P-ISSN: 2394-1685
E-ISSN: 2394-1693
IJPESH 2014; 1(1): 53-58

www.kheljournal.com
Received: 15-07-2014
Accepted: 23-08-2014

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Comparison of postural stability in different stances among gymnasts

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Abstract
For a long time, static postural stability has been studied bipedally and unipedally in gymnasts. Studies have been conducted by altering vision or involving tied weights, which directly increased the difficulty of controlling posture. However, there are postural stances other than the conservative bipedal and unipedal, where the study is required. This study was performed to fill this important knowledge gap. In this study, the authors investigated gymnast's postural stability in four stances, i.e., Bipedal, unipedal, semi-tandem, and tandem. Forty-nine subjects were recruited for the study, including gymnasts (n=20), non-gymnasts (n=19) and non-athletes (n=10). In the unipedal and semi-tandem stance, gymnasts showed a significant difference in postural control than non-gymnast athletes and non-athletes. Also, postural control was found significantly lower in a semi-tandem stance than in an unipedal stance. While males displayed a significant difference in postural control in unipedal stance than females and female gymnasts displayed significant differences in postural control in tandem stance than males. This results made us conclude that gymnast shows better postural control in semi-tandem stance than other groups, males are better in postural control during single-leg stance, and female gymnast are in better postural control during tandem stance.

Keywords: Bipedal, unipedal, tandem, semi-tandem, gymnasts, postural stability

Introduction

Posture can be described as the body segment's spatial organization (Winter, 1995; Isableu, Hlavackova, Diot, & Vuillerme, 2017) [22, 9]. In day to day life, erect posture plays an important role and is a fundamental basis for the organization of the relationship between human and environment (Duarte & Zatsiorsky, 2000; Sarre, 2000; Kluzik, Horak, & Peterka, 2005; Gautier, Thouvarecq, & Larue, 2008) [3, 17, 10, 6]. The human nervous system involves postural control as an active process in order to maintain an upright balance (Gautier, Thouvarecq, & Larue, 2008) [6]. It is a complex skill that requires hundreds of joints to organize and regulate subtle rotational motions through several hundred muscles to ensure the centre of pressure remains inside the base of support (Isableu, Hlavackova, Diot, & Vuillerme, 2017) [9]. Postural control is influenced by pathologies disturbing spatial orientation, sensory output, and force or movement control (Massion, 1994; Paillard & Noe, 2015) [11, 15].

An expert athlete in a specific sport can be described as a specialist who can achieve a high level of sport-related motor skills (Paillard, 2019) [14]. Moreover, the ability to achieve body balance is frequently mentioned and evaluated among various components that affect the level of performance of gymnastic athletes (Omorczyk, Bujas, Puszczalowska-Lizis, & Biskup, 2018) [13]. The ability to uphold body balance not only affects the gymnast's overall performance but is also a vital aspect in enhancing the athlete's safety during the movement. Consistent exposure to stationary balance in demanding postures in addition to dynamic movements in gymnastic skills reinforces their musculoskeletal and sensory systems to attain more excellent balance compared to competitors in other sports as well as non-athletes (Hrysomallis, 2011; Sloanhoffer, Harrison, & McCrory, 2018) [8, 18].

Postural control performance is frequently described by range of centre of pressure (CoP) displacement, CoP displacement speed, and sway area of CoP and used in numerous research studies to understand the underlying mechanism of motor control under difficult experimental conditions (Paillard & Noe, 2015) [15]. Lower values of CoP displacement range, speed of CoP, and sway area are indicative of better postural control during the execution of a given balance posture (Paillard & Noe, 2015; Sobera & Rutkowska-Kucharska, 2019) [15, 19].

