

# Impact of professional dance training on characteristics of postural sway

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The stability of human upright posture determines the range and dynamics of movements performed. Consequently, the repertoire and quality of the movements performed by a dancer are mainly determined by the efficiency of postural control. This is of particular importance in professional dance training that should focus on shaping optimal movement-posture interaction. To get a deeper insight into this problem, the impact of the training on postural sway characteristics during quiet stance was analyzed in 16 female students in the seventh grade of a ballet school and compared with the size- and age-matched group of secondary school students. Center of pressure trajectories were recorded for 25.6 s while standing quiet with eyes open (EO) and then with eyes closed (EC). The assessment of postural control was based on novel normalized sway parameters including sway vector (SV), sway anteroposterior (AP) and mediolateral (ML) directional indices (DIAP and DIML), and sway ratios (SRAP and SRML). The results document a significant contribution of vision to postural stability control in ballet students, which seems to compensate for training-related changes in joint mobility and altered activity ranges of the legs' muscles. In the control group standing with EC, SV amplitude increased only by 18% whereas in the ballet students tested in the same conditions, the increase exceeded 72%. Under full control of standing posture (EO test), the training-related increase of leg muscle forces allows dancers to maintain balance with lesser effort as documented here by 21% reduced SRAP. Additionally, the dancers while tested with their EC exhibited a 12% increase in the anteroposterior sway with a concomitant reduction of the mediolateral sway. The resulting changes in the postural control asymmetry were documented by both DIAP/DIML and SV azimuth. In conclusion, our novel analysis of postural sway seems a useful tool in monitoring the effects of training as well as the proper course of postural control development in children and adolescents.

**Key words:** postural control, motor learning, movement-posture interaction, ballet training

## INTRODUCTION

The stability of human-specific erect posture determines the repertoire, capabilities, and characteristics of available movements. Postural-motor coordination also known as movement-posture interaction (MPI) is fundamental for human motor activity (Massion 1992; 1994; 1998). Its basis is acquired in early childhood and then shaped in life-lasting motor learning processes (Verbecque et al., 2016; Błaszczyk et al., 2020a, b; Błaszczyk & Fredyk 2021). As a result of individual motor development, adolescents acquire a level of MPI, which allows them to perform locomotory and voluntary movements with the dynamics precisely adjusted

to postural control (Błaszczyk et al., 1993a; 2020a, b; Błaszczyk & Beck, 2023). Consequently, MPI is the main determinant of the quality and dynamics of gait and voluntary movements, which to a large extent impose boundary conditions on the performed movements (Johansson & Magnusson, 1991; Błaszczyk et al., 2020a, b). The achieved level of MPI is especially important in the case of skilled dexterity movements such as acrobatics or dancing.

From a neuroscience perspective, dance is a sequence of precisely coordinated body postures and movements performed fluently at a pace and rhythm synchronized with auditory and visual stimuli. As such, the dance requires an extraordinary MPI which

is achieved in multi-year training (Bouisset & Do, 2008; Guigon, 2010; Feldman, 2016). In this interaction, postural stability is the basis on which movement is organized and executed (Bleuse et al., 2005; Aruin, 2006; Bouisset & Do, 2008). The dancing positions and movements to varying degrees perturb the stability of the erect posture and to ensure the quality of movement, the dancer must coordinate the movement control with postural stability on an ongoing basis. Particularly demanding are fast movements shifting the body's center of gravity (COG) within the base of support and stability limits (Błaszczyk et al., 1997; Bouisset & Do, 2008; Krasnow et al., 2011; Bronner 2012; Gorwa et al., 2020; Stawicki et al., 2021).

Motor training of ballet students involves many aspects of movement-posture interaction and sensory-motor integrations (Karpati et al., 2015; 2017; Feldman, 2016). The question is how and to what extent the MPI can be modified to achieve the most desired aesthetic effects. The postural control is based on three sensory inputs: vestibular, visual, and proprioceptive are integrated within the brain to control the verticality of human standing posture (Massion, 1992; Hugel et al., 1999; Golomer et al., 1999; Karpati et al., 2015; Kiefer et al., 2013; Błaszczyk 2016; 2020a). The information carried by each sensory input is weighted depending on the motor task and the most reliable sensory inputs are emphasized and the less reliable inputs are weakened (Guigon 2010; Hugel et al., 1999; Golomer et al., 1999; Henry & Baudry, 2019). It is commonly accepted that professional dancers are less dependent on vision for dynamic postural control because dance training shifts the sensorimotor dominance from vision to proprioception (Golomer et al., 1999). Other studies, however, documented that in professional ballet dancers contribution of visual input to balance control is greater. Even while standing quietly with eyes closed the professional dancers sway more compared with non-dancers (de Mello et al., 2017; Michalska et al., 2018; Fredyk et al., 2022).

In healthy young adults, muscle proprioception rather than vision is the basis of postural control (Kiefer et al., 2013; Henry & Baudry, 2019; Brughelli & Cronin, 2007; Macefield & Knellwolf, 2018; Błaszczyk et al., 2020a). In particular, the calf muscles play an important role by stabilizing the ankle joints and providing the most relevant proprioceptive inputs (Błaszczyk et al., 1994; Henry & Baudry, 2019; Macefield & Knellwolf, 2018; Honeycutt et al., 2012). In the simple model of postural stability, the control of human standing posture is functionally reduced to the control of a single inverted pendulum with the pivot at the ankle joints (Błaszczyk et al., 2020a, b). In this model, the postural balance is maintained by controlling the body's center

of gravity (COG) position within the base of support (BOS) (Błaszczyk et al., 1993; 1994; Błaszczyk, 2016). In static posturography, the COG position is approximated the center of foot pressure (COP). Despite of integration of the three sensory inputs the COG thus COP oscillates within a limited range of BOS (Błaszczyk, 2016). These random oscillations are called postural sway and their characteristics are commonly used to assess the contribution of each sensory input. In young healthy and able-bodied individuals, the characteristics of COP sway are mainly affected by individual features of each subject: their anthropometry, muscle force of ankle stabilizers in particular and neuromuscular development (Błaszczyk et al., 2020a). From this perspective, it seems rational to use static posturography to assess changes in movement-posture interaction due to motor learning. Of particular interest is an assessment of the scope, direction, and mechanisms of changes in postural control due to intensive motor training.

The present study aimed to assess changes in postural control that may impact the performance of the dance movements and movement-posture interaction in particular. Towards this aim, we compared the postural sway characteristics during quiet stance with and without visual input in a group of female ballet students with the precisely matched control group, students of a general school. The main question was to what extent the control of postural stability can be modified by intensive motor training. To answer the question we applied the postural sway analysis based upon novel, developed in our laboratory, postural sway parameters that have been proven to be more sensitive and reliable measures of stability than conventional ones (Błaszczyk, 2008; Błaszczyk et al., 2014; Błaszczyk, 2016).

## METHODS

The study protocol was approved by the Senate Ethics Committee of the Jerzy Kukuczka Academy of Physical Education (resolution number 1/2011 of October 26, 2011). The experiments were conducted under the Declaration of Helsinki and all students gave their written informed consent before participation. The experimental group consisted of 16 female students of Ludomir Różycki Ballet School in Bytom. They had completed a 7-year course of professional motor training in the amount of 792 hours yearly (24 h/week). The control group consisted of sixteen girls, students in the third grade of secondary school. The latter group attended weekly 4 hours of physical education classes and declared no participation in any additional sports activities. The characteristics of both groups are summarized in Table 1.

Table 1. Characteristics of the experimental groups.

	DANCERS	CONTROL
Number of subjects	16	16
Age [yrs]	16	16
Body mass [kg]	54.8 ± 4.8	57.0 ± 5.6
Body height [cm]	167.6 ± 6.9	167.7 ± 5.5

During the 25.6-second trial, students standing barefoot on the force plate (QFP Medicapteurs, France) with heels aligned at a reference line and arms kept comfortably at the side were asked to maintain a motionless, comfortable stance. The first trial was performed with ‘eyes open’ (EO) and the next with ‘eyes closed’ (EC). Both recorded directional (anteroposterior AP, and mediolateral ML) components of the center-of-pressure (COP) trajectories were sampled at 40 Hz and then filtered off-line with a low-pass filter at 6 Hz (Cheby 2 in Matlab, MathWorks, Inc. USA). To retrieve center-of-gravity (COG) trajectories and compute the sway ratio (SR) index, the recorded COP signals were additionally low-pass filtered at 0.4 Hz (Cheby 2 in Matlab, MathWorks, Inc. USA). The following sway parameters were computed and analyzed to assess the postural stability:

COP sway stability vector (Błaszczyk, 2016) was defined with the amplitude (SVam) equal to the mean COP velocity (VCOP). The sway vector azimuth (SVaz) was computed according to the formula:

$$SVaz = \arctan \frac{VAP}{VML} = \arctan \frac{SAP}{SML}$$

where:  $VAP=SAP/T$  and  $VML=SML/T$  are the mean COG velocities during the entire test ( $T=25.6$  s) in the anteroposterior (AP) and mediolateral (ML) planes, respectively.

