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Dynamic Stability in Gymnasts, Non-Balance Athletes, and Active Controls

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ABSTRACT

International Journal of Exercise Science 11(1): 1-12, 2018. Gymnastics by nature is a balance sport requiring both static and dynamic stability. To our knowledge, the center of pressure (COP) movement of collegiate gymnasts has not been compared to other collegiate athletes and healthy controls during static and dynamic postural stability tasks. Our purpose was to investigate static and dynamic stability in collegiate gymnasts, non-gymnast athletes and non-athlete controls. Data were collected on female university gymnasts (n=10), university athletes in other sports (n=10), and active non-athlete controls (n=10). Static balance was measured using a commercially available six-condition static test and dynamic plantar/dorsiflexion perturbation test. Static stability variables included: mediolateral and anteroposterior COP sway, total COP displacement, average COP velocity, and standard deviation of vertical force. Dynamic perturbation variables included: initial COP sway, total COP sway, and sway velocity. A two factor ANOVA was performed (group x condition) on each variable ($\alpha=0.05$) in each assessment. Significant differences were found between the groups for mediolateral COP sway (gymnasts<controls; P=0.049), total COP displacement (controls<non-gymnast athletes, P=0.005), and sway velocity (controls<non-gymnast athletes, P=0.010). In response to dynamic perturbations, gymnasts demonstrated less total sway than controls (P=0.036) and less sway velocity than the non-gymnast athletes (P=0.016). All dependent variables were significantly different between conditions for both static and dynamic tests (P<0.05). Static and dynamic postural control is affected by participation in collegiate sports. In static testing, gymnasts display better mediolateral stability than non-athletes; in dynamic testing, gymnasts display less COP sway and velocity than controls and non-gymnast athletes.

KEY WORDS: Gymnasts, collegiate athlete, postural stability, postural control, dynamic posturography

INTRODUCTION

Anecdotally, gymnasts are thought to have good balance. Because gymnasts practice stationary balance in challenging postures as well as during dynamic landings from acrobatic skills, they may hone their sensory and musculoskeletal systems to have superior balance compared to athletes in other sports as well as non-athletes (14). Various researchers have studied static and dynamic balance in gymnasts compared to other populations. While most of the related studies endorse the notion of better postural control in gymnasts, the results are conflicting due to different testing paradigms, subject populations, and measures of interest.

Static postural stability, or the ability to maintain balance with minimal movement of either the center of mass or center of pressure (COP) (14), has been assessed by several research groups. Gymnasts demonstrated superior mediolateral and anteroposterior stability in tandem stance, as measured with a triaxial accelerometer on the trunk, in both eyes open and eyes closed conditions when compared to physical education majors and other non-athletic collegiate students (17). Similarly, gymnasts and collegiate soccer athletes displayed better static bipedal stability on stiff and compliant surfaces, as assessed via the Balance Error Scoring System, than did collegiate basketball players (3). Vuillerme and coworkers reported that, when compared to skilled athletes in other sports, gymnasts displayed better static postural control, as assessed via COP movement, during various stance conditions (25), required less attentional demand to maintain static stability (26), and recovered from disturbed proprioception earlier than the other athletes (27). On the contrary, Gautier, Thouvarecq, and Vuillerme (9) reported no differences in COP movement between gymnasts and non-athlete controls in response to alterations to optical flow.

Additionally, because gymnasts must be stable when landing from tumbling skills, assessment of dynamic stability is key. Dynamic postural stability, or the ability to regain balance following a perturbation (14), has been evaluated between gymnasts and other populations. Debu and Woollacott (6) reported increased muscle latencies in gymnasts compared to non-athletes following surface perturbations under various visual and stance conditions. Gautier, Thouvarecq and Larue (8) compared COP movement following an upper-body perturbation in gymnasts and athletes in other sports and reported no differences in the magnitude of COP movement between the groups, but rather an earlier COP response latency. Conversely, Bressel et al. (3) did not find differences between gymnasts and other collegiate athletes using the Star Excursion Balance test.