Previous studies that included examination of postural regulation in gymnasts or athletes were performed in bipedal or unipedal stance only (Vuillerme, *et al*., 2001; Gautier, Thouvarecq, & Larue, 2008; Edis, Vural, & Vurgun, 2016; Isableu, Hlavackova, Diot, & Vuillerme, 2017; Omorczyk, Bujas, Puszczalowska-Lizis, & Biskup, 2018; Sloanhoffer, Harrison, & McCrory, 2018; Pau, *et al*., 2019; Sobera & Rutkowska-Kucharska, 2019; Thapa, Kumar, Sharma, Rawat, & Narvariya, 2019) [21, 6, 4, 9, 13, 18, 16, 19, 20]. Even though the feet can be aligned to various possible conditions in bipedal stance, such as feet apart, feet together, semi-tandem and full tandem (Paillard & Noe, 2015) [15], there are no studies that considered testing gymnasts or athletes for postural control in stances rather than bipedal or unipedal stance. This research was aimed at testing in different postural stances (bipedal, unipedal, semi-tandem, and tandem stance), the postural regulation of gymnasts, and non-gymnast athletes.

Materials and Method
Subjects
A total of forty-nine subjects were involved in this study, which included twenty athletes who practice gymnastics (10 male and 10 female), nineteen athletes who practiced outdoor sports (11 female and 8 male), and ten non-athlete individuals (9 male and 1 female). The subjects belonged to age 21 ± 4 years (mean ± sd), height 165.96 ± 9.21 cm (mean ± sd), and weight 59.76 ± 9.33 kg (mean ± sd). The non-gymnast athlete included soccer players (n=10; 5 males, 5 females) and volleyball players (n=9; 5 males, 4 females). Non-athlete individuals were selected from the university who served at the administrative office, and the level of activity varied from no participation in exercises to participation in exercises for four to five hours a week (e.g., brisk walking, running, or yoga classes). This exercise duration was not less than 14 hours to 16 hours a week reported by the university athletes.

The participants were physically active and training for inter-university competition when the data were recorded. The inclusion criteria of subjects for the study was the absence of recent lower limb injury, neurological or spinal injury, and musculoskeletal dysfunction. The research was conducted in compliance with the ethical principles for research on the human subject, as specified in the Declaration of Helsinki. Subjects signed written consent forms, and the institution's Sports Biomechanics Departmental committee approved the conduct of the study.

Procedure
Subjects reported for testing and recording of data to LNIPE's Sports Biomechanics Laboratory. Before data recording, the experimental procedure was explained to the subjects. A questionnaire was completed by each subject, providing information about the physical activity of subjects over the past year, and this questionnaire was used to classify the subjects as gymnast, non-gymnast athlete or non-athlete healthy individuals.

The static balance of the subjects was measured using BTS P-Walk (pressure platform with acquisition frequency up to 100Hz, pressure range 30-400 Kpa, 2304 resistive sensors), which measures the foot plantar pressure in static and dynamic stages. The pressure platform was firmly placed on the ground. Before the recording of data, a demonstration of all the four different stances was given *viz*. bipedal, unipedal, semi-tandem, and full tandem stance (figure 1). In a bipedal stance, the legs were kept straight, and the feet formed an angle of 30˚. The intermalleolar distance was 5 cm (Vuillerme, *et al*., 2001; Paillard & Noe, 2015) [21, 15]. In the unipedal stance test, the dominant leg was chosen as the supporting leg. To select the superior leg researcher asked as to which leg the subject would prefer to kick a football. The non-supporting leg was lifted and bent 90˚ at the knee level (Paillard & Noe, 2015) [15]. In a semi-tandem stance, the feet were positioned close together, and the toe of the dominant foot was positioned in line with the heel of the opposite foot (Doheny, *et al*., 2012). In full tandem stance, the dominant foot was placed behind in line with the non-dominant foot.