The COP directional indices (DI) in the AP and ML plane (Błaszczyk et al., 2014) were computed according to the following formulas:

$$DIAP = \frac{VAPCOP}{VCOP} \quad \text{and} \quad DIML = \frac{VMLCOP}{VCOP}$$

where:  $VAPCOP$ ,  $VMLCOP$ , and  $VCOP$  are the mean COP velocities during the trial.

Sway ratio (SR) has been defined as the COP-to-COG ratio computed according to the following formula (Błaszczyk, 2008):

$$SR = \frac{VCOP}{VCOG}$$

where:  $VCOP$  and  $VCOG$  are the mean COP and COG velocities during the trial; the COG trajectories were retrieved from the COP signals by low-pass filtering at 0.4 Hz.

All statistical analyses were performed with Statistica v.6.0 (StatSoft Inc.USA). The parameters for each group were quantitatively analyzed using the arithmetic mean value and standard deviation. To verify the normal distribution of the analyzed data, the W Shapiro-Wilk test was used. Two-way repeated-measures analysis of variance (ANOVA) was used to compare variables between both groups (dancers vs. control) and both experimental conditions (EO vs. EC). The significance level was accepted at  $p \leq 0.05$ .

## RESULTS

The performed statistical analyses were aimed at verifying the claim of how and to what extent many years of intense motor training change the control of postural balance. Changes in three normalized sway parameters characterizing the most important control mechanisms were analyzed: the sway stability vector, sway directional indices, and sway ratios. The results of the statistical analysis are summarized in Table 2.

The mean sway vector amplitude was lower in the group of dancers while tested with ‘eyes open’ ( $8.0 \pm 1.75$  mm/s vs.  $9.5 \pm 1.3$  mm/s) for dancers and controls, respectively. Importantly, the amplitude increased significantly up to  $13.8 \pm 4.4$  mm/s and  $11.1 \pm 2.2$  mm/s in dancers and non-dancers, respectively. There was also significant group x vision interaction  $F_{1,31}=22.5$ ,  $p \leq 0.001$ . The results are depicted in the upper panel of Fig. 1.

Eyes closure resulted in the increase of sway vector azimuth (SVaz) in both groups. However, the magnitude of the increase was significantly different in dancers and control subjects. While standing quietly with eyes open SVaz stayed at a similar level i.e.,  $0.83 \pm 0.1$  rad and  $0.86 \pm 0.1$  rad in the dancer and control groups, respectively. The exclusion of visual input resulted in a significant increase of the sway vector azimuth to  $0.96 \pm 0.1$  rad in dancers, while in the control group; the slight increase did not reach the level of significance (Fig. 1 the lower panel).

Table 2. Mean and standard deviations of the main postural sway measures in dancers and control group including Sway Vector amplitude (SVam) and Sway Vector azimuth (SVaz); Directional Indices DIAP and DIML in anteroposterior (AP) and mediolateral (ML) plane; Sway Ratios SRAP, SRML in AP and ML planes.

	DANCERS		CONTROL	
	EO	EC	EO	EC
SVam [mm/s]***	8.0 ± 1.7	13.8 ± 4.4	9.4 ± 1.3	11.1 ± 2.2
SVaz [rad]***	0.83 ± 0.1	0.96 ± 0.1	0.86 ± 0.1	0.88 ± 0.1
DIAP***	0.66 ± 0.1	0.74 ± 0.1	0.68 ± 0.05	0.69 ± 0.05
DIML***	0.60 ± 0.1	0.51 ± 0.1	0.59 ± 0.05	0.57 ± 0.05
SRAP**	3.3 ± 1.0	3.4 ± 1.0	4.2 ± 1.0	4.1 ± 1.0
SRML	4.1 ± 2.0	4.3 ± 2.0	4.4 ± 1.0	4.2 ± 1.0

\*\*\*- significant group x vision interaction,  $p \leq 0.001$ ; \*\* - significant group effect,  $p \leq 0.02$ .