To our knowledge, comparison of COP movement during static stance and surface perturbations in gymnasts, athletes in other sports, and healthy controls has not been performed. This information is important as existing literature is unable to fully explain the superior performance of gymnasts compared to other athletes and non-athletes. Understanding the skills that are required by gymnasts may allow for enhanced training methods and assessment. Therefore, the purpose of this study was to compare static and dynamic postural stability, based on COP analysis, in collegiate gymnasts, other collegiate athletes, and healthy non-athlete controls. Based on the results of previous studies (17, 25), we hypothesized that gymnasts would demonstrate less COP movement during the static testing. Because other authors reported no differences in dynamic stability between gymnasts and other athletes (3, 8), we hypothesized that there would be no differences between subject groups following perturbations.

METHODS

Participants

Three groups of individuals were selected and evaluated in this study including ten NCAA Division I gymnasts, ten NCAA Division I athletes in sports other than gymnastics, and ten non-athlete healthy controls.. Subject demographics are provided in Table 1. The gymnasts were younger than the other participant groups (p=0.004). The non-gymnast athletes included cross-country runners (n=3), divers (n=3), a swimmer (n=1), tennis player (n=1), rower (n=1), and volleyball player (n=1). Non-athlete controls were recruited from an exercise science class at our university. The level of activity for the control group ranged from no exercise participation to exercise participation for as much as four hours a week involving resistance training or aerobic exercise (e.g. running or taking exercise classes). This exercise, however, was much less than 20 hours a week reported by the NCAA athlete groups.

All subjects were recruited by word of mouth. Exclusion criteria for all groups included: male gender (as our university only has a women's gymnastics team, it was not possible to recruit male gymnasts for this study), not being between age 18 and 30, being pregnant or less than three months post-partum, having a balance disorder, persistent dizziness, vertigo, neuromuscular impairment, neurological disorder or musculoskeletal dysfunction, history of high blood pressure or diabetes, lower extremity injury that affected gait or required limited load bearing, previous back surgery, lower extremity fracture within the past year, ankle sprain within the previous six months, or a history of significant lower extremity ligament tear. This experiment followed procedures in accordance with the standards set by the Helsinki Declaration. (IRB Approval #: WVU IRB 1306055834).

A power analysis was performed a-priori to estimate sample size. Gautier et al. (8) performed an anteroposterior translational perturbation on a group of eight male collegiate gymnasts and eight male athletes who competed in sports other than gymnastics. With a statistical power of 0.08 and an alpha level of 0.05, we estimated that we would need 30 participants in this study to achieve statistical significance on this variable.

Table 1. Subject demographics, shown as mean ± standard deviation, for the gymnasts, other collegiate athletes, and non-athlete control participants in this study. Gymnasts were significantly (*) younger than the other two groups (P<0.05). Height and mass did not differ between groups (P>0.05).

	Age (yrs)*	Height (cm)	Mass (kg)
Collegiate gymnasts	19.6 ±1.3	161.5±3.4	59.4±6.3
Other collegiate athletes	21.4±1.4	165.6±7.8	59.2±8.7
Non-athlete controls	21.1±0.9	163.4±5.6	59.7±9.7

Protocol

Subjects reported to the Balance and Falls Laboratory at West Virginia University for testing. After the experimental procedure was explained, the subject provided university-approved written informed consent (WVU IRB Approval #: 1306055834) in accordance with the standards sets by the Helsinki Declaration. Subjects completed a physical activities questionnaire that provided data on the subject's physical activity over the past year. The purpose of this form was to confirm that our subjects were correctly classified into being a gymnast, other athlete, or healthy control. The NCAA mandates that athletes be limited to no more than 20 hours of exercise a week (20). As such, almost all of the participants in the athlete groups reported exercise participation of 20 hours per week. Non-athlete controls reported between no exercise and four hours per week.

Static and dynamic postural stability assessments were performed using a SMART Balance Master ® (NeuroCom International, Inc., Clackamas, OR, USA). Subjects wore comfortable athletic clothing, and all testing was performed with the subjects barefoot. Each participant wore a harness to ensure safety. The subject's feet were aligned properly on the force plate according to manufacturer's specifications.

Static stability was assessed using the six-condition Sensory Organization Test (SOT) as prescribed by the manufacturer. COP data were collected at 100 Hz. The subject was instructed to stand as still as possible while she underwent three 20 second trials of each of the following six conditions: (1) eyes open, (2) eyes closed, (3) eyes open with the visual surround referenced to anteroposterior sway of the subject, (4) eyes open with surface position referenced to anteroposterior sway of the subject, (5) eyes closed with surface position referenced to anteroposterior sway of the subject, and (6) eyes open with both visual surround and surface position referenced to anteroposterior sway of the subject.

Subsequently, dynamic postural stability was assessed using the Adaptation Test (ADT) according to the manufacturer's guidelines. Specifically, each subject underwent five "toes-up" perturbations followed by five "toes-down" perturbations. Each perturbation consisted of an 8° degree rotation at 20°/s of the support surface. The subjects were informed of the direction of perturbation at the beginning of each condition but were not cued to the onset of the five perturbation trials in each condition. Data were collected for a total of 3 seconds during each trial, with the perturbation being delivered at 0.5 seconds into the trial; thus, 2.5 seconds of COP data were collected following each perturbation.

Data were processed in Matlab (Version R2008a. Mathworks, Inc., Natick, MA, USA). The mediolateral and anteroposterior position of the COP and the vertical force (Fz) were determined at each time point. Data were filtered using a fourth order low-pass zero-phase lag Butterworth filter with a cutoff frequency of 20 Hz. The following variables were calculated from the static trials: mediolateral sway (i.e. maximum medial COP position – maximum lateral COP position), anteroposterior sway (i.e. maximum anterior COP position – maximum posterior COP position), COP displacement (length of the path of the COP), and the average sway velocity (i.e. the COP displacement/time of trial). Additionally, the standard deviation of the vertical reaction force was determined for each static trial (11).

The following variables were determined during each of the dynamic perturbation trials: initial COP sway (i.e. the amount of anteroposterior COP movement from the start of the perturbation until the maximum initial COP displacement), total COP sway (i.e. the difference between the maximum anterior and posterior COP displacement following the perturbation), and the sway velocity (i.e. the initial COP sway/time to reach maximum displacement).

Statistical Analysis

All statistical analyses were performed using IBM SPSS Statistics v.21 (IBM, Inc., Armonk, NY, USA). Group (gymnast, non-gymnast athlete, and non-athlete control) was our primary independent variable in each analysis. An ANOVA was performed to compare subject demographics between groups ($\alpha=0.05$). A two-factor ANOVA (group x condition) was performed on each dependent static stability variable, namely: mediolateral sway, anteroposterior sway, COP displacement, average sway velocity, and standard deviation of the vertical force ($\alpha=0.05$). Subsequently, a two-factor ANOVA (group x direction) was performed on the ADT variables of initial sway, total sway, and sway velocity. Tukey post-hoc analyses were performed when appropriate ($\alpha=0.05$).

RESULTS

Static assessment: Several variables were significantly different between groups or conditions in the static postural stability assessment (Tables 2-4 and Figure 1). Gymnasts displayed significantly lower mediolateral sway than the healthy controls (P=0.049), while mediolateral sway of the non-gymnast athletes did not differ from either group. Mediolateral sway was also significantly altered by condition (P=0.001). Mediolateral sway was significantly less in the eyes open, eyes closed, and eyes open surround referenced conditions than in the three latter conditions in which the surface was referenced to the anteroposterior sway, and condition 4 (eyes open, surface referenced) was different from all other conditions (Figure 1). No significant group x condition interaction was noted in mediolateral sway (P=0.564).