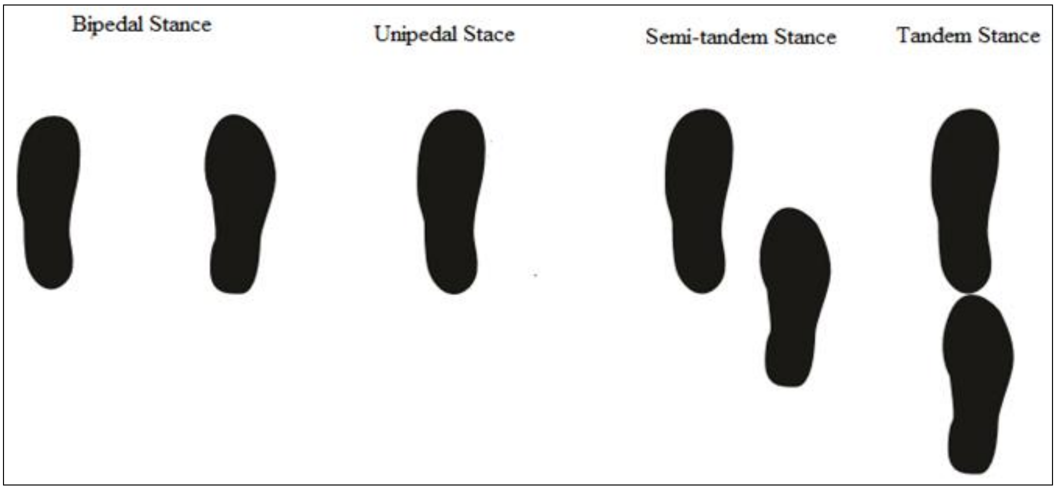

Fig 1: Illustration of different foot positions (stances)

In all the different postural stances mentioned above, the subjects were told to stand barefooted in a comfortable manner and arms kept by the side of the body, and their eyes fixated on a red mark fixed on the wall 1.50 m away from the subjects (Vuillerme, *et al*., 2001) [21]. Subjects were instructed to remain as still as possible during the trials and to avoid any voluntary movements (Vuillerme, *et al*., 2001; Muehlbauer, Besemer, Wehrle, Gollhofer, & Granacher, 2012; Thapa, Kumar, Sharma, Rawat, & Narvariya, 2019) [21, 12, 20]. Before the final recording of data, subjects performed two preparation trials of each postural stance on the pressure platform (Muehlbauer, Besemer, Wehrle, Gollhofer, & Granacher, 2012; Thapa, Kumar, Sharma, Rawat, & Narvariya, 2019) [12, 20].

Three 20 seconds trails were performed for each postural stance and recorded, and a rest period of 1 minute was provided between consecutive trials. A chair was provided to sit during the rest period (Isableu, Hlavackova, Diot, & Vuillerme, 2017) [9]. A total of 12 trials were conducted per subject. The best trial in each postural stance was selected based on the least CoP displacements and was used for further analysis (Muehlbauer, Besemer, Wehrle, Gollhofer, & Granacher, 2012; Thapa, Kumar, Sharma, Rawat, & Narvariya, 2019) [12, 20].

Three dependent variables were used to describe the postural behavior of the subject, range of CoP displacements (in mm), mean speed of CoP displacements (mm/sec) and surface area covered by the barycentre (mm^2). The range of CoP is the cumulative distance that the barycentre covers throughout sampling. The mean CoP displacements speed is the sum of the displacement scalers divided by the sampling duration (Vuillerme, *et al*., 2001) [21].

Data Analysis

In order to evaluate the static balance data in different postural stance, G-studio (version 3.3.22.0) software was used. Stabilometric data section in G-studio was used for evaluation of CoP displacement, the average speed of CoP, and surface area covered by barycentre.

Statistical Analysis

IBM SPSS (version 20.0.0) was used to analyze the acquired data statistically. The data were assessed for violations of assumptions of normality using the Shapiro-Wilk test. In cases where the data violated the assumptions of normality, non-parametric tests were used.

One-way ANOVA was used with gymnast, non-gymnast athlete, and non-athlete individuals as independent variables and CoP displacements, the average speed of CoP and sway area being the dependent variable. Kruskal-Wallis tests (non-parametric) were used in place of one-way ANOVA, in case of violations of the assumptions. Dunn's test with Bonferroni correction (P=0.013) was used for post-hoc analysis, where significant differences occurred.

Single-factor ANOVA with repeated measures with four levels (bipedal, unipedal, semi tandem, and tandem) was used with CoP displacements, the average speed of CoP, and sway area being the dependent variables. Mauchly's test for sphericity was used to check the violations of assumptions of sphericity and Greenhouse-Geisser corrections were used wherever violations were found in assumptions of sphericity. Post-hoc paired t-tests with a Bonferroni adjustment (P=0.013) were used in finding significant differences between levels. Friedman's tests (non-parametric) were used in place of repeated-measures ANOVA, where the data violated the assumptions. Dunn's test with Bonferroni correction (P=0.013) was used for post-hoc analysis, where significant differences occurred.

