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Specificity of foot configuration during bipedal stance in ballet dancers

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ABSTRACT

Background and Aim: Learning highly specialized upright postures may be of benefit for more common as well as for novel stances. In this study, we asked whether this generalization occurs with foot configurations previously trained or depends on a generic increase in balance difficulty. We also explored the possibility that the benefit may concern not only the level of postural performance but also the structural organization of the upright standing.
Methods: Ten elite professional ballet dancers were compared to ten untrained subjects, measuring the motion of the center of pressure (COP) across a set of five stances with different foot configurations. The balance stability was measured computing the area, the sway path, and the root mean square of the COP motion, whereas the structure of the postural control was assessed by compute approximate entropy, fractal dimension and the mean power frequency. The foot position included common and challenging stances, with the level of difficulty changed across the configurations. Among these conditions, only one foot configuration was familiar to the dancers.
Results: Statistically significant differences between the two groups, for all the parameters, were observed only for the stance with the foot position familiar to the dancers. Stability and structural parameters exhibited comparable differences.
Conclusions: We concluded that the benefit from classical ballet is limited to a specific foot configuration, regardless of the level of stance difficulty or the component of postural control.

1. Introduction

Most of the everyday actions, such as walking or reaching, require an accurate spatio-temporal control of the standing posture. Generally, the nervous system elaborates the postural commands based on the planning of upcoming movements [1,2]. Thus, the formation of the postural orders to modulate the upright stance is functionally linked to the specificity and complexity of the action execution. This association is important for those sports or artistic activities, such as gymnasts or ballet, where the control of body orientation and equilibrium are critical for the performance optimization. A debated topic is whether the specific postural training, required for specific movements, can be of benefit for the standing control during common stances and/or in novel challenging postures.

Several authors who addressed this question, found that subjects practicing activities with a specific demand of postural ability exhibited improvements in stance stability mainly in contexts for which their practice was related to [3–6]. For example, ballet dancers perform better balance control than untrained subjects only for specific foot configurations associated with the ballet training, such as point and demi-pointe [3].

However, in these studies two important elements were overlooked. First, the most challenging postures were also the most specific, whereby it was problematic to distinguish the effects of the task specificity from a generic influence of the postural difficulty. Second, the standing performance was evaluated with respect to the level of stability, neglecting a possible generalization of the strategic components of the postural control, i.e. the ways in which the upright balance is maintained.

To deal with the first point, we compared ballet dancers and untrained subjects using a set of five foot configurations with increasing level of postural instability. The two most difficult postures included a familiar stance for the dancers but not for the no-dancers, and an unfamiliar stance for both the groups. The

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hypothesis that the benefit from a previous training is limited to specific postures would be validated if the differences between the two groups will occur only for the foot configuration familiar to the dancers. Conversely, if only the dancers will show a performance improvement parallel to the increase of postural challenge, it will mean that the level of standing difficulty contributes to the postural ability generalization, regardless of the task specificity.

To further explore the possibility of generalization of postural skills learned by ballet dancers, the upright performance was evaluated not only measuring the stance stability, but also using parameters regarding the dynamic structure of the motion of the center of pressure (COP). Thus, we provided data on the frequency spectrum, the temporal, and the spatial dynamic of the sway oscillations, making clearer and more complete the information on the postural benefit associated with the ballet.

2. Materials and methods

2.1. Persons

Two groups of 10 women participated in this study. The first group consisted of professional ballet dancers (age 23.7 ± 2.5, height 162 ± 5.9 cm, weight 53.4 ± 4.8 kg) with more than 10 years of practice. The second group included sedentary subjects (age 27.6 ± 3.5, height 159.6 ± 5.8 cm, weight 56.1 ± 5.2 kg) with no experience in competitive sports or activity requiring balance training. There were no statistically significant differences in weight, height and foot length between the groups. All participants had normal or corrected-to-normal vision and no history of neurological or motor deficits. They were naive to the experimental hypotheses and signed an informed consent. The study was conformed to the Declaration of Helsinki and approved by the local ethics committee.