Table 2. Mediolateral sway and anteroposterior sway in NCAA gymnasts, non-gymnast NCAA athletes, and non-athlete controls during static postural stability testing are shown below. Results of statistical comparisons are provided. Significant results are highlighted in bold **blue** font.

	Mediolateral sway (mm)	Anteroposterior sway (mm)
Gymnasts	7.39±4.64	41.67±32.97
Non-gymnast athletes	8.05±5.91	38.06±31.26
Non-athlete controls	8.59±6.39	39.55±32.36
Group P-value	**0.049 (Gym > Con)**	0.204
Condition P-value	**0.001**	**0.001**
Group x Condition P-value	0.564	0.727

Table 3. Center of pressure (COP) displacement and average velocity in NCAA gymnasts, non-gymnast NCAA athletes, and non-athlete controls during static postural stability testing are shown below. Results of statistical comparisons are provided. Significant results are highlighted in bold **blue** font.

	COP displacement (mm)	Average COP velocity (mm/s)
Gymnasts	367.25±229.75	18.36±11.49
Non-gymnast athletes	383.94±267.81	19.20±13.39
Non-athlete controls	336.15±211.44	16.81±10.57
Group P-value	**0.005 (Con < Non-gym athlete)**	**0.0010 (Con < Non-gym athlete)**
Condition P-value	**0.001**	**0.001**
Group x Condition P-value	**0.039**	**0.001**

Table 4. Standard deviation of the vertical force (Fz) in NCAA gymnasts, non-gymnast NCAA athletes, and non-athlete controls during static postural stability testing is shown below. Results of statistical comparisons are provided. Significant results (P<0.05) are highlighted in bold **blue** font.

	Standard Deviation of Fz (N)
Gymnasts	0.47±0.67
Non-gymnast athletes	0.37±0.27
Non-athlete controls	0.47±0.60
Group P-value	0.072
Condition P-value	**0.001**
Group x Condition P-value	0.204

