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Inter- and intra-lower limb joint coordination of non-expert classical ballet dancers during tiptoe standing

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ABSTRACT

The main objective of this study was to compare ballet dancers' and non-dancers' joint coordination during tiptoe standing. Nine female non-expert ballet dancers and nine female non-dancers were asked to perform heel-toe and tiptoe standing for approximately 30 s, during which the center of pressure (COP) and kinematic data from the metatarsophalangeal, ankle, knee, and hip joints were measured. Principal component analysis was performed on the angular displacements to determine joint coordination. The weighting vectors suggested that dancers' ankle and knee joints fluctuated in-phase in the anteroposterior direction, whereas all combinations of adjacent joints had anti-phase coordination for non-dancers. In addition, there was a significant difference in the intra-joint coordination pattern between groups. In particular, dancers' metatarsophalangeal (MP) and ankle joints tended to sway to the left-front or right-rear. However, there were no differences between the groups in the path length or rectangular COP. These results suggest that dancers maintained quiet postures via a decrease in the mechanical degree of freedom and that postural expertise may not be determined from a traditional COP analysis, even during unstable tiptoe standing. This in-phase coordination, which has an arch-like configuration, could be characteristic of dancers' lithe legs.

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1. Introduction

One of the fundamental aesthetic elements of a dancer is his or her slim, lithe, and strong legs. Although most of the aesthetical components of ballet may exist during dancing and largely depend on upper body posture, it is possible that even when standing, dancers have different postural control compared to non-dancers, which may be partially because of leg joint movements. By investigating dancers' leg joint coordination during standing, we can observe leg joint fluctuations at the micro-level for an aesthetical discussion, namely, we will be able to obtain insight into whether subtle fluctuations of this joint coordination could lead observers to describe a dancer's posture as beautiful.

Tiptoe standing (relevé or demi-pointe) is one of the fundamental postures in ballet dancing and is referred to as three-quarter pointe, during which the ankle is located directly above the metatarsophalangeal (MP) joint. In ballet training, controlling the dancer's position in relevé has obvious benefits for learning all pirouettes (turns) and making a dancer's legs appear slimmer (Warren, 1989). Therefore, ballet students in beginner courses dedicate themselves to acquiring accurate standing while in relevé. Because ballet dancers exhibit better postural control as a result of their ballet training (Rein, Fabian, Zwipp, Rammelt, & Weindel, 2011), many studies have focused on ballet dancers' balance expertise (Bläsing et al., 2012). Dancers have a lower power of body oscillations (Golomer, Dupui, & Monod, 1997) and are less dependent on vision for postural control with increased accuracy of their proprioceptive inputs (Golomer, Cremieux, Dupui, Isableu, & Ohlmann, 1999). However, these results have only been reported during ordinary heel-toe standing. Despite the importance of relevé for classical ballet, no current studies have focused on ballet dancers' joint coordination in this position. Because of its difficulty compared to heel-toe standing, researching relevé could be an appropriate task to determine postural control differences between dancers and non-dancers. We have previously observed that non-dancers performed tiptoe standing with a different neurophysiological mechanism compared to heel-toe standing (Tanabe, Fujii, & Kouzaki, 2012). Understanding how dancers stand on tiptoe will provide more insight into ballet dancers' skills. Therefore, in this study, we investigated postural expertise during tiptoe standing in ballet dancers and compared it with that of non-dancers.

Many studies have investigated dancers' postural control during static posture by using a center of pressure (COP) analysis; however, these results are not always consistent in linear (Gerbino, Griffin, & Zurakowski, 2007; Kilby & Newell, 2012; Stins, Michielsen, Roerdink, & Beek, 2009) and non-linear (Kilby & Newell, 2012; Stins et al., 2009) analyses. The joint movements involved in maintaining a standing position result in a fluctuation of the COP. Thus, if we suppose that postural maintenance strategies of dancers and non-dancers are different, it is difficult or impossible for a COP analysis to discriminate postural control between dancers and non-dancers. However, investigating a joint's oscillations and its relationships to other joints (inter-joint coordination) could elucidate the postural control process from a mechanical perspective. This knowledge could also lead the argument of postural control to the discussion regarding the visible portion because it is easier to perceive joint fluctuations compared to a COP movement, so this could lead to research with tangible benefits for ballet pedagogy with regard to balance control. Therefore, in this study, we measured joint movements in the MP, ankle, knee, and hip joints during both heel-toe and tiptoe standing.

In the present study, both inter- and intra-joint coordination were investigated using principal component analysis (PCA) during heel-toe and tiptoe standing. PCA is useful to detect invariant coordinative structure of the system (Daffertshofer, Lamoth, Meijer, & Beek, 2004) and has been applied to studies of posture (Aramaki et al., 2001; Kuo, Speers, Peterka, & Horak, 1998; Pinter, van Swigchem, van Soest, & Rozendaal, 2008), gait (Deluzio, Wyss, Zee, Costigan, & Sorbie, 1997; Hubley-Kozey, Deluzio, Landry, McNutt, & Stanish, 2006; Ivanenko, Cappellini, Dominici, Poppele, & Lacquaniti, 2005; Troje, 2002), and rhythmic movements (Toiviainen, Luck, & Thompson, 2010) because of its potential for data reduction and explanation (Jolliffe, 1986). The central objective of PCA is to reduce the dimensionality of a data set while retaining the variation and to summarize the most important information in the data set (Jolliffe, 1986). This summation of the information in the data set can be described in the following manner: