



## Full length article

## Influence of dance training on challenging postural control task

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## ABSTRACT

**Background:** Previous studies have shown that dance training affects postural control, particularly during challenging tasks. However, it is still unknown whether dance training also affects the ability to use vestibular, somatosensory, and visual cues, thus leading to postural control differences.

**Objective:** The main goal of the present study was to evaluate the influence of dance training on sensory weighting during static postural control.

**Method:** The center of pressure of 24 participants was recorded (12 dancers and 12 control non-dancers) using a force platform as well as the modified Clinical Test of Sensory Organization in Balance (mCTISB).

**Results:** The results suggest that dancers perform significantly better than controls in conditions where somatosensory cues are disturbed. Moreover, a significant negative correlation between vestibular frequency band and training intensity was observed, along with, a significant positive correlation between visual frequency band and training intensity.

**Significance:** This research outlines dancers' increased ability to modulate sensory weighting differently than non-dancers during postural task where somatosensory cues are reduced.

## 1. Introduction

Postural control requires the integration of multisensory cues in order to position the body in space [1], namely, vestibular, somatosensory, and visual cues. These sensory signals are integrated and, depending on the available sensory cues, a sensory reweighting process can occur to enhance the contribution of more reliable sensory information [2]. There is evidence suggesting that balance training can enhance this sensory reweighting process in fall-prone older adults [3,4].

Dance is considered a multisensory training, since one needs to integrate different sensory cues to position their body in space. Several brain imaging studies report significant structural differences in dancers as opposed to non-dancers [5,6,7, and 8]. Most of these studies found significant differences in white matter and gray matter volume between dancers and non-dancers in multimodal areas, such as the parietal cortex [6,9] and the sensory-motor pathways, including the premotor cortex, supplementary motor cortex, corticospinal tract [5,8]. Moreover, dance video games have been shown to activate the temporoparietal cortical areas [10,11]. As well, these same regions, in particular the superior temporal gyrus (STG), are suggested to play an important

role in reweighting the visual, vestibular, and proprioceptive sensory inputs [12]. A recent study showed that participants with long-term dancing experience have increased cortical thickness in the STG [13] and increased white matter diffusion between various brain areas [8].

It is possible to hypothesize that these structural changes can influence postural control in dancers. Indeed, several studies have shown that, when assessed using postural tasks, during which visual and somatosensory cues are unreliable, dancers perform significantly better than non-dancers [14–17]. Another study has investigated the effect of vestibular stimulation on postural control in dancers [18]. The results showed that, in contrast to non-dancers, professional dancers are less influenced by vestibular stimulation during postural control tasks. These studies suggest that dancers modulate sensory reliance more efficiently than non-dancing controls. However, the specific influence of visual and somatosensory cues during postural control of dancers is still unclear. Some authors suggest that dancers' improved postural control could be due to an enhancement of visual reliance [19,20], while others suggest an enhancement of somatosensory reliance [15–17]. Differences in methodology and task complexity may explain, in part at least, the observed discrepancy in the results.