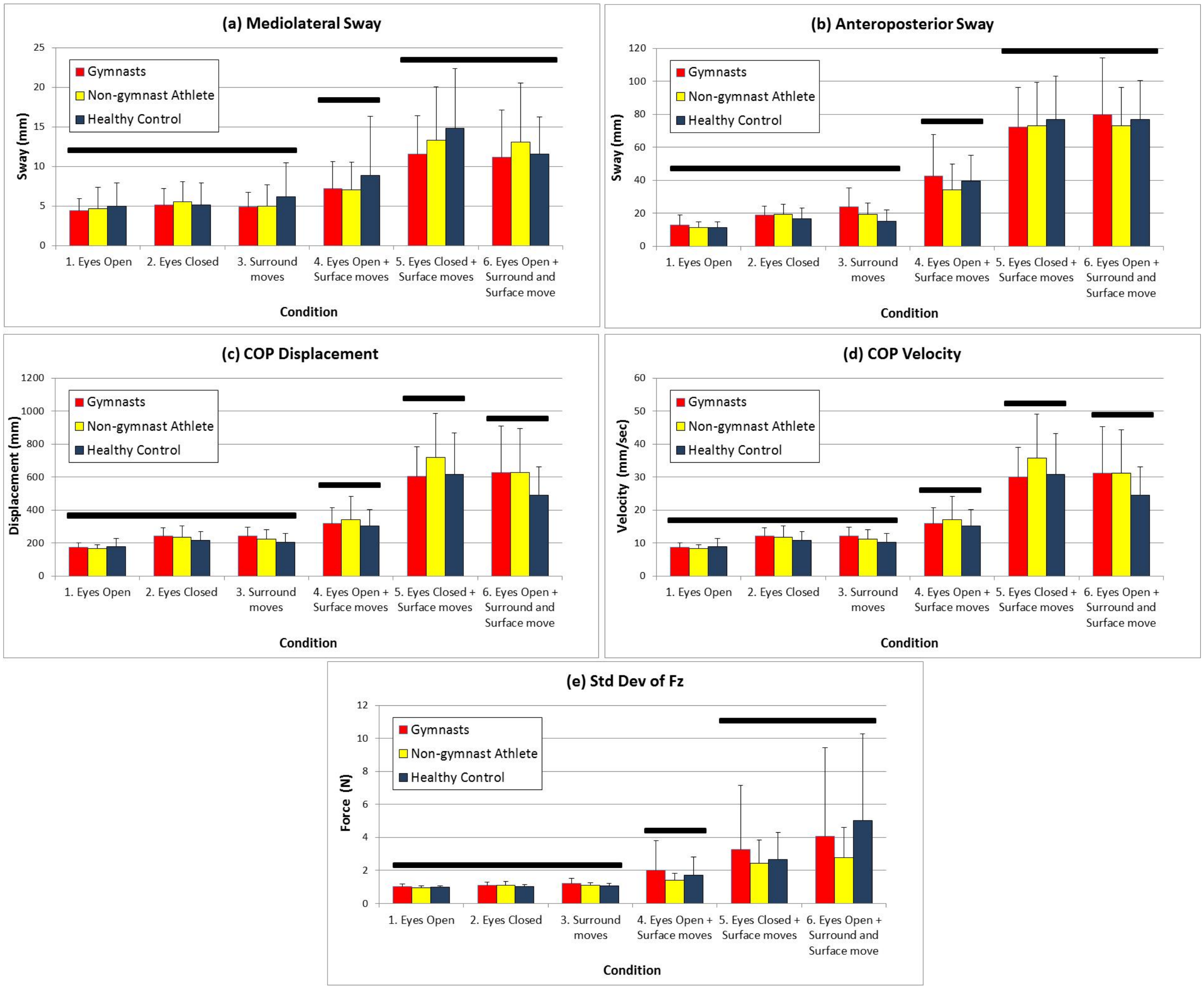

Figure 1. Static postural stability variables for the gymnasts, non-gymnast athletes, and healthy controls for each of the six Sensory Organization Test (SOT) conditions. Error bars indicate within group standard deviation for each measure. Differences between SOT conditions as determined by the Tukey post-hoc tests (p<0.05) are indicated by the horizontal black lines above the bar graphs. Conditions under the same horizontal line are not significantly different from each other, but conditions under a different black line are statistically different. Variables are shown in the following order: (a) mediolateral COP sway, (b) anteroposterior COP sway, (c) total COP displacement, (d) average COP velocity and (e) standard deviation of the vertical force.

Anteroposterior sway was not significantly different between subject groups (P=0.204), although it was significantly different between conditions (P=0.001; Figure 1). Anteroposterior sway in the eyes open, eyes closed, and eyes open surround referenced conditions was less than in conditions the three latter conditions in which the surface referenced to anteroposterior sway, and the eyes open surface referenced condition was different from all other conditions. The group x condition interaction was not significant (P=0.727).

Overall COP displacement, or length of the path of the COP, was greater in non-gymnast athletes compared to non-athlete controls (P=0.005), while the COP displacement of the gymnasts did not different from the other two groups. COP displacement was less in conditions the eyes open, eyes closed, and surround referenced conditions compared to the eyes open surface referenced, eyes closed surface referenced, and eyes open surface and surround referenced to anteroposterior sway conditions, which were in turn all different from one another (P<0.05). The group x condition interaction was also significant (P=0.039) such that the non-gymnast athletes had a very large COP displacement in condition eyes closed surface referenced condition.

Average COP velocity was significantly different between groups (P=0.010) and conditions (P=0.005). Specifically, COP velocity was greater in non-gymnast athletes compared to the non-athlete controls. The eyes open, eyes closed, and surround referenced conditions were not different but latter three conditions with the support referenced to anteroposterior sway were all significantly different than all other conditions (P<0.05). The group x condition interaction was also significant (P=0.001) in that the non-gymnast athletes displayed a very large COP velocity in response to condition eyes closed surface referenced condition.

