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Dance and the brain: a review

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Dance is a universal form of human expression that offers a rich source for scientific study. Dance provides a unique opportunity to investigate brain plasticity and its interaction with behavior. Several studies have investigated the behavioral correlates of dance, but less is known about the brain basis of dance. Studies on dance observation suggest that long- and short-term dance training affect brain activity in the action observation and simulation networks. Despite methodological challenges, the feasibility of conducting neuroimaging while dancing has been demonstrated, and several brain regions have been implicated in dance execution. Preliminary work from our laboratory suggests that long-term dance training changes both gray and white matter structure. This article provides a critical summary of work investigating the neural correlates of dance. It covers functional neuroimaging studies of dance observation and performance as well as structural neuroimaging studies of expert dancers. To stimulate ongoing dialogue between dance and science, future directions in dance and brain research as well as implications are discussed. Research on the neuroscience of dance will lead to a better understanding of brain–behavior relationships and brain plasticity in experts and nonexperts and can be applied to the development of dance-based therapy programs.

Keywords: dance; brain plasticity; action observation; neuroimaging

Introduction

Dance can be defined as the movement of one or more bodies in a choreographed or improvised manner with or without accompanying sound.[1] Dance is universal across human cultures and may have emerged as early as 1.8 million years ago.[2,3] Throughout history, dance has played a pivotal role in cultural[4] and social practices[5] and has also developed into a form of art and entertainment. Dance provides a unique model to investigate how the brain integrates movement and sound as well as the development of motor expertise combined with artistic creativity and performance. Dance involves long-term and intensive practice of sensorimotor skills, and the type and duration of training can be quantified. As such, studying dance offers a unique window to study human brain plasticity and the interaction between the brain and behavior.

Although several studies have examined the behavioral basis of dance,[1,6] fewer studies have investigated the brain basis of dance.[1,7] This article provides an up-to-date and succinct review of empirical studies on the neuroscience of dance. This review does not aim to cover all studies on dance but rather to provide a focused review of studies on the functional and structural brain correlates of dance. More specifically, we first review the role of the action observation network in dance. Next, we review studies that have examined the functional brain networks involved in dance performance. Finally, we review studies on the structural brain correlates of dance training, including some preliminary data from our lab on this topic. We conclude with some future directions and implications of work on the neuroscience of dance.

The neural correlates of action observation in dance

Dancers often learn choreography by watching others perform and by observing their own actions in

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order to perfect the movements. Accordingly, research on dance observation has been influenced by studies of the "mirror neuron system" (or action observation network) in primates and humans and, in particular, by the idea that this network supports the observation and simulation of others' actions.[8] The human action observation network is thought to involve premotor and parietal cortices,[9] which may be involved in action simulation along with the supplementary motor area, superior temporal sulcus, and primary motor cortex.[10]

Investigating the brain activity of dancers while they observe dance performance can provide insight into how dance training may affect the action observation and simulation networks. To this aim, researchers have used functional neuroimaging techniques, including both functional magnetic resonance imaging (fMRI) and electroencephalography (EEG) methods. Whereas fMRI offers fine spatial resolution, EEG offers fine temporal resolution.[11]

In a key fMRI study of dance observation, Cross *et al.* examined training-induced brain activity in expert dancers while they simultaneously observed and imagined performing either familiar or novel movement sequences.[10] Brain activity associated with observing and imagining movements was found in the action observation and simulation networks (e.g., premotor cortex and inferior parietal lobule) and was related to how much experience participants had with the dance steps and how highly they rated their ability to perform them. In a subsequent fMRI study, Cross and colleagues scanned nondancers before and after 5 days of training in which they had to observe and perform a dance video game.[12] Training-induced brain activity was found in the action observation and simulation networks, including the premotor cortex and inferior parietal lobule. In two other fMRI studies of dance observation, Calvo-Merino *et al.* found increased activity, particularly in premotor cortex, when expert dancers observed movements from familiar (versus novel) dance styles and when dancers had physical experience performing the movements compared to having only observed them.[13,14] In a later fMRI study, Pilgramm *et al.* found that ballroom dancers had greater activation in the premotor cortex than did nondancers while observing ballroom dance videos.[15] Taken together, these fMRI studies point to the critical role and plasticity of the premotor cortex in dance observation.

In terms of EEG studies of dance observation, Orgs *et al.* measured event-related desynchronization in a sample of expert dancers and nondancers while they watched dance and nondance movements.[16] Event-related desynchronization was measured as a change in power of α and β frequency bands[16] and is thought to represent inhibition of sensorimotor cortex activity by the action observation system.[17] Dancers showed a larger event-related desynchronization while watching dance movements, indicating greater activation in the action observation system. Most recently, Amoruso *et al.* used EEG to measure event-related potentials in a sample of expert tango dancers, beginner tango dancers, and nondancers as they watched videos of correctly or incorrectly executed tango steps.[18] Anticipatory activity generated by frontal, parietal, and occipital brain regions showed differences between groups and also predicted later activity in motor and temporal regions. The above EEG studies add to the fMRI evidence of functional brain differences of the action observation network in dancers, particularly in terms of temporal brain dynamics in motor and temporal regions.

