3-2016

Athletes Who Train on Unstable Compared to Stable Surfaces Exhibit Unique Postural Control Strategies in Response to Balance Perturbations

D. S. Blaise Williams III
Virginia Commonwealth University

Nicholas G. Murray
Georgia Southern University, nmurray@georgiasouthern.edu

Douglas W. Powell
Campbell University

Available online at www.sciencedirect.com
ScienceDirect
Journal of Sport and Health Science 5 (2016) 70–76
www.jshs.org.cn

Original article

Athletes who train on unstable compared to stable surfaces exhibit unique postural control strategies in response to balance perturbations

D.S. Blaise Williams III [a], Nicholas G. Murray [b], Douglas W. Powell [c,d,*]

[a] Department of Physical Therapy, Virginia Commonwealth University, Richmond, VA 23284, USA
[b] Department of Health Sciences and Kinesiology, Georgia Southern University, Statesboro, GA 30458, USA
[c] Department of Physical Therapy, College of Pharmacy & Health Sciences, Campbell University, Buies Creek, NC 27506, USA
[d] Department of Physiology, School of Osteopathic Medicine, Campbell University, Buies Creek, NC 27506, USA

Received 2 March 2015; revised 26 October 2015; accepted 20 November 2015
Available online 11 January 2016

Abstract

Background: Athletes have been shown to exhibit better balance compared to non-athletes (NON). However, few studies have investigated how the surface on which athletes train affects the strategies adopted to maintain balance. Two distinct athlete groups who experience different types of sport-specific balance training are stable surface athletes (SSA) such as basketball players and those who train on unstable surfaces (USA) such as surfers. The purpose of this study was to investigate the effects of training surface on dynamic balance in athletes compared to NON.
Methods: Eight NON, eight SSA, and eight USA performed five 20-s trials in each of five experimental conditions including a static condition and four dynamic conditions in which the support surface translated in the anteroposterior (AP) or mediolateral (ML) planes using positive or negative feedback paradigms. Approximate entropy (ApEn) and root mean square distance (RMS) of the center of pressure (CoP) were calculated for the AP and ML directions. Four 3×5 (group $\times$ condition) repeated measures ANOVAs were used to determine significant effects of group and condition on variables of interest.
Results: USA exhibited smaller ApEn values than SSA in the AP signals while no significant differences were observed in the ML CoP signals. Generally, the negative feedback conditions were associated with significantly greater RMS values than the positive feedback conditions.
Conclusion: USA exhibit unique postural strategies compared to SSA. These unique strategies seemingly exhibit a direction-specific attribute and may be associated with divergent motor control strategies.

Keywords: Athletes; Balance; Negative feedback; Postural stability; Training

1. Introduction

Postural sway is the continuous movement of one's center of mass (COM) about the base of support in order to maintain an upright stance.[1] In an erect posture, humans are in a continuous state of adjustment and must counter the effects of gravity through alterations in tonic muscular control.[2] The central nervous system utilizes information from the sensory (visual, vestibular, and somatosensory) and motor systems to make adjustments in muscle activation to control upright stance through an efficient pairing of feedback and feedforward mechanisms.[1,3,4] From a motor control perspective, postural sway can be viewed as a measure of the effectiveness of sensorimotor integration in response to changing COM locations relative to the base of support.[5]

It has been suggested that optimal postural control is associated with minimal magnitudes of postural sway about a central point of equilibrium.[6] Thus, greater magnitudes of sway are interpreted as an inability to produce optimal control of posture and may be associated with an unhealthy state or general decline in sensorimotor performance such as with advancing age.[7,8] It is theorized that a more refined or healthy postural control system will exhibit smaller postural sway magnitudes during a given task compared to a less refined or pathological system. These postulations are supported by existing literature that has demonstrated that elite athletes exhibit smaller sway magnitudes when compared to either non-elite

Peer review under responsibility of Shanghai University of Sport.
* Corresponding author.
E-mail address: dwp0817@gmail.com (D.W. Powell).

http://dx.doi.org/10.1016/j.jshs.2016.01.010

athletes or non-athletes (NON).[9] In addition, healthy young adults demonstrate less sway magnitude when compared to older adults (65+ years) during eyes open, quiet stance, and a dynamic obstacle avoidance condition. These data suggest that the total sway magnitude is indicative of the status of the postural control system within a given individual. However, this suggestion is based upon the assumption that the magnitude of sway is indicative of precision within the system during a bilateral standing task.

