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Effect of expertise in ballet dance on static and functional balance

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ABSTRACT

Research question: The purpose of this study was to examine the postural sway characteristics of the ballet dance experts in quiet standing and at their limits of stability with an approach not used before in dancers.
Methods: The study was conducted on thirteen female ballet dancers and thirteen non-training females. The data were collected with a use of a force plate. To gain a better insight into the postural control processes, we used the rambling-trembling and sample entropy analyses in the COP data processing.
Results: The main findings of the study showed professional dancers to have higher values of postural sway characteristics in comparison to the non-trainees while performing simple motor tasks. Also, higher values of the trembling component in the group of dancers during quiet standing and the inclined positions were observed. This might be a sign of higher capacity of the postural system to deal with postural instability in dancers.
Importance: Our results confirmed that the visual information is important in the process of postural control of dancers', which is proven by increased dislocations of the COP without visual feedback. The sample entropy results indicated more irregular characteristics of postural sway in ballet dancers representing more automated postural control. The data analysis methods showed high sensitivity to the subtle changes in postural control due to the dance training.

1. Introduction

Professional dancers' routines demand efficient postural control that is often challenged when the moves of the choreography are performed in extreme positions and postures [1]. Flexible transitions between dance positions are proof of a high level of dance skill. Professional dancers present a high level of spatial orientation for their proper orientation and positioning in space (mirror, stage, audience), which depends mostly on training experience and fine coordination [2]. Further, the proper integration of visual, vestibular and proprioceptive information is the basis of efficient postural control [3]. However, the differences in effective postural control between dancers and non-dancers can only be noticed in tasks of increased difficulty [4], and it is not always possible to observe them during quiet standing or a single-leg stance [5,6]. The basic parameters of standard measurements in which force platforms are used, such as center of foot pressure (COP) path length, COP velocity and standard deviation of COP, are often not sufficiently sensitive to show differences where one would intuitively suspect their existence [7]. Thus, diverse COP signal analysis is needed [5]. We believe that the use of rambling-trembling COP signal decomposition introduced by Zatsiorski and Duarte [8,9] is a way to address this problem. Ferronato and Barela [10] assumed that the rambling component, to a certain degree, explains the process of refreshing sensory information within the reach of the body and that the trembling component relates to regaining input force value. This addresses the discrepancy between motor planning and performance of the motor task linked to the mechanical characteristics of muscles and joints.

Another approach is to analyze the dynamical structure of a COP signal during a simple motor task such as quiet standing, i.e., its regularity. This was found to be positively related to the degree of attention invested in postural control [11]. The regularity of COP trajectories was quantified by the sample entropy. Low values of entropy show more regularity in the COP signal, and high values signify less regularity in the COP signal [12]. The basic assumption is that the automatic control processes increase the entropy of the signal while the volitional control decreases it [13]. Irregularity and, thus, high entropy can be interpreted as a sign of a healthy, vigilant system [14]. Many authors observed more regular COP trajectories in clinical groups than in controls [15,16] and less regular COP trajectories in balance-expert

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groups [11]. Moreover, higher entropy was observed when attention was experimentally withdrawn from posture using an additional task [17] and with limited availability of visual information [7]. Because the sample entropy measures should provide augmented information about physical capacity, stability and adaptability of the postural system that may not be captured by more traditional data analysis methods, we have also incorporated them into our study.

In this study, we examined the effects of ballet dance expertise on body balance in quiet standing and postural stability with the limits of stability test (LOS test) [18] using an enhanced analysis of COP, which will allow the detection of subtle differences in the process of postural control in groups of different expertise. The literature review also shows that the role of the sensory systems engaged in postural control has been often discussed [2,19–22], but the opinions concerning the role of visual input for postural control in the groups of highly trained athletes are not unanimous. The hierarchical role in the process of postural control between the mentioned sensory systems is still unidentified. Crotts et al. (1996) noticed that dancers are capable of longer maintaining a stable position during single leg stance with eyes closed than non-dancers suggesting the leading role of proprioceptive system in postural control or its better functioning. During the same trial with eyes open, dancers get similar results as a control group, which proves that dancers' postural stability is less depended on visual information. In Simmons' (2005) research dancers presented a comparable level of postural control to the control group both with eyes open and with eyes closed. Pérez et al. (2014) suggested that better postural control of dancers depends on the availability of visual information. It relates to the characteristics of the sport, and more specifically to stage performances. According to Lin et al. (2011) only the incorrect reception of proprioceptive inputs related to an ankle injury differentiate dancers from other non-sports groups. In their study dancers were less stable than the control group after injury. In another study by Golomer et al. (1999) authors claim that long term dance training develops the sense of proprioception in such a degree that the process of postural control becomes less dependent on visual information. Therefore, we have decided to evaluate the influence of visual information on postural control with the use of more sensitive analysis methods. Ballet dancers should be treated as a highly qualified sports group. Therefore, we hypothesized that we would see greater variations of COP, thus proving a greater postural sway and more irregular signal in relation to untrained individuals, both in quiet standing and at their limits of stability. We would also like to use our novel approach to confirm that visual information plays a significant role in the process of maintaining body balance in dancers.

