide or tandem stance (increasing or decreasing support base) and eyes-open or eyes-closed (limiting or providing visual cues), while standing on a forceplate walkway. Through the recorded ground reaction forceplate-based, center-of-pressure (COP) position time series, we extracted velocity and displacement parameters that aided in identifying differences between the above groups.

Our general findings were that anterior-posterior (AP, or front-to-back) COP displacement and velocity measures for

female track athletes were unchanged relative to the (baseline) female non-athletes. However, mediolateral (ML, or side-to-side) measures, which have previously been shown to be associated with fall-risk, showed observable differences in displacement and velocity parameters, particularly for the female track athletes. Specifically, the female track athletes were better able to control their ML COP velocity in eyes-closed, wide, and eyes-open tandem conditions compared to non-athletes. However, tennis athletes had difficulty balancing in situations where eyes were closed (vision eliminated) and feet were tandem (base-of-support decreased) which was made apparent by the increases in all AP and ML COP-derived parameters. We interpreted this finding as the female tennis athletes were trained to rely heavily on visual cues (e.g., hand-eye or eye-body coordination), and also their balance may be more focused on maintaining their center-of-mass stability and body orientation, as opposed to COP per se.

Our study lends new insights as to how various types of athletic activities, and reliance on vision in athletes, impacts balance performance in un-impaired females.

INTRODUCTION

Balance is generally considered an important component of athletic activity. Lack of balance has been associated with increased injury risk among male and female athletes. However, female athletes are at greater risk of injury than male athletes playing similar sports [1-4]. For example,

epidemiological data on Anterior Cruciate Ligament (ACL) injury rates has shown an observable discrepancy between the genders. In fact, female athletes have a 2 to 10-fold higher incidence of ACL injuries than their male counterparts [1, 4]. Once the athlete is injured, they will miss 6 – 9 months of competitive play and will have to undergo reconstructive surgery and rehabilitation. Thus, injury prevention and injury-risk reduction is key.

Improved balance stability, in other words a reduction in muscle imbalances, is especially important in female athletes to prevent injury. A study conducted on female high school basketball athletes [2], showed that neuromuscular-training (including plyometric, functional-strengthening, balance, and stability-ball exercises) improved balance compared to controls. For this study, balance was observed by common (qualitative) clinical measures (i.e., the Balance Error Scoring System (BESS) and Star Excursion Balance Test (SEBT)) before and after the 6-wk intervention or control period. Although the authors observed a significant decrease in total BESS errors in the trained group at the posttest compared with their pretest and the control group quantitative, empirical measures may have lent further insights.

Bressel et al. [5] studied the effects of different types of athletic activities (i.e. gymnastics, soccer, and basketball) on balance and stability in female collegiate athletes. An advantage to this study, was that they assessed balance through a variety test conditions. Static balance was assessed via double leg, single leg, and tandem stances with either stiff surface or compliant surfaces, and dynamic balance was assessed via multidirectional maximal single-leg reaches from a unilateral base-of-support. From these measures, they observed that female gymnasts and soccer players did not differ in terms of their static/dynamic balance, but basketball players displayed inferior static and dynamic balance compared to the two other groups. Similar to the study by McLeod et al. [2] a setback of this study is that they failed to quantify measures via empirical data and instead utilized solely observations/qualitative-type assessments (i.e., BESS and SEBT assessments). The above literature examples did not provide sensitive, quantitative techniques for discriminating between (athlete) groups.

Gerbino et al. [6] compared standing balance in female collegiate dancers and soccer players. In comparison to the other studies mentioned above, the advantages to this study were that they measured the ground reaction center-of-pressure (COP) position shifts based on a high-resolution (Tekscan) forceplate and then they quantified the COP trace using parameters (sway index, path length, and sway velocity). The COP position times series, derived from ground reaction forces, has long been used in research and clinical practice to assess human standing balance. The COP position time series is the shift in the location of the resultant vertical ground reaction force vector of the subject's feet on the support surface [7-9]. Although this may not necessarily always be the case, in general, larger shifts may be interpreted as lesser ability to balance while smaller shifts may be interpreted as greater (better) ability to balance. In 5 of the 20 balance tests, they

found that dancers had significantly better balance scores than the soccer players. However, this study did not compare the difference between untrained, non-athlete subjects and the trained, athlete groups, nor the roles of vision and support base for the aforementioned groups.