During athletic participation, motor performance is goal-oriented and dependent upon the mechanical demands of the sport, training status, and training paradigm. Multiple studies have demonstrated that certain athletes (volleyball players, canoers, kayakers, and ice skaters) all demonstrate greater sway magnitude in eyes open conditions when compared to healthy NON.[10–12] During eyes closed and unstable platform conditions (foam board) these same athletes were not significantly different from healthy NON. As such, greater sway magnitude is not always an indicator of the health of the postural control system or reduced balance. This could be explained by the dynamical systems theory where biological systems self-organize in order to adapt to the environment, biomechanical and morphological constraints of the tasks.[5] All of these athletes participate and train in visually stimulating rapidly changing environmental conditions that involve moving suddenly from a static position (i.e., ready stance prior to a volleyball serve; calm slow water paddling transitioning to rough rapids or a sprint; smooth single plane motion skating to a jump, spin or turn). As a result, this greater sway magnitude could be a trained motor strategy that enables these athletes to fluidly switch from static positions to more unstable positions. These results could point to training adaptations, such as a unique training paradigm(s) that are adopted within the postural control system for certain athletes for specific motor performance training goals. Thus, caution is suggested when interpreting greater sway magnitude results in certain athletic populations.

Training status (trained *vs.* untrained) significantly affects postural stability across the lifespan.[9] In fact, most studies have focused solely on athletes who train and compete on a stable surface such as a floor or a ground. However, not all athletes compete on these stable surfaces. With the popularization of extreme sports such as surfing and snowboarding, an increasing number of athletes who participate in sports compete on unstable surfaces. Emerging evidence[10] has suggested that these athletes may adopt unique neuromuscular and biomechanical strategies to maintain upright stance (static stance). These unique postural control strategies are proposed to be a function of the characteristics of the support surface on which stable surface athletes (SSA) are compared to unstable surface athletes (USA) who train. We suggest that SSA apply force to their support surface, and in response their COM is translated in the opposing direction to that of force application. Conversely, USA apply force to their support surface, and in response the support surface moves in the direction of force application. The strategy adopted by USA during athletic performance (surfing or snowboarding) has been suggested to be dominated by a feedforward control strategy which manifests in a proximal to distal control strategy in response to balance perturbations. This is in contrast to the SSA which may initiate movement at the level of the foot and ankle.[10] Continued examination of these unique control strategies in dynamic environments will further elucidate these proposed mechanisms.

While few research studies have focused on the effects of training paradigm on postural control strategies in these functionally different groups, most studies pertaining to postural stability have utilized traditional measures of postural stability such as sway magnitudes or sway excursions. In contrast to traditional measures of postural stability, non-linear measures provide a quantitative assessment of the moment-to-moment variability within a time-series. An emerging body of literature has suggested that non-linear measures of postural stability may offer unique insight into the stability of the neuromuscular system and the efficacy of the postural control strategy.[1–3,5–9] Specifically, it has been shown that non-linear measures of variability such as approximate entropy (ApEn) are capable of detecting subtle differences in the characteristics of the center of pressure (CoP) profile even in the absence of significant differences in traditional measures of sway including CoP excursions, resultant distance or path length, and sway accelerations.[5,9,13,14] Measurement of both the quantity and quality of postural sway is likely to offer a more complete description of the health and performance of the underlying sensorimotor system.

At present, few research studies have focused on the effects of training paradigm on postural control strategies in these two functionally different groups. However, the unique training and postural control strategies may provide a platform from which evidence-based therapeutic interventions may be developed to improve balance in a variety of populations. Therefore the purpose of this study was to investigate the effect of different feedback training paradigms on traditional and non-linear measures of postural stability when balance is perturbed by a translating force platform. Supported by existing literature, it is hypothesized that USA will exhibit significantly greater measures of variability compared to SSA.

2. Methods

2.1. Subjects

Twenty-four healthy adults aged 18–30 years were recruited to participate in the current study. Participants were recruited based on the balance paradigm in which each athletic participant participated including: NON (age: 22.9 ± 2.5 years), SSA (age: 22.6 ± 3.2 years), and USA (age: 23.1 ± 2.5 years). NON participants were characterized as being sedentary or participating less than 30 min of recreational physical activity fewer than 3 days per week.[15] SSA participants were recreationally active in a traditional sport at least 30 min per day for 3 or more days per week on a stable surface. The subjects were primarily composed of graduate students who participated in intramural sports 4–5 days per week. Each of these games or practices lasted no less than 1 h. While no measures of physical fitness were measured, all participants were familiar with and capable of their sports. A stable surface was characterized by a surface on which the athlete's COM moved in direct response to the force applied to the support surface without translation of the support surface such as a basketball floor or playing field. The USA group was composed of individuals who regularly participated in sports in which the base of support moved in response to the forces applied to the surface such as a surfboard or snowboard. Participants were excluded if they had any history of orthopedic injury or neurological disorder that prevented them from maintaining a stable posture or from successfully participating in their selected sport at the time of testing. The experimental protocol was approved by the Institutional Review Board and all participants provided written informed consent prior to participation in this study.