The ANOVA for the anteroposterior directional index (DIAP) confirmed a significant vision effect ( $F_{1,31}=47.5$ ;  $P \leq 0.001$ ). The interaction of both grouping factors was also significant ( $F_{1,31}=23.4$ ;  $P \leq 0.001$ ). The *post hoc* tests documented significantly higher DIAP values in the dancers' group compared with the con-

trol in EC tests. In the dancers, eye closure resulted in the increase of the mean DIAP value from  $0.66 \pm 0.1$  to  $0.74 \pm 0.1$ , while in the control group, there were no significant changes in DIAP which remained at the level of  $0.68 \pm 0.05$  and  $0.69 \pm 0.05$  while measured with EO and EC, respectively (Fig. 2).

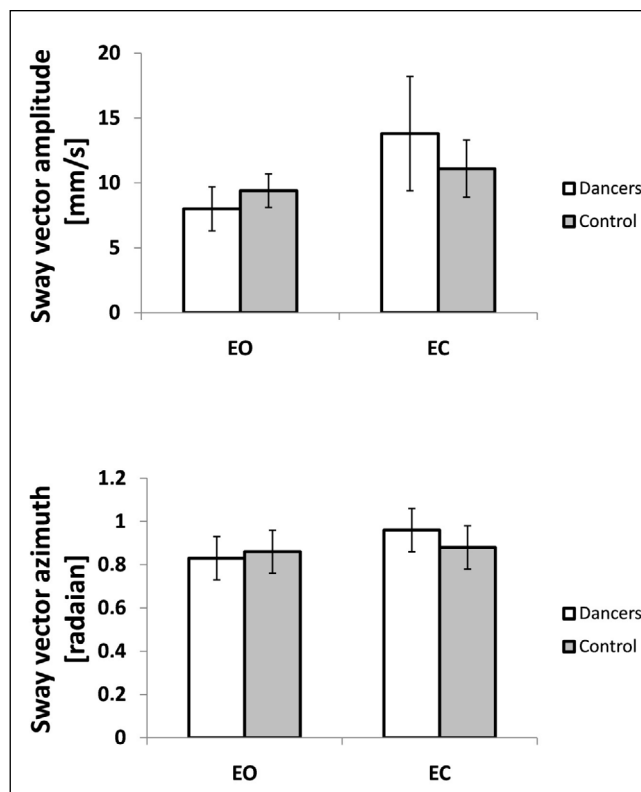


Fig. 1. Impact of the visual input on the mean ( $\pm$  s.d.) Stability Vector amplitude during quiet stance in 16 female ballet and 16 high school students. EO – eyes open, EC – eyes closed. \* –  $P \leq 0.05$ .

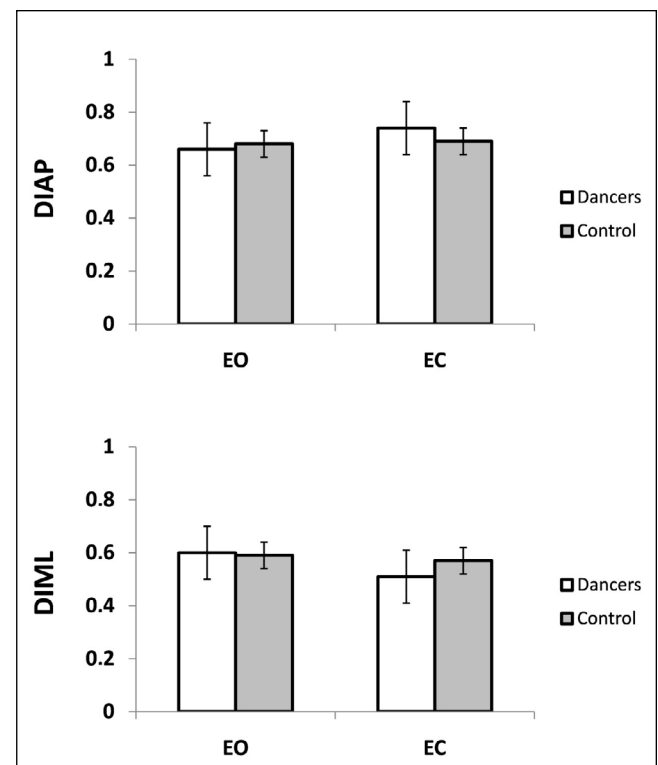


Fig. 2. The mean of Directional Sway Indices (anteroposterior AP and mediolateral ML) in dancers and non-dancers while tested with eyes open (EO) and eyes closed (EC). Error bars indicate standard deviations, \*\* –  $P \leq 0.001$ .