Standard deviation of vertical force was not significantly different between groups (P=0.072). However, it was significantly different between conditions (P=0.001; Figure 1). The standard deviation of vertical force was less in the first three conditions, and greater in latter two conditions in relation to the other four conditions. The group x condition interaction was not significant (P=0.204).

Table 5. Initial sway and total sway following toes up/down perturbations in NCAA gymnasts, non-gymnast NCAA athletes, and non-athlete controls during dynamic postural stability testing are shown below. Results of statistical comparisons are provided. Significant results (P<0.05) are highlighted in bold **blue** font.

	Initial sway (mm)	Total sway (mm)
Gymnasts	14.42±8.95	66.81±21.12
Non-gymnast athletes	15.71±7.59	68.36±20.43
Non-athlete controls	16.48±10.26	72.47±21.76
Group P-value	0.093	**0.036 (Gym < Con)**
Condition P-value	**0.001**	**0.001**
Group x Condition P-value	**0.022**	0.556

Dynamic assessment: In the dynamic postural stability assessment, the total COP sway was significantly less in the gymnasts compared to the healthy controls, while the COP sway of the non-gymnast athletes did not differ from the other two groups (P=0.036; Table 5).

Additionally, the sway velocity of the gymnasts was less compared to the non-gymnast athletes, while the sway velocity of the healthy controls did not differ between the other two groups (P=0.016; Table 6). The initial COP sway was not significantly different between groups (P=0.093). All three dependent variables were different between the perturbation directions (all P-values=0.001), with the "toes up" perturbation resulting in a larger displacement or velocity than the "toes down" perturbation (Figure 2).

Table 6. Sway velocity following toes up/down perturbations in NCAA gymnasts, non-gymnast NCAA athletes, and non-athlete controls during dynamic postural stability testing are shown below. Results of statistical comparisons are provided. Significant results (P<0.05) are highlighted in bold **blue** font.

	Sway velocity (mm/s)
Gymnasts	77.71±41.14
Non-gymnast athletes	90.90±38.74
Non-athlete controls	86.69±39.84
Group P-value	**0.016 (Gym < Non-gym athlete)**
Condition P-value	**0.001**
Group x Condition P-value	0.250