It was well known that complex interactions between the visual, somatosensory, and vestibular systems are used to elicit a postural response [10]. If one or more of the systems are receiving limited cues, this may affect one's posture. Previous research has shown that postural stability during quiet stance (i.e., standing in the absence of voluntary movements or external perturbations) is affected by the: a) base-of-support [9, 10]; b) lack of visual cues & loss of vestibular function [10, 11]; c) support surface characteristics (e.g., lack of support surface cues) [10, 11]; and d) addition of external sensory information (e.g., non-weight bearing sensory cues (or "light touch")) [12]. Here, we examined how base-of-support and visual cues affected balance (in terms of the COP) in female non-athletes, female tennis athletes, and female track athletes.

We used a Tekscan forceplate walkway to acquire the COP position trace as a function of time for non-athlete and athlete groups. For our test battery, we varied visual cues and also stance width to make the standing task more and more difficult. Most importantly, instead of qualitative measures (e.g., survey data or observations), we observed COP time series data to extract descriptive displacement and velocity features from the COP, namely the: root-mean-square displacement (RMS), peak-to-peak range of displacement (maximum distance, or MAXD), root-mean-square velocity (RMSV), and mean velocity (MV). These parameters have been used previously in quantifying differences between young healthy adults [13], as well as elderly adults [14, 15]. Using these parameters, we were better able to make comparisons between female non-athlete and athlete test groups, as well as form initial conclusions about the effects of athletic training on balance and postural control.

METHODS

This paper describes a subset of results that are part of a larger, on going research study involving athlete and non-athlete balance. All human subject testing was conducted within the University of the District of Columbia's (UDC's) Center for Biomechanical & Rehabilitation Engineering (CBRE) Laboratory. Prior to subject recruitment and experimentation, the human subject protocol was approved by the UDC Institutional Review Board (IRB).

All subjects performed quiet stance balancing tasks. Quiet stance testing involves static posture testing in the absence of external perturbations. We chose static balance testing because is a simple and safe to test to perform and administer to all subject populations (e.g., healthy individuals, as well as the elderly and disabled individuals we plan to test in future works).

This study consisted of three, female test groups: 1) a (control) group of three, "non-athletes" that exercised with below moderate activity, less than 2 sessions per week, each

week; 2) a group of three, track athletes whom participated in collegiate track at UDC; and 3) a group of three, tennis athletes whom participated in collegiate track at UDC. The participants' ages were insignificantly different (track athletes: 21.7 +/- 1.2 years old; tennis athletes 21.3 +/- 3.2 years old; non-athletes: 20.7 +/- 1.5 years old). Further, all subjects were free from sensory neuropathies, were able to ambulate without assistance, had not suffered from a stroke, and had not suffered from a fall-related injury and/or concussion in the past 5 years.

For standing balance, subjects were tested for eyes-open/eyes-closed (i.e., receiving/not receiving visual system input) for both wide/tandem foot placement conditions (i.e., wide foot placement and front-to-back foot placement, respectively) leading to four test conditions: 1) wide/eyes-open, 2) wide/eyes-closed, 3) tandem/eyes-open, 4) tandem/eyes-closed (as shown in [13]). For each subject, for each condition, 4 sets of 30-second data were recorded with 1 minute of rest in between (i.e., 12 trials total per condition). The results were then pooled for each group. For each test condition, average parameters were computed for each group. A picture of one of the subjects performing the eyes-closed, tandem task is in Figure 1.

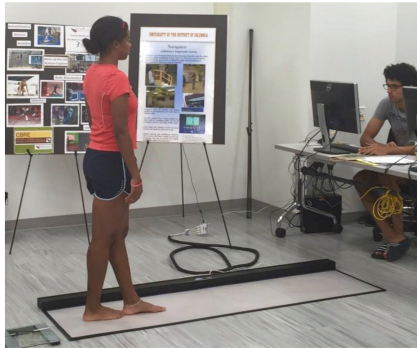


Figure 1. FEMALE TRACK ATHLETE PERFORMING THE EYES-CLOSED/TANDEM CONDITION.