2.2. Apparatus and procedures

Participants performed the tests on a force platform (KISTLER 9286 B, Winterthur, CH), and the data were sampled at 100 Hz by a computer equipped with an AD converter.

Each experimental session consisted of five repetitions of 30 s, for each of the following foot configurations (Fig. 1).

Common stances:

parallel feet with the heels spaced 10 cm;
parallel feet with the heels spaced 20 cm;
feet in extra-rotation, with the heels spaced 15 cm, and an opening angle of 20°.

Challenging stances:

feet in extra rotation, with heels together and an opening angle of 140° (duck stance);
feet aligned along the sagittal axis with the toes of one foot close the heel of the other (tandem stance).

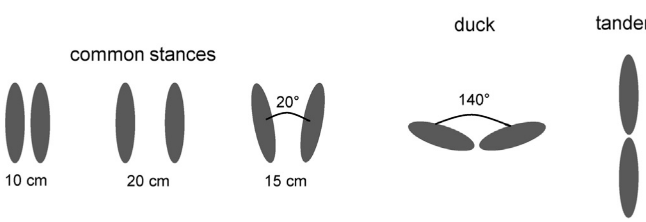

Fig. 1. Schematic representation of the five foot configurations used for the postural tests.

Subjects stood barefoot with their feet inside the outline borders, and their eyes focusing on a mark placed at a distance of 2.5 m. The order of presentation of foot configurations was randomized across participants.

2.3. Data processing and measurements

The raw signals of forces and moments acquired by the force platform were first filtered (second-order low-pass Butterworth filter, cutoff frequency 5 Hz) and then used to calculate the anterior-posterior (AP) and the medial-lateral (ML) coordinates of the COP position. From AP and ML time series, two-dimensional trajectory of the COP was reconstructed and two subsets of parameters were determined.

A first set of measurements included parameters describing the level of stability of the COP:

Area: total area covered by the COP trajectory computed as the 95% confidence ellipse;
Sway path: the total length of the COP trajectory computed as the sum of the distances between two consecutive points in the two-dimensional space;
Root mean square (RMS): variability along AP and ML directions computed as standard deviation from the mean of each time series.

The second set of parameters describes the structural dynamic of postural signals in time, space and frequency domain:

Approximate entropy (ApEn): estimation of the level of regularity of the time series oscillations, taking into account the non-stationarity of the postural signal. The ApEn was computed using input parameters based on our data and former established protocols [7]: the time series length was 3000 points; the pattern length of compared data was two data points; the tolerance window was normalized to 0.2 times the standard deviation of individual time series; the lag value was set to 10. The ApEn ranges between 0 and 2 with 0 indicating a linear phenomenon with high regularity, while 2 indicating a data behavior completely random; intermediate values are typical of deterministic systems more or less regular.
Fractal dimension (FD): a measure of the two-dimensional COP trajectory complexity. The FD was computed using the following equation [8]:

$$\mathrm{FD} = \frac{\log(N)}{\log(N \cdot d / \text{sway path})} \quad (1)$$

where N is the number of data points ($N = 3000$); $d = (2a \cdot 2b)^{1/2}$ where a and b are the major and the minor axes of the 95% confidence ellipse, respectively. The geometrical complexity of COP trajectory increases as the two-dimensional FD passes from 0 to 2.
Mean power frequency (MPF): represents the mean frequency contained within a power spectrum, and was determined for AP and ML directions as follow:

$$\mathrm{MPF} = \frac{\sum f \cdot P(f)}{\sum P(f)} \quad (2)$$

where f represents frequencies in the signal and P is the amplitude of the power spectral density (PSD) at each frequency. The PSD was computed from unfiltered AP and ML time series using the multitaper estimation method [8]. Since no discernable spectral peaks were visible above 1.5 Hz, the frequency-domain measures were calculated in the range 0.025–1.5 Hz (bins of