2.2. Instrumentation

Consistent with previous research investigating these populations,[7] ground reaction forces (GRFs) were recorded from two 0.23 m (width) × 0.45 m (length) force platforms placed side by side and embedded within a 1.8 m × 1.8 m raised platform (200 Hz; Natus Medical, Inc., Clackamas, OR, USA). This resulted in a stance width of approximately 0.23 m during testing. CoP was calculated from the GRFs recorded from the two adjacent force platforms.

2.3. Procedure

As described previously,[7] subjects were asked to perform a quiet standing task with each foot placed at the center of each force platform, with the participant's feet aligned with the anteroposterior (AP) axis of each force platform and the arms placed by the participant's side in a relaxed position. Foot placement was standardized by marking the initial foot position prior to the first trial and was maintained throughout the entirety of testing. Participants were asked to fix their gaze on a target located 1.67 m away from the participant in the AP direction at a vertical height approximately equal to the participant's head. Participants completed five successful 20-s trials in each of five experimental conditions with 30 s of rest between individual trials.

The experimental conditions included a static condition (STATIC) and four dynamic conditions in which the force platform upon which participants were standing translated in the AP or mediolateral (ML) directions in a positive- or negative-feedback paradigm. A successful trial in the STATIC condition was characterized by the participant completing a 20-s quiet standing trial on the support surface while the surface remained stable and did not move. In the positive-feedback condition, the force platform translated in response to the changing position of the CoP beneath the participant using a positive-feedback paradigm in the AP (AP_{pos}) or ML directions (ML_{pos}). For example, as the participant's CoP position moved in the positive AP direction (toward the participant's toes), the force platform translated in the positive AP direction (toward the participant's toes). Conversely, in the negative-feedback condition if the participant's CoP moved in the positive AP direction (toward the participant's toes), the force platform translated in the negative AP direction (toward the participant's heels). Participants were tested in the negative-feedback paradigm in both the AP (AP_{neg}) and ML directions (ML_{neg}). The experimental protocol included positive- and negative-feedback conditions in both the AP and ML directions.

CoP-dependent platform translation occurred immediately upon the initiation of each experimental trial and followed a period of quiet stance (rest) on the force platforms. The beginning of each experimental trial was initiated by the investigator. Platform translation in the AP and ML directions could reach a maximum magnitude of 0.13 m and a maximum translation velocity of 1.81 m/s.

2.4. Data analysis

Raw AP and ML CoP time-series were filtered using a fourth-order, zero phase Butterworth low-pass digital filter with a 50-Hz cut-off frequency. While many entropic measures have been used to quantify the regularity and complexity of biological signals, due to the abundance of existing data pertaining to postural stability using ApEn, it was selected to quantify the regularity of the CoP time-series in this study. ApEn calculations yield a value between 0 and 2 which reflects the predictability of future values within a time-series based on the preceding values of that time-series. A value that approaches 0 is indicative of a highly regular, highly predictable signal such as a sinusoidal wave form. Conversely, high ApEn values (approaching 2) are representative of irregular wave forms in which each future value within a time-series is independent of and cannot be predicted by the preceding values within that time-series. An example of a signal that would result in a high ApEn value is white noise as each point in the time-series is an independent observation and no deterministic pattern exists within the white noise signal. The ApEn values for the ML and AP CoP time-series were calculated using the algorithm denoted in Eq. (1):

$$\mathrm{ApEn}(m, r, N) = \ln\left[\frac{C_m(r)}{C_{m+1}(r)}\right] \tag{1}$$

where m was the length of the compared runs ($m = 2$), r was the similarity criterion between points in a time-series ($r = 0.2 \times \mathrm{SD}$), N was the number of measurements in the time-series (i.e., number of points). As oversampling has been demonstrated to alter ApEn values,[16] a lag of 20 was applied to the time-series. A lag function was used to down sample the time-series and functionally reduced the sampling frequency to 10 Hz.[13] The ApEn values were calculated for the AP and ML CoP time-series for each trial for each subject. A subject mean was then calculated as the average ApEn of all trials within a given condition for a given subject. Subject means were used in statistical analysis of the data.

Traditional measures of postural stability were calculated as previously described.[17] Specifically, the root mean squared (RMS) distances of the AP and ML CoP time-series (RMS_{AP} and RMS_{ML}) from the mean CoP location were calculated average distances from the mean CoP location. The algorithm used to calculate the RMS distance in RMS_{AP} is shown in Eq. (2).

$$RMS_{AP} = \frac{1}{N}\sum\left[AP(n)^2\right]^{1/2} \qquad (2)$$

The standard deviation of the RMS signal (RMSD) was also calculated as a traditional measure of variability.