During our experiments, subjects' standing balance COP position for mediolateral (ML, or side-to-side) and anterior-posterior (AP, or front-to-back) trace was measured using a Tekscan Forceplate Walkway (Figure 1) and data acquisition involved the use of the Tekscan Forceplate Software. Each subjects' ground reaction force data was acquired at a rate of 50 Hz. The Tekscan software also allowed for the raw ground reaction force and center-of pressure (COP) position data to be exported. Shifts in COP position, or changes in the location (position) of resultant vertical ground reaction force vector, as a function of time were recorded. Examples of raw, COP position time series are shown in Fig. 2 A & B.

From the COP position trace as a function of time acquired using the Tekscan software, we further post-processed the data using MATLAB software (MathWorks, R 2014a) to compute displacement, velocity, parameters [16, 17]. Parameters were computed for front-back (anterior-posterior, AP) as well as side-side (or mediolateral, ML) COP displacement. In

particular: root-mean-squared (RMS), peak-to-peak range of displacement (maximum distance, or MAXD), root-mean-square velocity (RMSV), and mean velocity (MV) of the COP. (as in [13]).

For each group, for each test condition, trials were averaged and standard errors computed for the above parameters. Results were compared using t-tests for equal sample size, unequal variance.

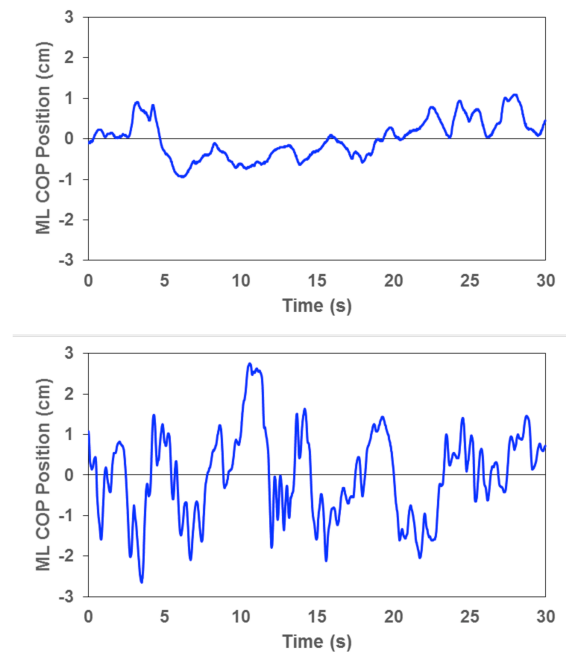


Figure 2. EXAMPLE OF MEDIOLATERAL (ML) COP POSITION TIME SERIES TRACES FOR A FEMALE NON-ATHLETE SUBJECT: top) eyes-open/wide (easiest) test condition and bottom) eyes-closed/tandem (hardest) test condition.

RESULTS

In comparing the female track athletes to female non-athletes, ML COP displacement measures for the track athletes were either less than non-athletes or are unchanged 2 of the 4 conditions. For eyes-closed/wide condition, reductions in ML displacement and velocity were seen (ML RMS: $df = 15$, $t = -3.13$, $p < 0.01$; ML MAXD: $df = 18$, $t = -2.60$, $p < 0.02$; ML MV: $df = 15$, $t = -4.43$, $p < 0.001$; ML RMSV: $df = 13$, $t = -3.93$, $p < 0.002$). For the eyes-open tandem condition, reductions in ML velocity were observed (ML MV: $df = 14$, $t = -5.76$, $p < 0.001$; ML RMSV: $df = 15$, $t = -5.57$, $p < 0.002$). Lastly, for eyes-closed/tandem there were significant decreases in the track athletes for ML COP displacement (ML RMS: $df = 22$, $t = -2.00$, $p < 0.05$).

In comparing the female tennis athletes to non-athletes, for the AP COP in the eyes-open/wide condition, there were significant decreases in displacement measures (AP RMS: $df = 19$, $t = -3.32$, $p < 0.05$; AP MAXD: $df = 21$, $t = -3.01$, $p < 0.01$). For the ML COP in the eyes-open/tandem condition there were

significant decreases in displacement and velocity measures (i.e., ML MAXD: df = 22, $t = -3.04$, $p < 0.01$; ML MV: df = 20, $t = -3.32$, $p < 0.005$; ML RMSV: df = 21, $t = -2.48$, $p < 0.05$).