Independent t-test and Mann-Whitney U test (non-parametric) were used for comparisons between males and females as independent variables.

The effect size was calculated for every statistical test. Cohen's f and Cohen's d were calculated for One-way ANOVA and Kruskal-Wallis tests with f = 0.10 and d = 0.20 defining small effect, f = 0.25 & d = 20 a medium effect and f = 0.40 and d = 80 a large effect (Cohen, 1988). Partial η^2 were also calculated for repeated measure ANOVA with 0.01 defining small, 0.06 medium, and 0.14 large effect. While for Friedman's test, Kendall's W was calculated with 0.1 defining small, 0.3 moderate, and 0.5 large effects (Cohen, 1988). The significance level for all statistical analyses was set at P = 0.05.

Results

Postural sway parameters between gymnasts, non-gymnast athlete and non-athletes

The results revealed by gymnasts, non-gymnast athletes, and non-athletes from different static postural stances (bipedal, unipedal, semi-tandem, and full tandem) are reported in table 1.

Table 1: Postural sway parameters for gymnasts, non-gymnast athlete and non-athlete individuals

		Gymnasts (n=20) mean ± SD; median (IQR)	Non-Gymnast athletes (n=19) mean ± SD; median (IQR)	Non-athlete individuals (10) mean ± SD; median (IQR)	p-value	E.S. (Cohen's f & Cohen's d)
Bipedal Stance	Cop Displacement (mm)	317.91±83.73	333.02±64.19	301.32±70.26	0.512	0.174
	Speed of CoP (mm/s)	15.89±4.2	16.65±3.22	15.07±2.51	0.516	0.174
	Sway Area (mm^2)	37.37 (22.41-54.96)	39.93±25.38	56.99±23.75	0.129	0.046
Unipedal Stance	Cop Displacement (mm)	373.48 ± 92.2	457.1 ± 132.95	424.75 (360.03-643.8)	0.044*	0.637
	Speed of CoP (mm/s)	18.68 ± 4.6	22.86± 6.64	21.25 (17.98-32.23)	0.043*	0.642
	Sway Area (mm^2)	272.87 ± 111.61	301.52 ± 168.72	336.43 (209.07-735.70)	0.410	0.138
Semi-Tandem Stance	Cop Displacement (mm)	242.15 (225.35-272.65)	280.1±54.9	286.01±51.46	0.042*	0.647
	Speed of CoP (mm/s)	12.1 (11.25-13.6)	14.01±2.76	14.3±2.58	0.037*	0.667
	Sway Area (mm^2)	147.42±113.25	117.76±66.55	135.34 (106.63-218.12)	0.346	0.104
Full Tandem Stance	Cop Displacement (mm)	412.8±92.47	460.48±90.88	485.81±131.65	0.139	0.2741
	Speed of CoP (mm/s)	20.64±4.63	23.02±4.55	24.29±6.59	0.140	0.1989
	Sway Area (mm^2)	304.21±185.11	375.6±217.05	551.2±406.08	0.052	0.3185

*denotes significant differences at o.05 level of significance, IQR=Interquartile range, SD= standard deviation, E.S. = Effect Size

One-way ANOVA and Kruskal-Wallis (non-parametric) test detected no significant differences in postural sway parameters between gymnasts, non-gymnast athletes, and non-athlete individuals under bipedal stance and full tandem stance.

In contrast, Kruskal-Wallis test detected significant differences between groups in Cop displacement ($\chi^2(2) = 6.293$, p = 0.044, d = 0.637) and speed of CoP ($\chi^2(2) = 6.238$, p = 0.043, d = 0.642) in unipedal postural stance and Cop displacement ($\chi^2(2) = 6.364$, p = 0.042, d = 0.647) and speed of CoP ($\chi^2(2)$ = 6.6, p = 0.037, d = 0.667) in semi-tandem stance. In addition, post-hoc testing using Dunn-Bonferroni test did not reveal any specific pair being significantly different in both unipedal and semi-tandem stance in CoP displacement and CoP speed.