2.5. *Statistical analysis*

A 3 × 5 (group × condition) repeated measures analysis of variance (ANOVA) was used to determine the presence of significant main effects of group (NON *vs.* SSA *vs.* USA) and experimental condition (STATIC *vs.* AP_{neg} *vs.* AP_{pos} *vs.* ML_{neg} *vs.* ML_{pos}) for dependent variables including ApEn, RMS_{AP}, RMS_{ML}, $RMSD_{AP}$, and $RMSD_{ML}$. In the presence of a significant main effect or significant interactions, pairwise comparisons were made using a Tukey's *post hoc* analysis to determine the source of the significant finding. Alpha level was set at $p < 0.05$. All statistical analyses were conducted using SPSS Version 21.0 (IBM, Armonk, NY, USA).

3. Results

3.1. *AP ApEn*

The statistical analysis of ApEn values of the AP CoP signals revealed a significant main effect of group ($F = 5.920$; $p < 0.009$) and condition ($F = 41.178$; $p < 0.001$) (Fig. 1A). Pairwise comparisons of group demonstrated that with conditions collapsed the USA group had significantly smaller ApEn values in the AP CoP signal compared to SSA group ($p = 0.008$). With conditions collapsed, the AP CoP ApEn values for the NON group were not significantly different when compared to the SSA ($p = 0.125$) or USA groups ($p = 0.747$), respectively.

Pairwise comparisons of condition revealed that the STATIC condition had significantly smaller ApEn values than the AP_{pos}, AP_{neg}, ML_{pos}, and ML_{neg} conditions ($p < 0.001$). AP_{pos}, ML_{pos}, and ML_{neg} conditions had significantly smaller ApEn values compared to the AP_{neg} condition ($p < 0.001$).

No significant group × condition interaction was observed for AP CoP ApEn values ($F = 0.907$; $p = 0.521$).

3.2. *ML ApEn*

For the ApEn of ML CoP signals, the statistical analysis revealed a significant group × condition interaction ($F = 2.203$; $p = 0.048$). The pairwise comparisons for group demonstrated that the ApEn values at ML_{neg} condition were significantly larger than those at AP_{pos}, AP_{neg}, and ML_{pos} conditions ($p < 0.05$). The STATIC condition had smaller ApEn values than AP_{pos}, AP_{neg}, ML_{pos}, and ML_{neg} conditions ($p < 0.050$). There were no significant differences between AP_{pos} condition and AP_{neg} ($p = 0.967$) or ML_{pos} conditions ($p = 1.000$) (Fig. 1B).

3.3. *AP RMS distance*

Statistical analysis of the RMS_{AP} revealed a significant main effect of condition ($F = 42.899$, $p < 0.001$) while no significant main effect of group ($F = 0.969$; $p = 0.396$) or group × condition interaction ($F = 1.051$; $p = 0.417$) was observed (Fig. 2A). The *post hoc* pairwise comparisons of conditions revealed that the AP_{neg} condition had greater RMS_{AP} values than all the other

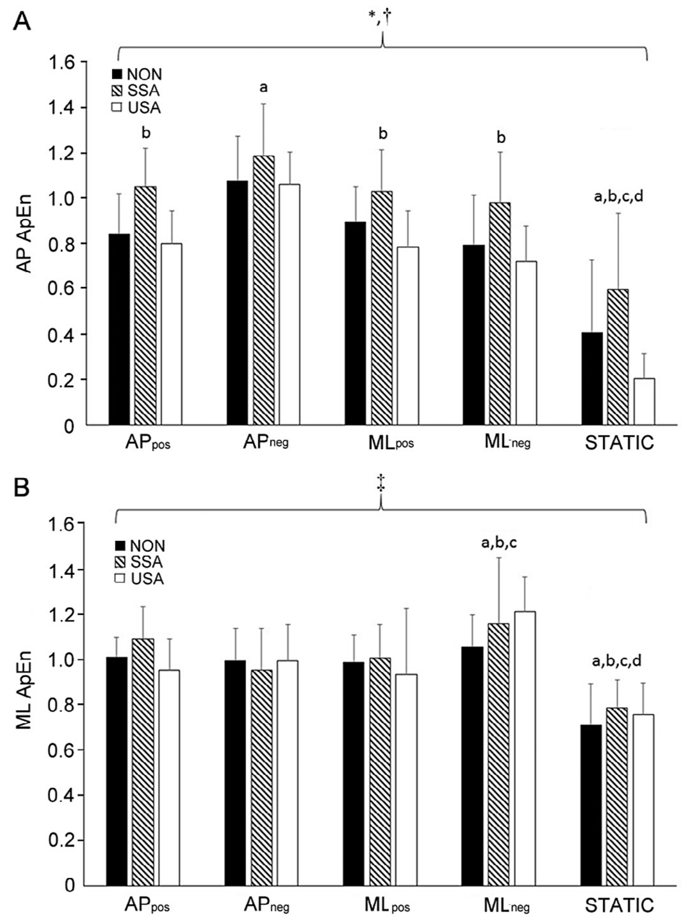

Fig. 1. Mean approximate entropy (ApEn) values in the anteroposterior (AP) (A) and mediolateral (ML) (B) directions for the non-athletes (NON), stable surface athletes (SSA), and unstable surface athletes (USA) in each of the five experimental conditions (mean ± SD). *Significant condition effect; †Significant group effect; ‡Significant group × condition interactions; [a]Significant difference compared to AP_{pos} condition; [b]Significant difference compared to AP_{neg} condition; [c]Significant difference compared to ML_{pos} condition; [d]Significant difference compared to ML_{neg} condition.

conditions ($p < 0.001$). The RMS_{AP} values at STATIC condition were significantly smaller than the other conditions ($p < 0.05$). The ML_{neg} condition had significant greater RMS_{AP} values than the ML_{pos} condition ($p = 0.005$).