The main goal of the present study was to evaluate the influence of

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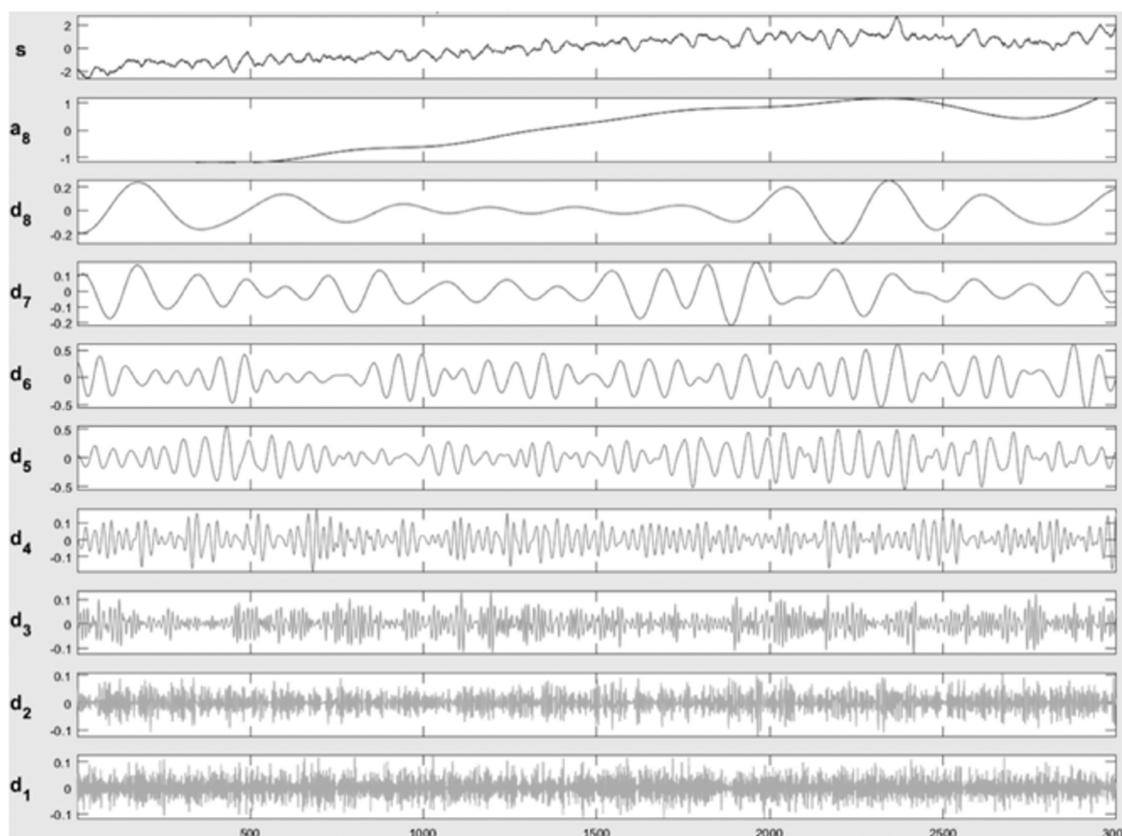
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**Table 1**  
Description of sample: sex, age, height, weight, length of experience and intensity.

	Male/Female	Age (years old)	Height (cm)	Weight (Kg)	Length of dance training (years)	Intensity of dance practice (hrs/week)
<b>Controls</b>	6/6	35.08 ( ± 9.26)	170.77 ( ± 8.33)	67.22 ( ± 13.9)	0	0
<b>Dancers</b>	3/9	30.91 ( ± 6.72)	165 ( ± 9.42)	63.21 ( ± 11.66)	9.20 ( ± 5.51)	16.66 ( ± 10.09)



**Fig. 1.** Representation of level 8 wavelet decomposition with Daubechies of order 20.

dance training on sensory weighting during static postural control using the modified Clinical Test of Sensory Integration in Balance (mCTSIB). This protocol is known to assess the contribution of the different sensory components (vision, somatosensory, vestibular) involved in balance [21] and could therefore provide information about the relative use of vision and somatosensory information during postural control tasks. Along with the mCTSIB, discrete wavelet analysis of the centre of pressure (CoP), a computational method judged more appropriate than Fourier transform for non-stationary signal, was performed to estimate the use of vestibular, visual and somatosensory systems [22].

## 2. Methodology

### 2.1. Participants

Twenty-four participants (12 dancers and 12 controls) were recruited. No significant difference for age, weight and height was observed (Table 1). All of the participants reported themselves to be healthy, to have normal-to-corrected vision, and to have no history of concussion or ear surgery. None of the participants included in this study had a history of chronic medical conditions and did not report taking any medication at the moment of the study. All participants had normal semicircular canal function as verified by video head impulse test. Dancers' length of dance training was 9.2 years, on average (2.5–20 years). Seven dancers had less than 10 years of training whereas five dancers had more than ten years. All dancers were actively

practicing diverse dance styles (salsa, jive, ballet, swing, hip-hop, modern jazz, contemporary dance) at the time of the study, at an average of 16.6 h per week (range: 4–30 hours per week). They were qualified as being expert as they regularly attend dance competitions and dance contests and practice over 4 h a week [23].

### 2.2. Protocol

Participants were assessed using the mCTSIB on a force platform (Accusway, AMTI, USA). The sampling rate of the platform was set at 50 Hz and each trial lasted 60 s, giving 3000 samples [24,25]. During the platform evaluation, pink noise (100 Hz – 4 kHz) was presented at a comfortable level through a speaker (Sound Source Type 4224, Bruel & Kjaer, Denmark) placed one meter behind the participant. The mCTSIB was used to isolate the different sensory components (vision, somatosensory) that are necessary to maintain balance [21]. For the mCTSIB, the participants stood in four different postural conditions: A) Eyes open on a firm surface, B) Eyes closed on a firm surface, C) Eyes open on foam, D) Eyes closed on foam. The foam pad (AIB Balance Foam, AIB, USA) is standardized to a maximum weight of 159 kg. Each sensory condition was repeated three times and the median value of each condition was retained for each participant. During each trial, the participant was requested to count backward starting from a thousand, since research shows that performing a cognitive task can be beneficial for posture [26].

### 2.3. Data analysis

First, the center of pressure (CoP) was used to derive sway area and sway velocity. Two MANOVA were performed to examine group differences on sway area and sway velocity. Two groups were compared (controls and dancers) on the four postural conditions (A, B, C, D).

Discrete wavelet analysis were performed using Matlab (version 2017b). Signal from the anterior-posterior and the medio-lateral axes were processed separately (for each condition). Following Suarez et al. [24] a level 8 decomposition with Daubechies wavelet of order 20 was selected (Fig. 1). Each decomposition level was associated with a different frequency band: the energy content of approximation 8 referred to the low frequency band (0–0.1 Hz); detail levels 8 and 7 referred to the medium frequency band (0.1–0.5 Hz); and finally detail 6 referred to the high frequency band (0.5–1 Hz). The low frequency band is associated with visual control, the medium frequency band with vestibular control, and the high frequency band with somatosensory control [27,28]. The higher the energy within a frequency band, the greater the error signal stemming from its associated sensory system [24]. To assess the energy content of the CoP signal in both anterior-posterior and medio-lateral axes, two repeated measures ANOVAs were performed, each with two groups (controls and dancers) by four postural conditions (A, B, C, D) by three frequency bands (low, medium, high). Finally, for the postural conditions that showed significant difference between groups on either sway area or sway velocity, bivariate correlations were performed between dancing experience (number of years), training intensity (number of hours per week), and the three frequency bands.

## 3. Results

### 3.1. Sway area and velocity

A significant group difference [ $F(4,19) = 2,962, p = .047$ ] was found with MANOVA using sway area (Fig. 2). The MANOVA revealed significant differences between two groups only for the eyes open on foam condition ( $F(1,23) = 10.10, p = .004$ ) and the eyes closed on foam condition [ $F(1,23) = 4.33, p = .049$ ]. No other significant difference was found. The MANOVA using sway velocity did not reveal any significant difference between the groups [ $F(4,19) = 0.881, p = .494$ ].

### 3.2. CoP wavelet analysis

The wavelet analysis on the signal from the antero-posterior axis did not reveal significant group difference [ $F(1,21) = 0.05, p = .826$ ] or any significant interaction between groups, postural conditions, or frequency bands [ $F_s(6,126) \leq 0.93, p_s \geq .579$ ]. Neither were any group differences [ $F(1,21) = 0.05, p = .345$ ] or interactions [ $F_s(6,126) \leq 0.60, p_s \geq .650$ ] observed for data from the medio-lateral axis (Fig. 3).

Interestingly, significant correlations within the dancer group were observed using wavelet data from the antero-posterior axis. A significant correlation was found between dance practice (number of hours/week) and both the medium frequency band [ $r = -.766, n = 12, p = .004$ ] and the low frequency band [ $r = .747, n = 12, p = .005$ ]. No other significant correlation was observed. No significant correlations were found between dancing experience or training intensity and any frequency band on condition C using data from the medio-lateral axis. Finally, no significant correlations were found between dancing experience or training intensity and any frequency band on condition D for both antero-posterior and medio-lateral axis.