3.2 Bipedal, unipedal, semi-tandem and full tandem postural sway parameters

The results of different postural parameters shown by gymnasts and non-gymnast athlete in different postural stance (bipedal, unipedal, semi-tandem and full tandem) are reported in table 2.

Friedman test (non-parametric) with four levels (bipedal, unipedal, semi-tandem and full tandem) detected significant differences between postural stances (CoP displacement, $\chi^2(3) = 32.94$, $p< 0.000$, $W = 0.549$, speed of Cop, $\chi^2(3) = 32.94$, $p< 0.000$, $W = 0.549$ and sway area, $\chi^2(3) = 37.98$, $p< 0.000$, $W = 0.633$) in Gymnast. Further, Dunn-Bonferroni post-hoc tests revealed similar significant differences in CoP displacement and CoP speed among bipedal stance and semi-tandem (D, p = 0.007; S, p = 0.007), unipedal stance and semi-tandem (D, $p< 0.000$; S, $p< 0.000$), bipedal and tandem stance (D, p = 0.005; S, p = 0.005) and semi-tandem and tandem stance (D, $p< 0.000$; S, $p< 0.000$). In sway area, post-hoc Dunn-Bonferroni test revealed significant difference between bipedal and unipedal stance ($p< 0.000$), bipedal and semi-tandem stance (p = 0.007) and bipedal and tandem stance ($p< 0.000$).

Further analysis using Friedman test and ANOVA with repeated measures also revealed significant differences between postural stances in male gymnasts (CoP displacement, $\chi^2(3) = 18$, $p< 0.000$, $W = 0.600$, speed of Cop, $\chi^2(3) = 18$, $p< 0.000$, $W = 0.6$ and sway area, $\chi^2(3) = 17.88$, $p< 0.000$, $W = 0.596$), as well as female gymnasts (CoP displacement, $F_{(3,27)} = 8.57$, $p< 0.000$, partial $\eta^2 = 0.488$, speed of Cop, $F_{(3,27)} = 8.548$, $p< 0.000$, partial $\eta^2 = 0.487$ and sway area, $\chi^2(3) = 21.72$, $p< 0.000$, $W = 0.724$).

Table 2: Different postural sway parameters in bipedal, unipedal, semi-tandem and full tandem stance

		Bipedal mean ± SD; median (IQR)	Unipedal mean ± SD; median (IQR)	Semi-tandem mean ± SD; median (IQR)	Full Tandem mean ± SD; median (IQR)	p-value	Effect size (partial η^2 or Kendall's W)
Gymnast (n= 20)	Cop Displacements (mm)	317.91±83.73	373.48±92.2	242.15 (225.15-272.65)	412.79±92.47	0.000*	0.549
	Speed of CoP (mm/s)	15.89±4.2	18.68±4.6	12.1 (11.25-13.6)	20.64±4.63	0.000*	0.549
	Sway Area (mm^2)	37.37 (22.41-54.96)	272.87±111.61	110.71 (67.97-193.06)	239.66 (189.92-455.9)	0.000*	0.633
Gymnast (Male) (n=10)	Cop Displacements (mm)	301.66±82.4	392.12±113.87	235.55 (227.05-286.55)	453.36± 91.7	0.000*	0.600
	Speed of CoP (mm/s)	15.07±4.12	19.61±5.68	11.8 (11.35-14.3)	22.68±4.57	0.000*	0.600
	Sway Area (mm^2)	36.85 (22.9-65.85)	312.22±133.49	172±111.84	393.62±191.2	0.000*	0.596
Gymnast (Female) (n=10)	Cop Displacements (mm)	334.16±86.16	354.83±64.87	243.43±28.87	372.22±77.35	0.000*	0.488
	Speed of CoP (mm/s)	16.7±4.33	17.74±3.24	12.16±1.44	18.6±3.88	0.000*	0.487
	Sway Area (mm^2)	40.48 (13.59-41.56)	233.53±70.97	77.2 (47.98-158.1)	190.58 (105.8-249.26)	0.000*	0.724
Non-Gymnast athlete (n=19)	Cop Displacements (mm)	303.8 (286-303.8)	457.1±132.95	280.1±54.90	460.48±90.88	0.000*	0.617
	Speed of CoP (mm/s)	15.2 (14.3-20.8)	22.86±6.64	14.01±2.76	23.02±4.55	0.000*	0.617
	Sway Area (mm^2)	39.93±25.38	274.83 (199.1-349.55)	117.76±66.55	375.6±217.05	0.000*	0.820
Non-Gymnast athlete (male) (n=8)	Cop Displacements (mm)	311.38±50.69	461.6 (410.63-505.05)	276.05±53.1	447.7±89.54	0.000*	0.813
	Speed of CoP (mm/s)	15.55±2.53	23.05 (20.55-25.28)	13.81±2.7	22.38±4.47	0.000*	0.813
	Sway Area (mm^2)	30.28±17.21	372.34±202.4	137.29±69.79	280.12±117.42	0.000*	0.701
Non-Gymnast athlete (Female) (n=11)	Cop Displacements (mm)	348.75±70.5	434.77±144.1	283.05±58.56	469.77±95.02	0.001*	0.521
	Speed of CoP (mm/s)	17.46±3.53	21.74±7.19	14.16±2.92	23.48±4.76	0.001*	0.521
	Sway Area (mm^2)	46.95±28.69	250.01±125.02	103.55±63.52	445.05±250.09	0.001*	0.611