For the DIML, the effect of vision ( $F_{1,31}=52.8$ ;  $P\leq 0.001$ ) and group by vision interaction ( $F_{1,31}=26.7$ ;  $P\leq 0.001$ ) were documented (Table 2). Whereas in the control group, while standing with EO the DIML stayed at the level of  $0.59 \pm 0.05$  in the dancers' group ranged at  $0.60 \pm 0.09$ . The exclusion of visual feedback in EC tests resulted in a nonsignificant decline of DIML to  $0.57 \pm 0.05$  in nondancers whilst in the dancers, the drop was pronounced (mean DIML EC= $0.51 \pm 0.09$ ,  $p\leq 0.001$ ).

'Group' by 'vision' repeated measure ANOVA showed a significant group effect for SRAP only ( $F_{1,31}=6.02$ ,  $p\leq 0.02$ ), while no statistically significant differences were found in the SRML index (Fig. 3). There was no significant group effect for other analyzed factors while the highly significant effects of vision, as well as group-by-vision interaction, were documented. For details see Fig. 3.

## DISCUSSION

The primary aim of this study was to assess changes in postural sway characteristics and alterations of the postural stability control due to professional dance training. In particular, we focused on the role of visual input by comparing the standing posture control with

and without vision in two anthropometrically homogenous groups of teenagers which differed significantly with the amount of motor training. The most striking result of our analyses showed better postural stability in the dancer's group as evidenced by significantly smaller sway vector amplitude during quiet stance with open eyes. The SV amplitude and azimuth, however, were heavily dependent on visual input. Importantly in the dancers' group exclusion of visual feedback resulted in the significant reorganization of postural control characterized by an almost 73% increase in sway vector amplitude combined with a 16% increase in sway vector azimuth. The trend of the reorganization was specified by the larger contribution of postural sway in the anteroposterior plane (a 7% increase in DIAP) with a concomitant decrease of the mediolateral sway (a 10% increase in DIML).

From the perspective of motor control and neuromechanics, intensive long-lasting motor training in ballet students aims to improve all aspects of motor control including body segments' coordination, sensory-movement interactions, joint mobility, and muscular force. All of these factors diversely impact postural stability. Training-related development of joint hypermobility is required firstly for aesthetic reasons since it allows for fluent movements in a greater range. The hypermobility among professional dancers can be as high as 44% (Day et al., 2011; Skwiot et al., 2019; Rassier et al., 1999). The joint hypermobility challenges, however, the postural control and affects the movement-posture interaction. In particular, the increased range of ankle joint motion leads inevitably to a shift of length-tension characteristics in the ankle stabilizers and this can have a profound impact on both motor and postural control (Bennell et al., 1999; Brughelli & Cronin, 2007). This might be just the case in ballet students' training where the tip-toe standing position increases the ankle range of motion and all training-related alternations in postural control are fully compensated by visual feedback. There is no doubt that elite dancers perform movements more efficiently, their coordination is smooth and aesthetically pleasing, their balancing strategies are effective, and overall they have higher skill sets (Krasnow et al., 2011; Bronner, 2012). Consequently, ballet dancers would exhibit better postural balance than non-dancers since the achievement of robust postural stability is a fundamental milestone in professional dancers that determines their artistic career (Janura et al., 2019; Harmon et al., 2020; de Mello et al., 2017; Michalska et al., 2018; Fredyk et al., 2022) while simultaneously increasing the functional length of the tibialis anterior and shortening the *triceps surae* complex. The effects of these functional modifications were not, however, observed during quiet stance with eyes opened.