## 4. Discussion

The results of the present study reveal the superior ability of dancers to maintain postural control in situations where somatosensory cues are disturbed when eyes are either open or closed. The present study deepens this understanding by proposing that this enhanced performance in dancers might be related to different sensory weighting in dancers. Indeed, the results suggest that dancers who practice more intensively (greater number of hours per week), showed reduced percentage of frequency band associated with vestibular control and increased percentage of frequency band associated with vision control when standing on foam with eyes open. Therefore, based on previous behavioral and imaging studies, it is possible to hypothesize that this observed relation between dance experience and sensory weighting may be related to the ability of dancers to reduce vestibular sensitivity in order to decrease dizziness, which is vital to their performance.

First, behavioral studies support this hypothesis that dancers can down regulate vestibular input. Nigmatullina et al. [6] revealed that dancers showed reduced oculo-motor and perceptual response as opposed to non-dancers after vestibular stimulation. Moreover, dancers as opposed to controls did not showed any association between the

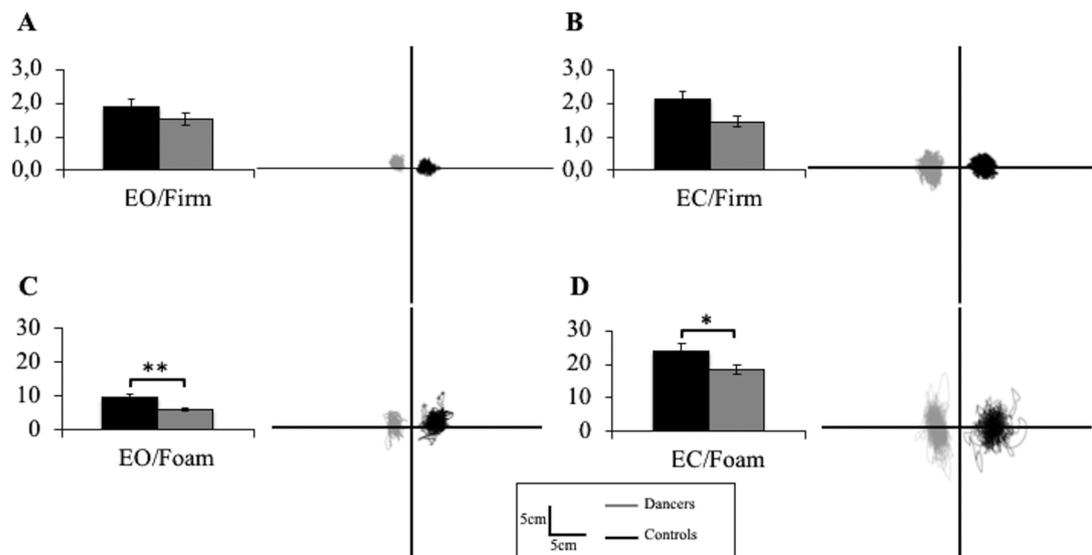


Fig. 2. Mean sway area for each postural condition for controls (white) and dancers (grey). Significant difference observed only for condition eyes open on foam (\*\*  $p < .01$ ) (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