*denotes significant differences at o.05 level of significance, IQR=Interquartile range, SD= standard deviation

Post-hoc comparisons using Dunn-Bonferroni tests in male gymnasts revealed significant differences in CoP displacement and speed of CoP in semi-tandem and tandem stance (displacement, $p< 0.000$; speed, $p< 0.000$) and bipedal and tandem stance (displacement, p = 0.006; speed, p = 0.006). While significant differences between bipedal and unipedal stance (p = 0.002) and bipedal and tandem stance ($p< 0.000$) were found in the sway area. Similar significant differences were found in female gymnasts in CoP displacement and speed of CoP between bipedal and semi-tandem stance (displacement, p = 0.008; speed, p = 0.008), unipedal and semi-tandem stance (D, $p< 0.000$; S, $p< 0.000$) and semi-tandem and tandem stance (displacement, p = 0.001; speed, p = 0.001). In the sway area of the female gymnast, significant differences were found between bipedal and unipedal stance ($p< 0.000$) and bipedal and tandem stance (p = 0.001).

In non-gymnast athlete Friedman test showed significant difference between postural stance (CoP displacement, $\chi^2(3) = 35.147$, $p< 0.000$, $W = 0.0.617$, speed of Cop, $\chi^2(3) = 35.147$, $p< 0.000$, $W = 0.617$ and sway area, $\chi^2(3) = 46.768$, $p< 0.000$, $W = 0.820$). Post-hoc test revealed significant difference in CoP displacement, speed of CoP and sway area between bipedal and unipedal stance (displacement, p = 0.003; speed, p = 0.003; sway, $p< 0.000$), bipedal and tandem stance (displacement, p = 0.001; speed, p = 0.001; sway, $p< 0.000$), unipedal and semi-tandem stance (displacement, $p< 0.000$; speed, $p< 0.000$; sway, p = 0.002) and semi-tandem and tandem stance (displacement, $p< 0.000$; speed, $p< 0.000$; sway, $p< 0.000$).

Further analysis of non-gymnast male and female athletes also showed significant differences between postural stances (male: CoP displacement, $\chi^2(3) = 19.5$, $p< 0.000$, $W = 0.813$, speed of Cop, $\chi^2(3) = 19.5$, $p< 0.000$, $W = 0.813$ and sway area, $F_{(3,21)} = 16.416$, $p< 0.000$, partial $\eta^2 = 0.701$; female: CoP displacement, , $F_{(1.92,19.18)} = 10.881$, p = 0.001, partial $\eta^2 = 0.521$, speed of Cop, $F_{(1.92,19.23)} = 10.886$, p = 0.001, partial $\eta^2 = 0.521$ and sway area, $F_{(1.37,13.73)} = 15.689$, p = 0.001, partial η^2 = 0.611). Post-hoc comparison of non-gymnast male showed significant differences in CoP displacement and speed of CoP between bipedal and unipedal stance (displacement, p = 0.002; speed, p = 0.002; sway, p = 0.002), bipedal and tandem stance (displacement, p = 0.007; speed, p = 0.007; sway, *p*< 0.000), unipedal and semi-tandem stance (displacement, *p*< 0.000; speed, *p*< 0.000) and semi-tandem and tandem stance (displacement, p = 0.002; speed, p = 0.002). Post-hoc test for sway area showed significant differences between bipedal and unipedal stance (p = 0.002), bipedal and semi-tandem stance (p = 0.003) and bipedal and tandem stance (*p*< 0.000). While, post-hoc comparisons of non-gymnast female showed significant differences in CoP displacement and speed of CoP between bipedal and semi-tandem stance (displacement, *p*< 0.000; speed, *p*< 0.000), bipedal and tandem stance (p = 0.007; speed, p = 0.007), unipedal and semi-tandem stance (displacement, p = 0.008; speed, p = 0.008) and semi-tandem and tandem stance (displacement, *p*< 0.000; speed, *p*< 0.000).

