Introduction

Some sportspersons, such as gymnasts or dancers require superior postural stability to maintain their balance on a narrow base of support (BOS), such as a balance beam or on their tiptoes [1,2]. However, Schmit et al. [3] indicated that there were no differences in the path length and variability of centre of pressure (COP) sway between ballet dancers and non-dancers during static standing. Moreover, Tanabe et al. [4] also reported an absence of differences in the path length and area of COP sway between ballet dancers and non-dancers when standing on tiptoes. It is still unclear how the COP and the body’s centre of mass (COM) are controlled under the challenging conditions such athletes face.

As the relationship between COP and COM, the difference between COP and COM positions (COP-COM distance) has been investigated in terms of postural stability in static balance [5]. A longer COP-COM distance is indicative of a greater body acceleration during quiet standing [6,7]. Mani et al. [8] reported that COP-COM distances were longer and that the mean displacements of COP were located more laterally from the COM during one-legged standing in athletes with superior postural stability, which would provide a basis for feedback training using both COP and COM displacements for improving static balance.

The purpose of this study was to examine the characteristics of COP and COM fluctuations during quiet standing for possible differences between ballet dancers and non-dancers. Ballet dancers possess superior postural stability compared to non-dancing controls [2,9]. We hypothesized that: the COP fluctuates around the COM closely and evenly in ballet dancers compared to normal control, based on the previous study [8].

Material and Methods

Participants in this study comprised 10 healthy young women participating in classical ballet dance as recreational athletes (Dancer group) and 10 healthy young women who did not do ballet (Control group), all without any known neurological or motor disorders. Anthropometric data were recorded for each participant (Table 1). In the dancer group, the average years of dancing experience was 15.1 ± 4.2 years (range: 7-20 years), and the average time per week spent dancing was 7.4 ± 3.6 h. The participants were instructed to maintain three standing positions as steadily as possible (two-legged stance, one-legged stance, and tiptoe stance) with their eyes open. The COP and COM displacements, the distance between COP and COM displacements (COP-COM distance), and the 95% confidence ellipse areas of the COP and COM in the anterior-posterior and mediolateral directions were calculated to assess postural stability. The mean absolute value of the COP-COM distance and the absolute value of the mean COP-COM distance in each direction during one-legged standing in the dancer group were shorter than these values in the control group. These results suggest that the COP fluctuates more closely and evenly, in both directions, around the COM during one-legged standing in athletes with superior postural stability, which would provide a basis for feedback training using both COP and COM displacements for improving static balance.

Keywords: Centre of mass; Centre of pressure; Postural control; Static balance
Force plate signals were collected at a sampling frequency at 1000 Hz and synchronized with the motion analysis system.

**Table 1:** Anthropometric data were recorded for each participant.

|                      | Dancer (N=10) | Control (N=10) |
|----------------------|---------------|----------------|
| Age (years old)      | 23.1±1.2      | 22.6±1.3       |
| Height (cm)          | 156.7±5.1     | 157.9±5.0      |
| Body weight (kg)     | 44.5±2.2      | 53.0±3.6       |
| Dominant foot        | Right: 9      | Right: 10      |
| Foot length (cm)     | 22.8±1.1      | 23.0±1.0       |
| Foot width (cm)      | 8.8±0.7       | 9.1±0.4        |
| mean ± SD            | *: p < 0.05   |                |

Participants were instructed to stand barefoot with their hands on their hips in front of a visual target, located at eye-level height about 3 m away. The task involved maintaining a standing position as steadily as possible under three conditions (two-legged stance, one-legged stance, and tiptoe stance), with their eyes open. First, the participants were asked to stand with both feet together in each condition for 10 s. Then, the participants were required to maintain the starting posture (two-legged stance), to stand on a non-dominant foot (one-legged stance), or to stand on tiptoes (tiptoe stance), randomly, for a period of 30 s [4]. Participants were required to keep the big toe of the lifted leg (i.e., of the dominant limb), in line with the malleolus medialis of the supporting leg, and the knee cap face anteriorly in the one-legged stance. Participants repeated the task until the successful trial was performed each condition. Five minutes of rest was allowed between each condition.

All signals were processed off-line using MATLAB software (MathWorks, Natick, MA, USA). The motion analysis system data were filtered with a 20-Hz low-pass, 4th order, zero-lag Butterworth filter [11], and the force plate data were filtered with an 8-Hz low-pass, 4th order, zero-lag Butterworth filter [12]. COP and COM path lengths per second (unit length), and the 95% confidence ellipse areas of the COP and the COM were calculated to assess postural stability [13]. In addition, the mean COP-COM distance in the AP and ML directions were calculated to define the direction in the AP or ML during the COP fluctuated around the COM. Furthermore, the mean absolute value of the COP-COM distance (COP-COM<sub>mean</sub>, Equation 1) and the absolute value of sum of the COP-COM distance (COP-COM<sub>even</sub>, Equation 2) were calculated as follows:

\[
COP - COM_{mean} = \frac{\sum_{t=1}^{N} (COP - COM)}{N}
\]

\[
COP - COM_{even} = | \sum_{t=1}^{N} (COP - COM) |
\]

Where N shows the total sampling number. Thus, a shorter COP-COM<sub>mean</sub> indicates that the COP fluctuates more closely around the COM. On the other hand, a shorter COP-COM<sub>even</sub> indicates that the COP fluctuates around the COM more evenly in the AP or ML direction.

Unpaired t-tests were used to evaluate the differences between the groups. All statistical analyses were performed with SPSS 18 (SPSS, USA). Statistical significance was set at p < 0.05.