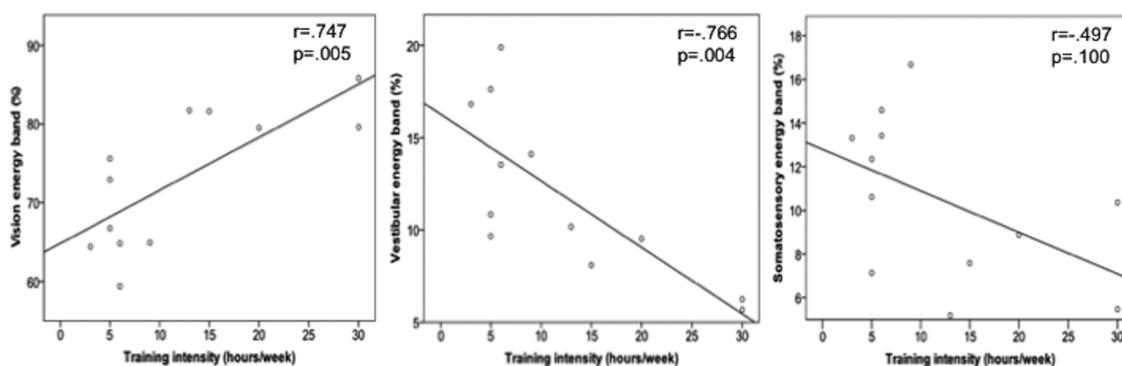


Fig. 3. Correlation between the three frequency bands and training intensity. A significant negative correlation between vestibular frequency band and training intensity was observed, along with, a significant positive correlation between visual frequency band and training intensity.

vestibulo-ocular reflex and perceptual response. This might suggest an ability of dancers to modulate vestibular activity. In support of this hypothesis, Hopper et al. [18] asked professional dancers and controls to stand on a force platform following repetitive pirouettes. The results revealed that professional dancers were not influenced by vestibular stimulation during the static postural task.

Secondly, previous imaging studies, structural changes that occur in the vestibulo-cerebellum in dancers. It is well known that the cerebellum directly projects to vestibular nuclei [29,30] and therefore can modulate their activity. Nigmatullina et al. [6] revealed a significant reduction of gray matter in the vestibulo-cerebellum in dancers, more specifically in lobules VIII and IX. This reduction of the gray matter in the vestibulo-cerebellum might reflect a more efficient processing of the vestibular signal, explaining the reduction of vestibular signal observed in the CoP signal during condition C of dancers with greater training intensity. Apart from the observed modulation of the vestibular control, several studies support the importance of visual input to explain the enhanced postural performances in dancers [20,31]. Imaging studies found that dancers, as opposed to musicians, showed a significant increase in radial diffusivity in the superior longitudinal fasciculus (SLF) [8]. This higher radial diffusivity in dancers was related to enhanced performance in a dance imitation task. The SLF is of importance to connect posterior sensory regions to parietal and frontal motor regions [32]. Giacosa et al. [8] proposed that the changes observed in SLF regions in dancers might explain the enhanced visuo-motor integration skills.

This enhanced postural control under conditions when visual cues are present might be related to the specificity of the dance training. It may suggest an enhancement of the weight accorded to visual cues, which could be related to specificity of dance training. In support of this hypothesis, Hutt et al. [33] studied the influence of an eyes-closed dance program on dynamic balance. They found a significant improvement in balance tests for the group that practice eyes-closed training program. The authors proposed that training with eyes closed could have led the participants to adopt a different sensory strategy to maintain balance.

Moreover, it is possible that other sensory cues may contribute to enhanced postural performance in dancers. The influence of auditory cues on postural control are often neglected as a possible additional cue to position our body in space. It has been well demonstrated that different auditory inputs can influence sensory reweighting during postural control tasks [34–36]. As dancers are trained to move in relation to music, they might use auditory inputs to a greater extent to maintain postural control as opposed to non-dancers. In the present study, pink noise was present in the room (located 1 m behind the participant). Consequently, the presence of this sound in our experiment might have had a particular influence for dancers compare to non-dancers. Further studies should assess the use of auditory cues for postural control in dancers.

Finally, the wide range of experience and heterogenous style of dance of the dancers in our sample may explain variability in the measured frequency bands in the different conditions. However, it is interesting that enhanced postural performance may be observed in a sample of dancers with great variability in dance experience and with an heterogenous style of dance. Even if this design doesn't provide specific information about the type of dance, it adds to the ecological validity of the results. Further studies should aim at assessing if there is a sensitive period or if a particular type of dance training can influence postural control and sensory weighting. This question is of interest, as dance training may serve as an intervention in different populations, such as older adults at risk of falls.

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#### Author contribution statements

M.M, L.B., M.N. and F.C. designed and performed the experiment. B.J. helped with data analysis. M.M. and F.C. wrote the paper and A.D., B.J. helped in the authorship. All authors discussed the results and implications and commented on the manuscript at all stages.

#### Conflict of interest statement

The authors have no conflict of interest to declare.

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