Postural sway parameters between males and females

No significant differences were detected between male and female using t-test for independent samples and Mann-Whitney U test across different postural stance (p > 0.05) other than in the CoP displacement of unipedal stance of overall subjects (U = 263.5, *p*< *0*.000, d = 1.159) and sway area in full tandem stance of gymnast (U = 17, p = 0.011, d = 1.344).

Table 3: Postural sway parameters between male gymnast, female gymnast, male non-gymnast athletes, and female non-gymnast athletes

		Male overall (n=49) mean ± SD; median (IQR)	**Female overall (n=37) mean ± SD; median (IQR)**	**Male Gymnast (n=10) mean ± SD; median (IQR)**	**Female Gymnast (n=10) mean ± SD; median (IQR)**	**Male athlete (n=8) mean ± SD; median (IQR)**	**Female Athlete (n=11) mean ± SD; median (IQR)**	**p-value overall (Cohen's d)**	**p-value Gymnast (Cohen's d)**	**p-value athlete (Cohen's d)**
Bipedal Stance	Cop Displacements (mm)	320.38±70.26	335.71±66.97	301.66±82.4	334.16±86.16	311.38±50.69	348.75±70.5	0.310 (0.223)	0.400 (0.386)	0.220 (0.592)
	Speed of CoP (mm/s)	16.01±3.52	16.78±3.36	15.07±4.12	16.7±4.33	15.55±2.53	17.45±3.53	0.307 (0.223)	0.400 (0.386)	0.214 (0.602)
	Sway Area (mm^2)	44.26 (22.53-56.9)	43.12 (22.53-56.73)	36.85 (22.9-65.54)	40.48 (13.59-51.56)	30.28±17.21	46.95±28.69	0.807 (1.159)	0.912 (0.068)	0.191 (0.677)
Unipedal Stance	Cop Displacements (mm)	53.21 (23.54-223.56)	419.49±124.73	392.12±113.87	354.83±64.87	461.6 (410.63-505.05)	434.77±144.1	0.000* (1.159)	0.380 (0.402)	0.492 (0.346)
	Speed of CoP (mm/s)	21.3±6.24	20 (16.6-23.65)	19.61±5.68	17.74±3.24	23.05 (20.55-25.28)	21.74±7,19	0.820 (0.049)	0.378 (0.404)	0.492 (0.346)
	Sway Area (mm^2)	288.5 (196.94-368.59)	288.5 (187.17-351.7)	312.22±133.49	233.53±70.97	372.34±202.41	250.01±125.02	0.760 (0.066)	0.117 (0.736)	0.121 (0.758)
Semi-Tandem Stance	Cop Displacements (mm)	258.6 (233.15-301.7)	268.58±47.86	235.55 (227.05-286.55)	243.43±28.87	276.05±53.1	283.05±58.56	0.976 (0.007)	0.739 (0.153)	0.793 (0.124)
	Speed of CoP (mm/s)	12.9 (11.65-15.1)	13.42±2.4	11.8 (11.35-14.3)	12.16±1.44	13.81±2.7	14.15±2.92	0.965 (0.009)	0.739 (0.153)	0.803 (0.12)
	Sway Area (mm^2)	113.69 (74.55-183.53)	105.16 (63.91-156.55)	172.01±111.84	77.2 (47.98-158.1)	137.29±69.79	103.55±63.52	0.257 (0.246)	0.143 (0.718)	0.288 (0.51)
Full Tandem Stance	Cop Displacements (mm)	446.18±102.98	440.25±94.17	453.36±91.7	372.22±77.35	447.7±89.54	469.77±95.02	0.784 (0.06)	0.460 (0.957)	0.615 (0.238)
	Speed of CoP (mm/s)	22.31±5.15	22.01±4.71	22.68±4.57	18.6±3.88	22.38±4.47	23.48±4.76	0.784 (0.06)	0.450 (0.962)	0.615 (0.237)
	Sway Area (mm^2)	301.47 (196.63-517.74)	251.69 (191.55-427.34)	393.62±191.2	190.58 (105.8-249.26)	280.12±117.42	445.05±250.93	0.432 (0.17)	0.011* (1.344)	0.750 (0.8)

