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Does motor expertise facilitate amplitude differentiation of lower limb-movements in an asymmetrical bipedal coordination task?

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ABSTRACT

The motor system's natural tendency is to move the limbs over equal amplitudes, for example in walking. However, in many situations in which people must perform complex movements, a certain degree of amplitude differentiation of the limbs is required. Visual and haptic feedback have recently been shown to facilitate such independence of limb movements. However, it is unknown whether motor expertise moderates the extent to which individuals are able to differentiate the amplitudes of their limb-movements while being supported with visual and haptic feedback. To answer this question 14 pre-professional dancers were compared to 14 non-dancers on simultaneously generating a small displacement with one foot, and a larger one with the other foot, in four different feedback conditions. In two conditions, haptic guidance was offered, either in a passive or active mode. In the other two conditions, veridical and enhanced visual feedback were provided. Surprisingly, no group differences were found regarding the degree to which the visual or haptic feedback assisted the generation of the different target amplitudes of the feet (mean amplitude difference between the feet). The correlation between the displacements of the feet and the standard deviation of the continuous relative phase between the feet, reflecting the degree of independence of the feet movements, also failed to show between-group differences. Sample entropy measures, indicating the predictability of the foot movements, did show a group difference. In the haptically-assisted conditions, the dancers demonstrated more predictable coordination patterns than the non-dancers as reflected by lower sample entropy values whereas the reverse was true in the visual-feedback conditions. The results demonstrate that motor expertise does not moderate the extent to which haptic tracking facilitates the differentiation of the amplitudes of the lower limb movements in an asymmetrical bipedal coordination task.

1. Introduction

It is often overlooked that skilled performance of complex interlimb coordination patterns requires years of extensive practice. Many studies have demonstrated the link between various levels of proficiency in musicians and dancers on the one hand and complex bimanual and bipedal motor coordination on the other (Fujii, Kudo, Ohtsuki, & Oda, 2010; Heijink & Meulenbroek, 2002; Miura, Fujii, Okano, Kudo, & Nakazawa, 2016; Miura, Kudo, & Nakazawa, 2013; Peper, Beek, & van Wieringen, 1995; Ridding,

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Brouwer, & Nordstrom, 2000; Schlaug, 2001).

Professional dancers require intensive practice of complex whole-body movement sequences that unfold over time in a fully prescribed manner in correspondence with or without a music prescribed tempo, and often in interaction with other dancers. Also in this context, dancers often simultaneously execute bilateral movements over different amplitudes and rotation angles. Experienced dancers have acquired the capacity to do so by exploiting cognitive representations of spatial patterns that form the targets of their movements while processing external sensory cues, in the form of visual, proprioceptive and auditory information (Bronner, 2012; Miura, Kudo, & Yamamoto, 2015; Muelas Perez, Sabido Solana, Barbado Murillo, & Moreno Hernandez, 2014; Sofianidis, Hatzitaki, & Mckinley, 2012). During rehearsal, dancers use these cues to optimize their body positions. For example, dancers often use mirrors to monitor and correct their body-positions, or visual landmarks on their partners or in a specific object in the environment (Brown & Meulenbroek, 2016; Hugel, Cadopi, Kohler, & Perrin, 1999; Notarnicola et al., 2014). On the other hand, after extensive training, dancers rely less on visual cues and more on the dedicated proprioceptive acuity they have developed (Golomer & Dupui, 2000; Golomer, Dupui, Séréni, & Monod, 1999; Sofianidis, Hatzitaki, Grouios, Johannsen, & Wing, 2012).

An interesting finding in this context is that several studies have shown that complex movement planning can be bypassed when complex bimanual tasks are visually presented as a simple unified task (Boyles, Panzer, & Shea, 2012; Diedrichsen, Hazeltine, Kennerley, & Ivry, 2001; Franz & McCormick, 2010; Franz, Zelaznik, Swinnen, & Walter, 2001; Ivry, Diedrichsen, Spencer, Hazeline, & Semjen, 2004; Kovacs & Shea, 2010; Mechsner, Kerzel, Knoblich, & Prinz, 2001). In other words, when providing feedback that is simplified, a complex task can be performed easily by an untrained individual.

Another form of external sensory cueing that has been shown to facilitate complex interlimb coordination patterns in novices, i.e. moving the arms with different spatial patterns and different frequencies (Rosenbaum, Dawson, & Challis, 2006) and moving the lower limbs at different amplitudes (Roelofsen et al., 2016), is haptic tracking. Haptic tracking, or active assistive motion, arises when an individual moves his or her limbs in response to light touch on a moving (therapeutic) device or via an external guide while maintaining light contact with the guide's moving body (Rosenbaum et al., 2006). It is yet unknown whether individuals with a high level of motor expertise, such as dancers, benefit from haptic or visual feedback when performing a task which requires them to generate lower limb-movements with different amplitudes.

To answer this question, the present study exploits a bipedal coordination task which was utilized in a recent study that focused on the role of haptic guidance in the facilitation of complex motion in young healthy individuals (Roelofsen et al., 2016). In that study, participants were asked to simultaneously generate different amplitudes with the left and right foot in the forward-backward direction. Four feedback-conditions were tested: 1) a special haptic feedback condition, which required the participant to actively follow the motion of two sliders placed below the feet manipulated by two confederates, 2) a second haptic feedback condition involving passive motion, 3) a veridical visual feedback condition which provided the participant with computer-generated visual cues representing the participant's foot displacements, and 4) an enhanced visual feedback condition, in which the computer generated feedback was manipulated in such a way that the amplitude differences were neutralized on screen, while in fact the participants still had to produce amplitude differences with their feet.

In the present study, we aim to explore the role of motor expertise in our asymmetrical bipedal coordination task. We compared pre-professional dancers to novices and asked whether dancers would be better in cyclically moving the feet across diverging amplitudes while being supported by different types of feedback. We expected dancers to be more proficient than novices in generating different amplitudes with the left and right foot in the special haptic-feedback condition and the enhanced visual-feedback condition, as reflected by smaller amplitude-assimilation effects. Moreover, amplitude differentiation should result in lower correlations between the left and right foot-displacement functions and in higher standard deviations (SD) of relative phase between the feet. Finally, we wanted to explore if there would be differences in the predictability of the feet displacements over time between dancers and non-dancers. For this purpose, we compared the sample entropy measures of the position-time signals of their feet (Richman & Moorman, 2000).

2. Methods

2.1. Participants

Two groups took part in this study. The first group, the dance-group, comprised fourteen pre-professional dance students (7 male, 7 female; mean age 20.9 years ± SD 2.0 years) from the bachelor dance program of the ArtEZ University of the Arts (Arnhem, the Netherlands). The students were first-, second- or third year students with 12.4 years (SD 4.6 years) of dance experience. The second, control group consisted of fourteen healthy young adults (7 male, 7 female; mean age 21.1 years ± SD 2.3 years) with no formal dance training. The participants in this group were students of the Radboud University (Nijmegen, the Netherlands) who were sex and age matched to the dancers. In addition, participants in both groups were matched on their footedness, which was determined by a Dutch translation of the Waterloo Footedness Questionnaire (Elias, Bryden, & Bulman-Fleming, 1998). Prior to participation, all subjects gave their written informed consent. The study was approved by the ethics committee of the Social Sciences Faculty of the Radboud University Nijmegen.

2.2. Experimental set up

The current study is a follow-up of Roelofsen et al. (2016) with healthy subjects in which the role of haptic and visual feedback in performing a bipedal coordination task was investigated. The experimental set up of the present study shown in Fig. 1 is similar to