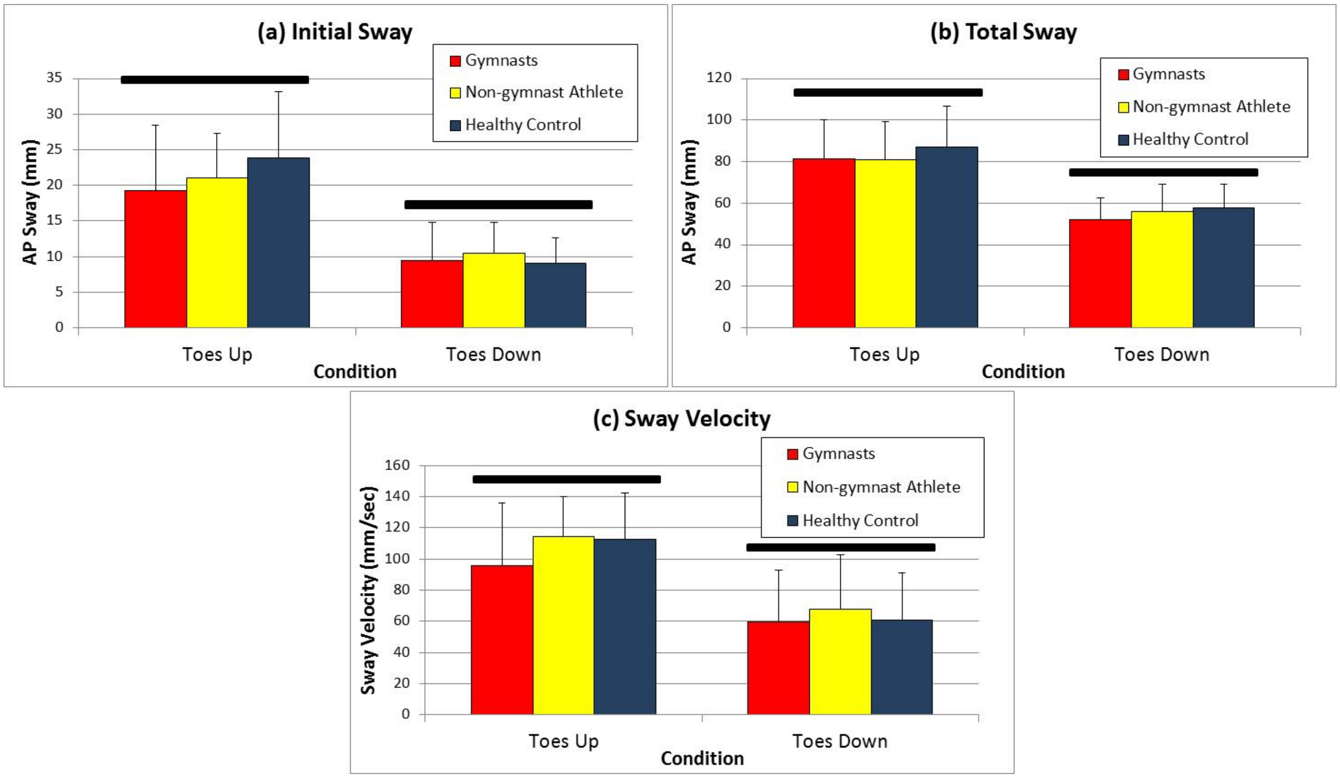

Figure 2. Dynamic postural stability variables for the gymnasts, non-gymnast athletes, and healthy controls for the toes up and toes down perturbation. The error bars representing the within group standard deviation for each variable are provided. The horizontal black bars above each set of bar graphs indicate significant differences (P<0.05) between "toes up" and "toes down" conditions. Variables are shown in the following order: (a) initial sway, (b) total sway, and (c) sway velocity.

DISCUSSION

The purpose of this study was to compare static and dynamic postural stability, assessed via center of pressure (COP) analysis, in collegiate gymnasts, collegiate athletes in other sports, and healthy controls. Based on previous studies, we hypothesized that gymnasts would demonstrate greater postural stability during the static trials but not in the dynamic perturbation trials. Our results partially confirm these hypotheses in that the gymnasts displayed less mediolateral sway than controls during the static tasks; however, other variables did not reveal better static postural stability in gymnasts. Additionally, following dynamic perturbations, gymnasts had less total COP sway than non-athlete controls, as well as less sway velocity of the COP than the accomplished athletes in other sports.

Given that a standard competition balance beam is 10 cm wide (24), it is not surprising that the collegiate gymnasts in this study, who have trained for many hours on the apparatus (20), display significantly less mediolateral COP movement during static balance testing. Further support of this finding comes from Lamoth et al. (17), who reported better mediolateral control of the trunk in the gymnasts compared to physical education students as well as students in other majors. Bressel and colleagues (3) reported better postural stability in gymnasts and soccer players compared to basketball players when static balance was challenged via alterations to vision and stance. Asseman (1) reported that gymnasts displayed less area encompassing the path of the COP during unipedal stance when compared to other sportsmen. However, velocity of the COP was not different between groups (1).

Interestingly, in this study the healthy controls displayed smaller COP displacement and velocity compared to the non-gymnast athletes, and the group x condition interaction was significant for each of these variables. Non-gymnast athletes demonstrated significantly greater response to condition 5, in which the subjects were asked to stand as still as possible with eyes closed while the support surface was unlocked so that it was free to move in a plantar/dorsiflexion direction, similar to a balance board. It may be that non-gymnast athletes are very reliant on visual input and its removal is related to poorer postural control. Further research is necessary to explain this result.