*denotes significant differences at 0.05 level of significance, IQR=Interquartile range, SD= standard deviation

Discussion

The study's first goal was to compare postural control in different stances between gymnasts, non-gymnast athletes, and non-athletes. Results showed that gymnast in bipedal and tandem stances was not better in postural control than non-gymnast athletes and non-athletes. A study conducted by Vuillerme, *et al*. (2001) [21] supports the findings of our study, where the gymnasts were found not more stable than other sports experts in the visual condition of the experiment. The failure to transfer the effects of gymnast's balance training to less challenging balance condition may be the cause of insignificant differences in bipedal and full tandem stance (Vuillerme, *et al*., 2001; Isableu, Hlavackova, Diot, & Vuillerme, 2017) [21, 9]. While the results also showed gymnasts better in postural control than other groups in unipedal and semi-tandem stance. Unipedal and semi-tandem stance complexity than bipedal and tandem stance may be the cause of significant differences to be observed in them. A study by Vuillerme, *et al*. (2001) [21] also reported lower postural sway in gymnast than other groups when the difficulty was increased by removing vision in unipedal stance.

The second objective of this research was to compare gymnasts and non-gymnast athletes postural control in various postural stances (bipedal, unipedal, semi-tandem, and full tandem stances). The results showed significant differences in postural control between different stances in both gymnasts and non-gymnast athletes. Gymnast displayed lower CoP displacement in a semi-tandem stance, while lower sway area was observed in a bipedal stance. Further, a separate analysis of male and female gymnast revealed similar findings as above. Non-gymnast athletes also displayed lower CoP displacement in semi-tandem stance and lower sway area in bipedal stance.

Male and female comparisons were also carried out in different stances. The males displayed better postural control in an unipedal stance than females with large effect sizes. A study conducted by Graci, Dillen, & Salsich, (2012) [7] showed different movement strategies used by males and females at all levels of the kinetic chain (trunk, pelvis, hip, and knee) during a single leg squat. Females exhibited more erect posture than males during the descent phase of the single-leg squat, which demanded more involvement of quadriceps to maintain the centre of mass. Single leg squat and static unipedal stance exhibits some similarity. Both of which are difficult than its counterpart, bipedal squat, and stance. This study supports the findings of Graci Dillen, & Salsich, (2012) [7] that females are more prone to postural instability than males when a single leg is used.

Further analysis revealed female gymnasts covered significantly lower sway area than male gymnasts in full tandem stance. The large effect size between male and female gymnasts may be for a reason that female gymnasts trained regularly in a balance beam whose standard width is 10 cm (Sloanhoffer, Harrison, & McCrory, 2018) [18]. Balance beam activities repeatedly use movements similar to the tandem stance, which might have improved the female gymnasts in postural control during tandem stane.

Conclusions

The study concludes that gymnasts showed better CoP displacement and speed of CoP in unipedal and semi-tandem stance than non-gymnast athletes and non-athlete individuals. Also, CoP displacement and speed of CoP was found to be significantly lower in semi-tandem than unipedal stance, which makes us conclude further that gymnast shows better postural control in semi-tandem stance than other groups. Also, males displayed better CoP displacement than females in unipedal stance, and female gymnasts displayed lower sway area in tandem stance than males.

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