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Dance and music training have different effects on white matter diffusivity in sensorimotor pathways

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ABSTRACT

Dance and music training have shared and distinct features. Both demand long and intense physical training to master. Dance engages the whole body, and requires the integration of visual, auditory and motor information. In comparison, music engages specific parts of the body and primarily requires the integration of auditory and motor information. Comparing these two forms of long-term training offers a unique way to investigate brain plasticity. Therefore, in the present study we compared the effects of dance and music training on white matter (WM) structure using diffusion tensor imaging (DTI), and examined the relationship between training-induced brain changes and specific measures of dance and music abilities. To this aim, groups of dancers and musicians matched for years of experience were tested on a battery of behavioural tasks and a range of DTI measures.
Our findings show that dancers have increased diffusivity and reduced fibre coherence in WM regions, including the corticospinal tract, superior longitudinal fasciculus and the corpus callosum. In contrast, musicians showed reduced diffusivity and greater coherence of fibres in similar regions. Crucially, diffusivity measures were related to performance on dance and music tasks that differentiated the groups. This suggests that dance and music training produce opposite effects on WM structure. We hypothesize that intensive whole-body dance training may result in greater fanning of fibres connecting different brain regions, an increase in crossing fibres, or larger axon diameter. In contrast, musical training may result in more focussed enhancements of effector-specific pathways. These findings expand our understanding of brain plasticity by emphasizing that different types of training can have different long-term effects on brain structure (Takeuchi et al., 2011; Baer et al., 2015).

1. Introduction

Dance and music are universal forms of human expression that have both shared and distinct features. Both dance and music training require long, intense and quantifiable training to master. Dance training engages the whole body, and requires the integration of visual, auditory and motor information. It focuses on perfecting movement through observation and imitation. In comparison, music engages specific parts of the body, typically the hands and fingers, and primarily requires the integration of auditory and motor information. Music training emphasizes perfecting sound through listening and refining movement. Thus, the neural systems relevant for long-term dance training likely include those important for whole-body control, visual and auditory sensorimotor integration and the "action observation network" (AON) (Cross et al., 2009b; Grafton, 2009; Keysers and Gazzola, 2009; Caspers et al., 2010). Conversely, the neural systems relevant for long-term music training likely include the regions important for control of specific effectors and those engaged in auditory–motor integration (Bangert et al., 2006; Lahav et al., 2007; Zatorre et al., 2007). Therefore, comparing white matter (WM) structure between dancers and musicians provides a new window to investigate the neural correlates of long-term training. Examination of long-term training in a variety of domains has shown that it has lasting effects on brain structure and function (Maguire et al., 2000; Draganski et al., 2004; Driemeyer et al., 2008; Jäncke et al., 2009; Keller and Just, 2009; Taubert et al., 2010; Bezzola et al., 2011). Among these disciplines, music training has received particular attention (Hyde et al., 2009a, 2009b, Schlaug et al., 2009; Herholz and Zatorre, 2012; Groussard et al., 2014; Schlaug, 2015). In contrast, research about the structural neural correlates of dance training is still at a very early stage and very few studies have specifically addressed this topic (Hänggi et al., 2010; Nigmatullina et al., 2015). However, these works compared dancers only to untrained controls, and there were no behavioural measures of dance performance. Thus, our goals in the present study were to characterize the specific effects of dance training on WM structure in comparison with another group of experts with similar long-term sensorimotor training, and to relate those changes to their acquired skills. To do this, we directly compared

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expert dancers with equally well-trained musicians and untrained controls using both behavioural and a range of DTI measures.

1.1. Previous work on dance and music

The study of specialized training such as dance and music offers a unique way to investigate brain plasticity and its interaction with behaviour. The literature about the neural correlates of music training is much richer than the one about dance and has been previously reviewed (Moore et al., 2014); therefore, here, our main focus will be on dance training.

Previous research about dance has been largely behavioural. These studies have examined various components of dancers' acquired skills, such as postural, balance and motor control (Crotts et al., 1996; Golomer et al., 2010; Kiefer et al., 2011; Costa et al., 2013), timing, synchrony and choreography (Minvielle-Moncla et al., 2008; Waterhouse et al., 2014; Woolhouse and Lai, 2014), as well as memory (Poon and Rodgers, 2000; Vicary et al., 2014) and imagery for sequences of movements (Golomer et al., 2008) (see (Bläsing et al., 2012) for a review). Further, dance expertise has been shown to improve skills that are closely related to the training received, such as balance, posture and sensitivity to the biological motion of familiar actions (Calvo-Merino et al., 2010; Kattenstroth et al., 2011).