Challenging balance by disrupting different systems can give clues as to how gymnasts achieve improved balance. Vuillerme and colleagues have conducted a series of studies demonstrating that gymnasts are less affected in balance measures by disrupted vision, suggesting that gymnasts are less reliant on eyesight for balance than others (9, 25-27). However, our results do not support this as we did not find differences between groups in response to the eyes-closed balance tasks. This could be because our tasks were not challenging enough. Similar to our results, Gautier et al. reported that no differences were noted between gymnasts and other expert athletes when optic flow was altered using a virtual reality system (9).

In the dynamic perturbation testing, gymnasts displayed less total sway than controls and less sway velocity than the other non-gymnast athletes. Bressel and colleagues (3) reported no differences between gymnasts and other athletes following the dynamic Star Excursion Balance test, a clinical test of balance that does not include COP movement analysis. Debu and Woollacott (6) reported that stance condition (bipedal vs unipedal), but not vision, affected the muscle latency responses of gymnasts to fore-aft perturbations to stance, while untrained controls were affected by both stance and vision. This supports the assertion of Vuillerme (25, 27) that gymnasts are less reliant on vision in maintaining postural stability.

Few researchers have reported COP movement data during dynamic perturbation trials for gymnasts compared to other populations. Gautier et al. (8) perturbed stance in gymnasts and other athletes by attaching a weight equal to 7% body weight to the back of each participant, and then suddenly detaching the weight, causing a perturbation in the anterior direction. The magnitude of COP movement was not different between gymnasts and other athletes, however the time to restabilization was shorter in the gymnast (8). These results support the findings of Vuillerme and coworkers who also reported faster recovery time in gymnasts following disruption to proprioception during static tasks (27).

Our statistical analyses included two independent variables: participant group and testing condition. The static test, the Sensory Organization Test, included six conditions in which the challenge to static postural control was increasingly difficult (21). The dynamic perturbation test, the Adaptation Test, involved two conditions in which stance was perturbed in either a toes up or toes down direction (13). In this study, our primary focus is a comparison between participant groups. However, the statistical analysis of every dependent variable revealed significant differences between conditions. Our results for the various conditions concur with numerous other studies in the literature (2, 4, 5, 12, 13, 21, 22). This indicates that our gymnasts, other expert athletes, and healthy controls all responded to challenges to static and dynamic balance in the expected manner.

Because this study was not a training intervention, we cannot report if the gymnasts in this study came to be such accomplished gymnasts because they inherently possessed greater mediolateral stability during static stance and less total sway and sway velocity following dynamic perturbations, or if they developed these attributes during the course of their training since childhood. Research on other populations has revealed that postural stability can indeed be improved following exercise training or Tai Chi interventions (15, 16, 23, 28) and although most of the studies were performed on older adults, studies on children and young adults also report improved postural stability following the interventions (5, 19).

This study has several limitations. We could only test female gymnasts because the university only has a female gymnastics program. Additionally, when these athletes were being tested, they were inside a lab and not in the athlete's normal environment.

In the future, we hope to perform this same study on male participants to see if male gymnasts, non-gymnast athletes, and non-athlete controls share similar static and dynamic stability as the females in this study. Several other studies have only included male participants (1, 7, 8, 25-27), but they did not examine the same variables as the current research. We would also like to compare gymnasts' static and dynamic stability with other balance athletes such as divers and/or dancers. Others have examined postural control in dancers (10, 18), but have not examined stability between dancers and athletes whose sports require a strong balance component. Additionally, it would be interesting to investigate whether or not the improved dynamic stability found in gymnasts and non-gymnast athletes would have long-term effects, such as reducing fall risk in later life.

Gymnasts demonstrated greater mediolateral stability during static testing as well as less total sway and sway velocity following dynamic perturbations to stance. These results support previous studies in the literature that suggest that gymnasts have adapted sensory integration systems that allow them to display improved postural control compared to other age-matched populations.

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