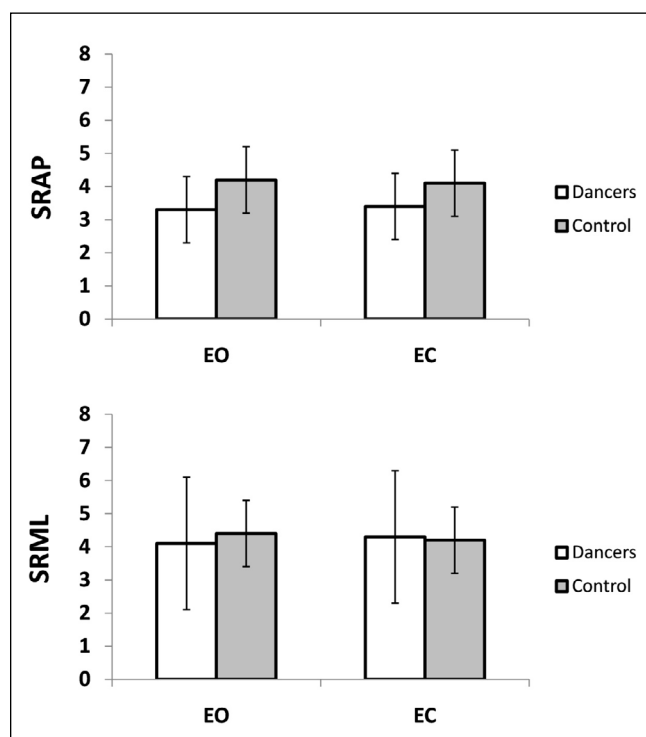


Fig. 3. Effect of visual feedback (EO vs. EC testing) on anteroposterior (AP) and mediolateral (ML) Sway Ratio in female students. Error bars represent standard deviations. \* –  $P\leq 0.05$ , \*\* –  $P\leq 0.001$ .

Classical ballet involves the performance of complex movements that require high-level motor skills and good postural control (de Mello et al., 2017). Dancing regularly for several years seems to improve both the quality of movement and postural stability (Michalska et al., 2018; Stawicki et al., 2021). The main difficulty in the control of a multijoint biomechanical system, such as the human body, is the dynamic interaction between its different segments (Bronner, 2012; Krasnow et al., 2011; Feldman, 2016). Therefore ballet training aims to remove some natural constraints making a dancer's motion optimal and omnidirectional (Aruin 2006). The effects of such dedicated training were documented here in the tests with EC by increased body sway in the AP plane whilst the ML sway contribution, as evidenced by DIML value, was decreased. In contrast to statistically insignificant differences in DIAP and DIML in the control group, significant changes in these parameters in the dancers' group suggest that the AP plane is more loosely controlled. This notion is additionally supported by the SRAP values, which is an indicator of neuromuscular efforts involved in maintaining the upright posture in the AP plane was improved both in EO and EC trials.

An intriguing particularity in postural control in ballet students is a greater dependency on visual feedback. Eyes closure excludes one of the main sensory inputs that imposes reorganization of the control which in EC trials must rely on the altered proprioceptive feedback only. This phenomenon has been documented in several studies (Janura et al., 2019; Michalska et al., 2018; Fredyk et al., 2022). Here, this effect was observed in the greater sway vector amplitude (SVam) which is consistent with the aforementioned results. Additionally, we observed in the dancers' group an increase in the SV azimuth which means an alteration in the proportion between anteroposterior and mediolateral postural controls (DIAP and DIML).

One may ask whether elevated postural sway due to professional training can be considered an enquired deficiency of postural control. The postural sway as observed during a quiet stance does not threaten the stability of the posture. It is well documented that in young healthy subjects, the margin of stability is substantially large thus allowing successfully to recover equilibrium even in the face of perturbations larger than those at the maximal magnitude of the sway stability vector (Błaszczyk, 2016). Thus no functional deficit due to professional training can be claimed. Additionally, sway ratio (SR) analysis documented elevated efforts of the postural control system in maintaining the erect posture in our subjects. The increased SR values, especially while standing with eyes closed may suggest more flexible postural control in the dancers (Błaszczyk, 2008).

A growing body of evidence indicates that training-related prolonged perturbation of proprioceptive input from leg muscles modifies the perception of the body's vertical position which alters postural control (Henry & Baudry, 2019). The reduction in proprioceptive inputs that accompany ballet training leads to increased amplitude of body sway, reflecting somehow a greater dependence on visual information (Ribot-Ciscar et al., 2013). The increased postural sway, however, may constitute a means of improving postural stability in subjects with proprioceptive deficits (Błaszczyk et al., 1993b). Consequently, the increased postural sway while students were tested with eyes closed may indicate a shift to proprioceptive control which cannot be fully compensated for changes in visual input.

## CONCLUSION

Our results indicate that classical dance training substantially modifies postural stability and body balance control allowing students to expand the limits of dynamic stability. It seems that achieved coordination skills allow them to give up more restrictive static control. Moreover, the normalized parameters of postural sway recorded during quiet standing posture are useful measures of postural stability that can be also used to assess the performance status of a dancer. Motor training has a distinct impact on postural stability control. Increased joint mobility can impair slightly the postural balance but, on the other hand, it allows to improve the dynamic stability by increased muscular force and intermuscular coordination. Due to increased joint mobilities, the control of postural stability in dancers is omnidirectional compared with controls in which the AP control is dominated. All these training-related changes in postural control are fully compensated by visual input. It should be kept in mind, however, that the dancers rely more strongly on visual cues which, when limited, may affect their performance.

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