2. Materials and methods

2.1. Subjects

Thirteen ballet dancers with an average of 17 years of dance experience and thirteen non-training students voluntarily participated in the study (Table 1). Based on the medical interview, the general inclusion criteria were: no history of musculoskeletal injury or intervention within the last two years and no history of neurological or vestibular problems. Additionally, the criteria for the dancers included more than 5 years of classical ballet experience, and for non-dancers they included no experience in competitive sports or activity involving balance training. All subjects were females. The subjects gave informed written consent for voluntary participation in the study. All participants met the inclusion criteria and successfully completed the experiment. The study was approved by the Institutional Bioethics Committee.

Table 1
Physical characteristics of subjects.

	N	Sex	Age (mean SD) [years]	Height (mean SD) [cm]	Weight (mean SD) [kg]
Dancers	13	F	28.0 ± 7.0	169 ± 3.6	55.7 ± 3.3
Control Group	13	F	23.0 ± 3.0	167.1 ± 6.2	56.4 ± 5.9

2.2. Apparatus and procedures

To assess balance and postural stability, we used the force plate (AMTI, Accugait, Watertown, MA, USA) by which the ground reaction forces and moments were registered at a 100 Hz sampling frequency.

The experimental procedure comprised quiet standing (QS) and limits of stability (LOS). During QS trials, subjects stood barefoot on the force platform with their arms along their sides. They were asked to maintain a stable posture with their gaze fixated at a reference point located 3 m away in front of them. The QS trials were performed under two condition, with eyes open and with eyes closed. In the LOS test, subjects were instructed to stand quietly during the first 10 s of the trial, next to lean as far and as fast as they were able, and then to maintain this position (the extreme posture at the stability limit) until the end of the test. Therefore, the LOS test have three distinct phases: 1) quiet standing, 2) transition to maximum forward leaning position and 3) quiet standing in maximum leaning position [18]. In this study, we have analyzed only the first and third phases. Although the second (transition) phase is also interesting, unfortunately very brief. The rationale behind the comparison of the first and third the phase is that these phases are essentially static in nature and can reflect possible change in the postural control processes. LOS test was done sequentially in two directions: forward and backward. The QS and LOS test trials were repeated three times and lasted 30 s [18,23].

2.3. Data processing

The raw data from the platform were processed offline using the Matlab r2017b software (Mathworks Inc., Natick, MA, USA) with a 7 Hz, fourth-order, low-pass Butterworth filter. Richman and Moorman's [12] algorithm for sample entropy and Zatsiorsky and Duarte's [8,9] method for rambling and trembling decomposition were used. The following variables were further analyzed: range (ra-COP, ra-ramb, ra-tremb), velocity (v-COP, v-ramb, v-tremb), sample entropy.

2.4. Statistics

The basic parameters of the descriptive statistics were calculated. The independent-samples *t*-test was conducted to compare the first and third phases of the LOS test between the groups. Intra-group differences were calculated by dependent-samples *t*-test. Intraclass correlation coefficients (ICC) were calculated for the LOS test in the forward and backward directions. The levels of reliability were considered poor ($ICC < 0.40$), moderate ($0.40 \le ICC < 0.60$), good ($0.60 \le ICC < 0.80$), and excellent ($ICC \ge 0.80$), according to Mancini et al. [3]. Good test-retest reliability was achieved for the parameters of the first and third LOS phases in both the forward and backward directions (composite equilibrium score above ICC = 0.75).

Additionally, the statistical power of LOS was calculated, which for all measured parameters showed values above 0.8. All calculations were carried out using STATISTICA v.13.1 (StatSoft, Inc., USA).

3. Results

3.1. Comparison of the 1st and 3rd phases of the LOS test

Significantly higher values of each analyzed variable were registered in the control group between the 1st and 3rd phases of the LOS test, both forwards and backwards ($p < 0.05$) (Fig. 1). Such differences were observed in the group of dancers only in the maximum forward