An interesting finding was that the AP and ML COP displacement and velocity conditions showed that the female tennis athletes tested (had increased movement and velocity of the COP) in the eyes-closed/tandem condition. The AP COP showed significant increases in all displacement and velocity parameters (AP RMS: df = 22, $t = 6.81$, $p < 0.001$; AP MAXD: df = 22, $t = 8.87$, $p < 0.001$; AP MV: df = 16, $t = 6.21$, $p < 0.001$; AP RMSV: df = 13, $t = 6.63$, $p < 0.001$). The ML COP showed significant increases in all displacement and velocity parameters (ML RMS: df = 17, $t = 3.40$, $p < 0.005$; ML MAXD: df = 16, $t = 3.53$, $p < 0.005$; ML MV: df = 20, $t = 3.54$, $p < 0.002$; ML RMSV: df = 16, $t = 3.56$, $p < 0.001$) for the eyes-closed/tandem condition, but had significantly decreases for the eyes-open tandem condition (as stated in the previous paragraph).

Table 1. SUMMARY OF CHANGES IN ML AND AP COP BETWEEN FEMALE TRACK AND FEMALE TENNIS ATHLETES COMPARED TO NON-ATHLETES

	Track Athletes (re Non-Athletes)				Tennis Athletes (re Non-Athletes)			
	eyes-open/ wide	eyes-closed/ wide	eyes-open/ tandem	eyes-closed/ tandem	eyes-open/ wide	eyes-closed/ wide	eyes-open/ tandem	eyes-closed/ tandem
ML RMS		***		*				
ML MAXD		**					***	***
ML MV		*****	*****				****	****
ML RMSV		*****	*****				*	*
AP RMS					****			*****
AP MAXD					***			*****
AP MV								*****
AL RMSV								*****

*	$p < 0.05$		increase
**	$p < 0.02$		decrease
***	$p < 0.01$		
****	$p < 0.005$		
*****	$p < 0.002$		
*****	$p < 0.001$		

DISCUSSION

In comparing the female track athletes to non-athletes, AP COP displacement and velocity measures for track athlete were insignificantly different than non-athlete's measures for the 4 conditions. In comparing female track athletes and non-athletes, ML COP velocity measures showed decreases for the eyes-closed/wide stance and eyes-open/tandem; This was an important finding in that sway velocity is more important for postural control than sway displacement [16, 17], and also increases in ML sway is has been shown to be related to increases fall-risk [18]. Thus, better control of ML balance has the potential to lead to fall-risk reduction.

Female tennis athletes had decreases in AP COP displacement or ML measures (increases in stability) when visual cues were provided (i.e., for eyes-open/wide and eyes-open/tandem, respectively). However, for the eyes-closed tandem condition, both AP and ML COP displacement and velocity increased showing that the tennis athletes tested

allowed liberal movement of their COP in this condition. We took this as an indication that the tennis athletes rely more heavily on visual cues to balance in more challenging (standing) conditions. Also, the tennis players may have been trained to place priority on stabilizing their center-of-mass (related to body positioning and orientation in space) as opposed to COP position (related to ground reaction forces).

We further interpreted our results by examining the types of activities associated with each athletic group. The female track athletes were all sprinters. Their exercises and training regimen was focused on aerobic and anaerobic workouts; weight lifting and power-building exercises; fast-twitch muscle activity and conditioning; core strength, yoga, and plyometric activities. The female tennis athletes were focused on drilling activities and training eye-to-body coordination. This major focus placed on eye-to-body or hand-eye coordination, and reactive response, could have impacted the reliance tennis athletes have on visual cues/vision. This was observed in the difficulty the tennis athletes had for the eyes-closed, tandem condition, but no difficulty with the eyes-open, tandem condition. By performing (drilling) activities while limiting visual cues, balance performance could be impacted (improved).

CONCLUSION

Balance is generally considered an important component of athletic activity, and improved balance could also alleviate/reduce injury risk. Although we did not tie improved balance to improved performance in each group, in our initial results, we did observe differences in the athletic groups studied and interpreted our results. We aim to substantiate our findings and interpretations through the continued study of a larger number of individuals in each group.

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