**Results**

Age, height, foot length and foot width, but not body weight, were not significantly different between the groups (Table 1). The mean body weight in the dancer group was significantly lighter than that of the control group. The mean values of COP-COM<sub>close</sub> and COP-COM<sub>even</sub> in each direction during one-legged standing in the dancer group were significantly shorter than those in the control group (p < 0.05; Figure 1). The mean values of COP and COM unit lengths, the 95% confidence ellipse area of COP and COM, and the mean values of COP-COM in the AP and ML directions in the one-legged stance were not significantly different between the groups. None of the kinetic parameters for two-legged stance or tiptoe stance differed significantly between the groups. In the kinematic aspects, the height of the calcaneus marker was significantly higher in the dancer group than in the control group during tiptoe stance (Dancer: 13.6 ± 3.2 cm, Control: 10.5 ± 2.2 cm).

The mean values of the mean absolute value of the COP-COM distance per second (COP-COM<sub>mean</sub> as well as the mean values of the absolute value of sum of the COP-COM distance (COP-COM<sub>even</sub>) in each direction, under the one-legged stance condition in the dancer group were significantly shorter than in the control group *p < 0.05.

**Discussion**

The findings of this study were that the COP-COM distance decreased and the COP fluctuated more evenly around the COM in the AP and ML directions during one-legged standing in the dancer group than in the control group. On the other hand, the differences in the COP-COM parameters between the groups were not shown while standing on tiptoes or on both legs. The posture of tiptoe-standing is similar to that of ‘relevé’, which is a common pose in classical ballet [14]. In this study, the height of the calcaneus marker was higher in the dancer group than in the control group during tiptoe stance. This might suggest that the dancer group had superior balance control, as they did not show increased sway, even though they were on average 3 cm higher off the ground, which would have induced the narrower BOS and the higher COM. No differences in COP-COM parameters were seen between the groups during two-legged stance. The long period of training would produce postural memories for a specific foot configuration [15].

In conclusion, the biomechanical characteristics of maintenance of static balance in ballet dancers are that the COP fluctuates...
closely and evenly around the COM during one-legged standing. The finding of this study could provide useful information for the feedback training using COP and COM for postural stability in the fields of sports as well as rehabilitation.

![Graph showing COP-COM close and COP-COM even in two directions under three conditions in both groups.](image)

**Figure 1:** COP-COM close and COP-COM even in two directions under three conditions in both groups

**References**

1. Vuillerme N, Danion F, Marin I, Boyadjian A, Prieur JM, et al. (2001) The effect of expertise in gymnastics on postural control. Neurosci Lett 305(2): 83-86.

2. Costa MSS, Ferreira AS, Felício LM (2013) Static and dynamic balance in ballet dancers: a literature review. Fisioterapia e Pesquisa 20(3): 299-305.

3. Schmit JM, Regis DJ, Riley MA (2005) Dynamic patterns of postural sway in ballet dancers and track athletes. Exp Brain Res 163(3): 370-378.

4. Tanabe H, Fuji E, Kouzaki M (2013) Inter- and intra-lower limb joint coordination of non-expert classical ballet dancers during tiptoe standing. Hum Mov Sci 34: 41-56.

5. Corriveau H, Hébert R, Prince F, Raîche M (2001) Postural control in the elderly: an analysis of test-retest and interrater reliability of the COP-COM variable. Arch Phys Med Rehabil 82(1): 80-85.

6. Masani K, Vette AH, Kouzaki M, Kanehisa H, Fukunaga T, et al. (2007) Larger center of pressure minus center of gravity in the elderly induces larger body acceleration during quiet standing. Neurosci Lett 422(3): 202-206.

7. Yu E, Abe M, Masani K, Kawashima N, Eto F, et al. (2008) Nakazawa K. Evaluation of postural control in quiet standing using center of mass acceleration: Comparison among the young, the elderly, and people with stroke. Arch Phys Med Rehabil 89: 1133-1139.

8. Mani H, Hsiao SF, Takeda K, Hasegawa N, Tozuka M, et al. (2015) Age-related changes in distance from center of mass to center of pressure during one-leg standing. J Mot Behav 47(4): 282-290.
9. Crotts D, Thompson B, Nahom M, Ryan S, Newton RA (1996) Balance abilities of professional dancers on select balance tests. J Orthop Sports Phys Ther 23(1): 12-17.
10. Winter DA (2009) Biomechanics and motor control of human movements, (4th eds), Hoboken, USA.
11. Corriveau H, Hébert R, Prince F, Raiche M (2000) Intrasession reliability of the “center of pressure minus center of mass” variable of postural control in the healthy elderly. Arch Phys Med Rehabil 81(1): 45-48.
12. Mancini M, Rocchi L, Horak FB, Chiari L (2008) Effects of Parkinson’s disease and levodopa on functional limits of stability. Clin Biomech (Bristol, Avon) 23(4): 450-458.
13. Prieto TE, Myklebust JB, Hoffmann RG, Lovett EG, Myklebust BM (1996) Measures of postural steadiness: Differences between healthy young and elderly adults. IEEE Trans Biomed Eng 43(9): 956-966.
14. Warren GW (1989) Classical Ballet Technique. Florida: University Press of Florida, USA.
15. Casabona A, Leonardi G, Aimola E, La Grua G, Polizzi CM, et al. (2016) Valle MS. Specificity of foot configuration during bipedal stance in ballet dancers. Gait Posture 46: 91-97.