3.4. *ML RMS distance*

Statistical analysis of the RMS_{ML} condition revealed significant main effects of group ($F = 4.595$; $p = 0.022$) and condition ($F = 13.883$; $p < 0.001$). No significant group × condition interaction was observed for the RMS_{ML} values ($F = 1.457$; $p = 0.206$) (Fig. 2B). *Post hoc* pairwise comparisons revealed that the USA group had significantly greater RMS_{ML} values compared to the SSA group ($p = 0.027$) in the AP_{neg} condition while no significant differences were observed between the NON group and either the SSA ($p = 1.000$) or USA groups ($p = 0.102$). RMS_{ML} values at ML_{neg} condition were significantly greater than all the other conditions ($p < 0.001$). The STATIC condition had significantly greater RMS_{ML} values than AP_{pos} and

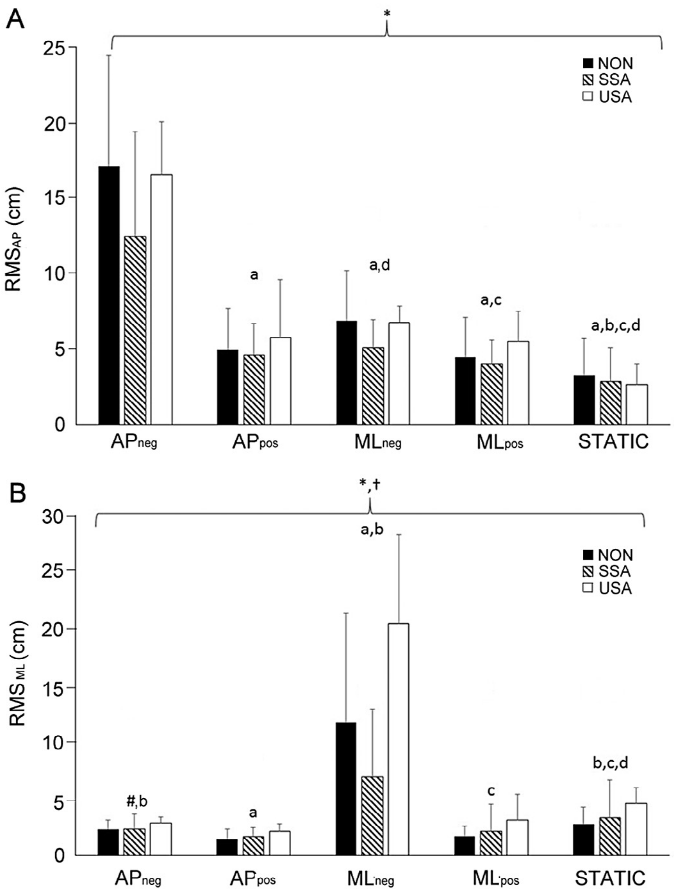

Fig. 2. Mean root mean square (RMS) distance values in the (A) anteroposterior (AP) and (B) mediolateral (ML) directions for the non-athletes (NON), stable surface athletes (SSA), and unstable surface athletes (USA) in each of the five experimental conditions (mean ± SD). *Significant condition effect; †Significant group effect; #Significant difference between SSA and USA groups; aSignificant difference compared to AP_{neg} condition; bSignificant difference compared to AP_{pos} condition; cSignificant difference compared to ML_{neg} condition; dSignificant difference compared to ML_{pos} condition.

ML_{pos} conditions ($p < 0.01$). RMS_{ML} values at AP_{pos} condition are significantly smaller than those at AP_{neg} condition ($p < 0.001$).

4. Discussion

The purpose of this study was to investigate if athletes who train with different feedback paradigms demonstrate differences in postural stability measures (traditional and nonlinear) when balance is perturbed by a translating support surface. The results of the current study demonstrated that athletes who trained regularly on surfaces with variable responsiveness (water, ice, wheels) demonstrated different postural stability from other athletes and that these responses differ depending on the plane of movement. Specifically, USA demonstrated more regular CoP patterns in the AP direction across all conditions. The USA demonstrated greater magnitudes of CoP RMS_{ML} values in the ML direction than SSA or NON especially when exposed to a negative-feedback environment, which was more familiar to these athletes. While no main effect existed for RMS_{AP}, USA demonstrated greater values across all dynamic conditions when compared to SSA. Overall, the static condition was associated with the most regular CoP patterns while negative-feedback environments resulted in the greatest magnitudes of CoP RMS values in the direction of applied perturbations.