Some recent research has investigated the functional correlates of dance (see (Bläsing et al., 2012; Karpati et al., 2015a) for review). A large part of this literature has focussed on the AON, which includes temporo-parietal and frontal sensorimotor regions that are involved in visuo-motor integration and learning of actions performed with specific effectors (Caspers et al., 2010; Landmann et al., 2011; Krüger et al., 2014) or the whole body (Calvo-Merino et al., 2005; Cross et al., 2006; Cross et al., 2009b; Gardner et al., 2015). In both animal and human studies (Grèzes and Decety, 2001; Rizzolatti and Craighero, 2004; Hecht et al., 2013), these regions have been found to be engaged during the observation and performance of mouth or single limb actions (Fadiga et al., 1995; Gallese et al., 1996; Rizzolatti et al., 1996a; Rizzolatti et al., 1996b; Buccino et al., 2001; Gazzola and Keysers, 2009), as well as of whole-body movements (Cross et al., 2009a; Sevdalis and Keller, 2011). It has been shown that this network is particularly relevant for dance learning, which requires observing, simulating and imitating others' whole-body movements (Calvo-Merino et al., 2005; Cross et al., 2006; Cross et al., 2009b). In addition to studies of dance observation, a few experiments have examined lower limb dance-like movements which can be performed during brain imaging. Cortical, subcortical, and cerebellar regions have been shown to be involved in specific aspects of these dance-like movements (Brown et al., 2006; Tachibana et al., 2011; Ono et al., 2014). These studies are the first ones that identified the regions that are functionally relevant for dance execution as opposed to dance observation. However, these paradigms have limited generalizability to real whole-body dance training, and the tested participants were not experts.

There are only few studies that have examined the structural neural correlates of dance expertise (Hänggi et al., 2010; Nigmatullina et al., 2015). Hänggi et al. (2010) compared female ballet dancers and non-dancers using voxel-based morphometry (VBM) and diffusion tensor imaging (DTI). They found that dancers had decreased GM volumes in cortical and subcortical structures critical for motor control and sensorimotor integration, along with decreases in WM volume and fractional anisotropy (FA) in sensorimotor pathways and the corpus callosum. They hypothesised that reductions of WM volume and FA might be the result of greater efficiency, or enhancements in crossing fibre pathways. Although these changes in brain structure were found to be related to the age of commencement of training, no behavioural measures of dance performance were obtained. Further, the authors reported only two global DTI measures, which give little information about crossing fibres. Similar decreases in FA were also found in fronto-parietal and sensorimotor pathways of professional gymnasts (Huang et al., 2013). Just like dancers, gymnasts are experts in whole-body movements and their training focuses on visual-motor integration and action observation. Therefore, their similar training might result in similar changes in WM structure.

Structural brain imaging studies have shown that music training is associated with enhancements of grey (GM) and white matter (WM) in motor regions associated with effector-specific motor control, the corpus callosum, and the auditory cortex (Schlaug et al., 1995; Sluming et al., 2002; Gaser and Schlaug, 2003; Bengtsson et al., 2005; Bermudez and Zatorre, 2005; Bermudez et al., 2009; Han et al., 2009; Hyde et al., 2009b; Abdul-Kareem et al., 2011; Groussard et al., 2014). Further, these brain differences have been linked to performance on music-related tasks (Foster and Zatorre, 2010a; Steele et al., 2013; Bailey et al., 2014; Elmer et al., 2014).

In summary, structural imaging studies in dancers and gymnasts showed a reduction in the WM volume and anisotropy localised in sensorimotor and commissural pathways, as well as fronto-parietal association fibres (Hänggi et al., 2010; Huang et al., 2013; Nigmatullina et al., 2015). In contrast, despite some inconsistencies (Schmithorst and Wilke, 2002; Imfeld et al., 2009), studies in musicians suggest that music training tends to increase fractional anisotropy, especially in the sensorimotor projection fibres (Bengtsson et al., 2005; Han et al., 2009) and in the corpus callosum (Schlaug et al., 1995; Steele et al., 2013).

1.2. DTI measures

Currently, DTI is the most widely used method to investigate the micro-structural properties of WM. It measures the characteristics of diffusion of water molecules in brain tissues. This motion is modelled as an ellipsoid characterised by three axes. Biological features, such as axonal size, density, coherence and degree of myelination all constrain water molecule motion, and thus influence diffusivity measures (Moseley et al., 1990; Basser et al., 1994; Neil et al., 1998; Gulani et al., 2001; Beaulieu, 2002; Assaf and Pasternak, 2008). Because no one-to-one relationship exists between any DTI measure and the architecture of WM structure (Wheeler-Kingshott and Cercignani, 2009; Jones et al., 2013; Walhovd et al., 2014), a multi-parametric combined analysis of diffusion data is helpful. Therefore, in the present study we examined both non-directional and directional measures in order to have a better understanding of the different possible underlying biological configurations (Alexander et al., 2007). The most commonly used DTI measure is fractional anisotropy (FA), which gives a global estimate of the elongation of the ellipsoid or the linearity of diffusion. Other non-directional measures are: axial diffusivity (AD) which measures the amount of diffusion along the principal axis; radial diffusivity (RD) which measures the diffusion on the plane perpendicular to the principal axis; mean diffusivity (MD) which quantifies the amount of diffusion in each voxel; and the mode of anisotropy (MO) which describes whether diffusion is more planar or linear (Basser and Pierpaoli, 1996; Beaulieu, 2002; Ennis and Kindlmann, 2006; Assaf and Pasternak, 2008). In addition, we assessed the partial volume fractions of primary and secondary fibres (F1 and F2). Based on the "ball and stick model" (Behrens et al., 2003), these directional measures give an estimation of the relative proportion of the primary and secondary fibres in the voxels where the co-existence of at least two fibre populations is detected.

1.3. Objectives and predictions of this study

Taken together, previous literature suggests that long-term dance training can have specific effects on the sensorimotor and action observation systems. The purpose of the present study is to investigate the effects of long-term dance training on WM structure by comparing dancers to musicians and untrained controls. Musicians are a useful comparison group for dancers because music and dance training are