Skilled athletes have been shown to have better balance when compared to untrained individuals during balance activities.[9] Moreover, level of training within athletes influences postural stability where elite athletes demonstrate better balance than either non-elite athletes or NON during dynamic balance tasks.[8,10,18] Beyond skill level, specific sports likely require different balance requirements. For example, postural stability in ballet dancers and judoists (two sports requiring stability and movement in single-leg stance) has been compared to untrained individuals. It was reported that ballet dancers and judoists exhibited greater postural control during bipedal standing, suggesting their specialized training may have some carryover to static balance.[19] In the current study, there exist differences between athletes in regularity in the AP direction during the static condition without changes in the magnitude. Because USA are required to maintain their balance in bipedal stance, the controlled movement of the CoP appears to be more important than the magnitude of movement.

Details regarding the underlying mechanisms of improved balance performance have been noted in ballet dancers. It has been demonstrated that the skilled balance produced by these athletes is likely due to an increased reliance and acuity upon somatosensory and vestibular cues and less sensory weighting of visual feedback compared to untrained individuals.[20] The current study did not evaluate the effect of vision on these athletes' ability to control balance. While differences were realized with surface feedback manipulation and vision held constant, reliance on vision cannot be evaluated in the current study. SSA and USA are required to react to their external environment during sport. For example, a running back in football must stop and cut to avoid a defensive tackle while a surfer must turn quickly at the bottom of a wave to avoid the crashing wave. However, the reliance on vestibular and somatosensory feedback may need to be enhanced in the surfer as his COM moves one direction while his feet slide the opposite direction. This is evidenced in the current study by the increase in movement with an improved regularity in USA compared to SSA when exposed to negative-feedback in the AP direction. While this is not true in the ML direction, this is likely due to the shift in planes present. USA such as those used in the current study require a sideway stance when they compete. This results in fore–aft movement of the board occurring as a result of ML planar control in the body, side-to-side movement of the board occurring as a result of AP planar movement of the body. Therefore, AP body movement becomes a more important controller of board manipulations such as turning.

Many studies have demonstrated that athletic skill is a strong predictor of improved balance. However, these studies have focused exclusively on athletes who train on stable surfaces and traditional measures of the quantity of motion experienced by the athlete. Previous research has shown that athletes have smaller magnitudes of postural sway when compared to NON.[21] However, in the current study, the USA demonstrated greater RMS_{ML} compared to NON and SSA, particularly when presented with negative-feedback in the ML direction. It is postulated that these increased RMS magnitudes are the result of larger sway envelopes in the USA developed through training with their COM outside of their base of support. A potential contributing factor to this phenomenon pertains to the posture adopted during participation in their sport of interest. Specifically, most USA are required to stand with their bodies facing the mediolateral axis of the support surface and direction of travel while their heads are oriented in the direction of travel and perpendicular to the body's anteroposterior axis. In order to steer their support surface (board) to the left or right, USA must lean beyond the dimensions of the support surface while maintaining an upright posture through a controlled movement. These two mechanisms may underlie the greater regularity exhibited by USA in the AP direction.

Due to previous research findings,[3,4,7] it is generally accepted that athletes exhibit better balance than NON. However, most studies investigating postural stability in these two groups have focused on variables of time,[20,22–25] sway magnitude,[26–28] and reach distance.[18,29] While these quantitative measures provide valuable information pertaining to the mechanical outcome of the motor program, they do little to describe the stability of the motor program. In an attempt to better describe the quality of movement during tasks, other methods including frequency analysis have been employed to investigate reflex control of postural sway (short *vs.* long loop reflex) and to compare between subject groups.[30] Additionally, differences in sway frequency are present across the lifespan during a quiet standing task, primarily in the low frequency bands (0.02–2 Hz). Differences also exist in dynamic balance control between athletes and NON where athletes perform significantly better in a low frequency band (0–2 Hz), indicating a reduced reliance upon vestibular and visual afferents during balance activities.[25] Additionally, dancers are less dependent on visual input when compared to NON especially in an eyes open condition.[20] Finally, elite rhythmic gymnasts exhibit superior postural control strategies (frequency) evidenced by performance in mediolateral displacements.[26] While frequency of sway was not evaluated in the present study, ApEn was a measure of movement strategy and was able to discriminate between athletes in the AP direction. USA utilized a feedforward strategy evidenced by reduced ApEn in both AP_{neg} and STATIC conditions. The SSA had larger values of ApEn in these conditions as a result of a more reactionary movement pattern, especially in the unfamiliar negative feedback environments.

Few studies have investigated the regularity of sway and fewer still have applied non-linear analyses to these unique athlete groups. In the present study, the USA demonstrated significantly greater regularity in the AP direction suggesting a need for a controlled sway pattern, particularly when there is an increased magnitude of movement. It is interesting that this postural control strategy is carried over to the basic task of static balance. However, this speaks to the presence of an underlying motor control strategy as opposed to a task-dependent mechanical outcome. Although the USA exhibited greater sway magnitudes, it can be argued that they exhibit an effective balance strategy which enhances their ability to maintain upright stance on an unstable surface. Thus, training in a more challenging environment may have implications for improved balance in athletes or may potentially be used as a training program for older adults at increased risk of falls.[31]

Static balance is defined as the ability to maintain the body's center of gravity over the body's base of support.[18] As an essential element of motor control, balance plays a key role in complex tasks such as sport-related and dual task activities. Balance is achieved through central processing of somatosensory, visual and vestibular afferent inputs resulting in appropriate neuromuscular efferent responses.[18] Dynamic balance is characterized by maintaining the body's center of gravity over the base of support during dynamic body motion or restoring equilibrium following a balance perturbation through rapid, successful body position changes.[22] While basic balance is required to perform simple activities of daily living, athletes encounter greater movement excursions, more rapid joint and segmental velocities and the need for decreased reaction times during sporting activities. These demands place an increased need for maintenance of dynamic balance. This is further complicated in USA by the fact that the surface is responding in an inconsistent and negative manner. USA need to predictively shift their weight away from the surface, temporarily destabilizing the system until the surface reacts and places the surface back under the athlete and the system becomes stable again. The differences seen in the current study between USA and SSA in both ApEn and RMS are potentially due to this "surface moving under the athlete" phenomenon.

The findings of the current study demonstrated that the magnitude of sway was greatly increased when subjects encountered a negative-feedback environment in the direction of measurement. Due to the novel nature of the dynamic balance task, participants may have been less able to control movement (NON) or may have been more comfortable (USA) in the negative-feedback environment. These results demonstrate that training paradigm has a distinct effect on an athlete's ability to monitor and control the magnitude and quality of COM motion.

Although this study presents novel findings that suggest the training paradigm or environment in which an athlete competes is associated with unique postural control strategies, the current study does have some limitations. One limitation of the current study is the limited sample size. The convenience sample was small, but is representative of the relatively small number of individuals who regularly participate in unstable surface sports such as snowboarding and surfing. The second limitation of this study was the short period of data collection. It is possible that the 20-s samples were too short to adequately represent postural profiles. Further, small sample sizes have been suggested to affect non-linear dynamic calculations. Finally, the current study found no differences in balance performance between the NON and SSA groups. It is possible that this is the result of the recreational nature of the athletes utilized in the current study or potentially the limited differences in balance performance between recreational athletes and healthy young adults.

5. Conclusion

Dynamic testing conditions resulted in an expected decrease in movement regularity and increase in movement quantity in all individuals across all feedback conditions and in all directions when compared to static balance. The increase in regularity of movement in USA in the AP direction may be the result of the specific needs of their sports. The shift of ML and AP local axes in the global environment is unique to these athletes and potentially aids in the development of their motor patterns during static and dynamic tasks. Future studies should address the efficacy of positive-compared to negative-feedback balance training programs on dynamic balance in unskilled athletes or individuals with balance limitations.

Authors' contributions

DSW contributed to project development, data collection, data reduction/analysis and manuscript preparation; NGM contributed to project development, data reduction/analysis and manuscript preparation; DWP contributed to project development, data collection, data reduction/analysis and manuscript preparation. All authors have read and approved the final version of the manuscript, and agree with the order of presentation of the authors.

Competing interests

None of the authors declare competing financial interests.

References

1. Winter DA. Human balance and posture control during standing and walking. *Gait Posture* 1995;**3**:193–214.
2. Horak FB. Clinical measurement of postural control in adults. *Phys Ther* 1987;**67**:1881–5.
3. Klous M, Mikulic P, Latash ML. Two aspects of feedforward postural control: anticipatory postural adjustments and anticipatory synergy adjustments. *J Neurophysiol* 2011;**105**:2275–88.
4. Riley PO, Mann RW, Hodge WA. Modeling of the biomechanics of posture and balance. *J Biomech* 1990;**23**:503–6.
5. Stergiou N, Decker LM. Human movement variability, nonlinear dynamics, and pathology: is there a connection? *Hum Mov Sci* 2011;**30**:869–88.
6. McKeon PO, Hertel J. Systematic review of postural control and lateral ankle instability, Part I: can deficits be detected with instrumented testing. *J Athl Train* 2008;**43**:293–304.
7. Yamamoto S, Kitazawa S. Reversal of subjective temporal order due to arm crossing. *Nat Neurosci* 2001;**4**:759–65.
8. Rocchi L, Chiari L, Horak FB. Effects of deep brain stimulation and levodopa on postural sway in Parkinson's disease. *J Neurol Neurosurg Psychiatry* 2002;**73**:267–74.
9. Lamoth CJ, van Lummel RC, Beek PJ. Athletic skill level is reflected in body sway: a test case for accelometry in combination with stochastic dynamics. *Gait Posture* 2009;**29**:546–51.
10. Powell DW, Williams 3rd DS. Athletes trained using stable compared to unstable surfaces exhibit distinct postural control profiles when assessed by traditional and nonlinear measures. *Hum Mov Sci* 2015;**44**:73–80.
11. Stergiou N, Harbourne R, Cavanaugh J. Optimal movement variability: a new theoretical perspective for neurologic physical therapy. *J Neurol Phys Ther* 2006;**30**:120–9.
12. Cavanaugh JT, Guskiewicz KM, Stergiou N. A nonlinear dynamic approach for evaluating postural control: new directions for the management of sport-related cerebral concussion. *Sports Med* 2005;**35**:935–50.
13. Cavanaugh JT, Guskiewicz KM, Giuliani C, Marshall S, Mercer VS, Stergiou N. Recovery of postural control after cerebral concussion: new insights using approximate entropy. *J Athl Train* 2006;**41**:305–13.
14. Cavanaugh JT, Mercer VS, Stergiou N. Approximate entropy detects the effect of a secondary cognitive task on postural control in healthy young adults: a methodological report. *J Neuroeng Rehabil* 2007;**4**:42.
15. Thompson WR, Gordon NF, Pescatello LS. *ACSM's guidelines for exercise testing and prescription*. 8th ed. Philadelphia, PA: Wolters Kluwer/Lippincott Williams & Wilkins; 2010.
16. Chen WT, Wang ZZ, Ren XM. Characterization of surface EMG signals using improved approximate entropy. *J Zhejiang Univ Sci B* 2006;**7**:844–8.
17. Prieto TE, Myklebust JB, Hoffmann RG, Lovett EG, Myklebust BM. Measures of postural steadiness: differences between healthy young and elderly adults. *IEEE Trans Biomed Eng* 1996;**43**:956–66.
18. Hansen MS, Diekmann B, Jensen K, Jakobsen BW. The reliability of balance tests performed on the kinesthetic ability training (KAT 2000). *Knee Surg Sports Traumatol Arthrosc* 2000;**8**:180–5.
19. Perrin P, Deviterne D, Hugel F, Perrot C. Judo, better than dance, develops sensorimotor adaptabilities involved in balance control. *Gait Posture* 2002;**15**:187–94.
20. Golomer E, Cremieux J, Dupui P, Isableu B, Ohlmann T. Visual contribution to self-induced body sway frequencies and visual perception of male professional dancers. *Neurosci Lett* 1999;**267**:189–92.
21. Kiers H, van Dieen J, Dekkers H, Wittink H, Vanhees L. A systematic review of the relationship between physical activities in sports or daily life and postural sway in upright stance. *Sports Med* 2013;**43**:1171–89.
22. Davlin CD. Dynamic balance in high level athletes. *Percept Mot Skills* 2004;**98**(3 Pt 2):1171–6.
23. Kioumourtzoglou E, Derri V, Mertzanidou O, Tzetzis G. Experience with perceptual and motor skills in rhythmic gymnastics. *Percept Mot Skills* 1997;**84**(3 Pt 2):1363–72.
24. Kioumourtzoglou E, Derri V, Tzetzis G, Theodorakis Y. Cognitive, perceptual, and motor abilities in skilled basketball performance. *Percept Mot Skills* 1998;**86**(3 Pt 1):771–86.
25. Guillou E, Dupui P, Golomer E. Dynamic balance sensory motor control and symmetrical or asymmetrical equilibrium training. *Clin Neurophysiol* 2007;**118**:317–24.
26. Calavalle AR, Sisti D, Rocchi MB, Panebianco R, Del Sal M, Stocchi V. Postural trials: expertise in rhythmic gymnastics increases control in lateral directions. *Eur J Appl Physiol* 2008;**104**:643–9.
27. Gerbino PG, Griffin ED, Zurakowski D. Comparison of standing balance between female collegiate dancers and soccer players. *Gait Posture* 2007;**26**:501–7.
28. Demura S, Kitabayashi T, Noda M, Aoki H. Age-stage differences in body sway during a static upright posture based on sway factors and relative accumulation of power frequency. *Percept Mot Skills* 2008;**107**:89–98.
29. 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**:42–6.
30. Horak FB, Nashner LM. Central programming of postural movements: adaptation to altered support-surface configurations. *J Neurophysiol* 1986;**55**:1369–81.
31. Sforza C, Grassi GP, Turci M, Fragnito N, Pizzini G, Ferrario VF. Influence of training on maintenance of equilibrium on a tilting platform. *Percept Mot Skills* 2003;**96**:127–36.