One limitation of the above studies on dance observation is the lack of ecological validity of the dance stimuli used. Dance stimuli typically consist of simple/short segments of recorded movements devoid of any real-life social context. In order to examine whether the co-presence of the actor and the spectator has an impact on motor resonance, Jola *et al.*[19,20] conducted a series of studies on dance observation in the context of live dance performance. For example, Jola and Grosbras used transcranial magnetic stimulation (TMS) to measure corticospinal excitability by means of motor-evoked potentials in spectators when watching live versus taped dance performances.[19] Participants showed enhanced motor corticospinal excitability when watching live compared to video-recorded dance. In a related study, Jola *et al.* tested the impact of visual experience on motor simulation by measuring motor-evoked potentials in experienced spectators and novices as they watched live dance performances.[20] They found enhanced corticospinal excitability in visually experienced versus novice dance spectators. Taken together, Jola *et al.*'s findings suggest that corticospinal excitability in response to observing dance is affected by whether the performance is live or recorded and also by the participants' visual experience.

Although ecologically valid, live dance performance cannot be strictly controlled to ensure that each participant views an identical performance. As a solution to this problem, Jola *et al.* conducted an fMRI study in novice dance spectators in which they used intersubject correlation to investigate which brain areas are synchronized across participants for uni- and multisensory versions of unfamiliar dance recordings.[21] Activity in the superior temporal gyrus was significantly correlated between subjects for audiovisual integration, but no regions showed significant correlations for higher level cognitive processes.

In sum, neuroimaging studies of action observation in dance have shown that (1) dancers show activation of the action observation and simulation networks, particularly the premotor cortex, when observing dance, likely because they have an enhanced motor representation of an observed movement; (2) functional differences in the action observation system of dancers are related to the degree of dance training; (3) short-term dance training is correlated with brain functional plasticity in nondancers; and (4) observation of recorded versus live dance performance results in differential brain activity. However, the studies reviewed in this section are limited by the fact that they only address *observation* of dance. A critical question in the field of neuroscience of dance is what the brain is doing when one is actually *dancing*.

Functional brain correlates of dance performance

Few studies have examined the functional brain correlates of an actual dance performance given the potential motion artifacts involved in measuring the body in motion in neuroimaging paradigms. However, some researchers have overcome this challenge by creating experimental paradigms that allow the study of some aspects of dance performance. For example, Brown *et al.* designed an apparatus allowing amateur tango dancers to perform tango steps (involving leg movements only) while in a positron emission tomography (PET) scanner.[22] Results showed that the cerebellum was activated in the entrainment of dance steps to music, the putamen was involved in metric motion, and the superior parietal lobule was implicated in spatial guidance of leg movements. Although the Brown *et al.* study[22] demonstrated that PET can be used to study some aspects of dance performance, these results may not be generalizable to more complex motor tasks or to real dancing, which involves the whole body in a variety of positions.

In order to measure whole-body dance movement, Tachibana *et al.* used functional near-infrared spectroscopy (fNIRS) to study brain activity in nondancers while they performed a dance video game.[23] Just as fMRI does, fNIRS measures brain activity in terms of oxyhemoglobin dynamics but has a higher temporal resolution and less motion sensitivity.[24] Task-related brain activation was found in the superior temporal gyrus and superior parietal lobule and increased as a function of task difficulty. In a subsequent fNIRS study using the same video game paradigm, Ono *et al.* showed that frontotemporal oxyhemoglobin dynamics predicts performance accuracy of dance simulation gameplay.[25]

In addition to PET and fNIRS, EEG has also been used to study dance performance. Cruz-Garza *et al.* used EEG to study brain activity in dancers who performed movements in three conditions: (1) nonexpressive movements while thinking nonexpressive thoughts; (2) nonexpressive movements while thinking of an expressive quality; and (3) expressive movements.[26] EEG was used as an input to a machine learning algorithm that classified movements based on the thought or performed expression. Activation was found in premotor, motor, and parietal regions, and the classification was not limited by motion artifacts. This study demonstrates the feasibility of using EEG to investigate the expressive nature of movement in dance.

In sum, the above studies suggest that it is possible to use certain neuroimaging techniques, such as PET, fNIRS, and EEG, to study the functional neural correlates of actual dance performance. Findings from these studies point to a network of brain regions implicated in various aspects of dance performance, in particular the superior temporal gyrus, superior parietal lobule, frontopolar cortex, and middle temporal gyrus.

Future brain imaging studies on dance performance should continue to find methodological solutions to enhance the ability to measure more ecologically valid dance performance. One possible avenue for this would be the combination of motion capture technology and fNIRS or EEG during the execution of a dance video game or dance performance. Moreover, the work described thus far has focused on brain functional measures, but study of both brain function and structure is required in order to have a more complete understanding of the neural correlates of dance.

Brain structural correlates of dance training

Few studies have examined the structural neural correlates of dance. Hänggi *et al.* were the first to use structural MRI to measure gray and white matter structural differences in professional ballet dancers versus nondancer controls.[27] Dancers showed reduced gray and white matter volumes compared to nondancers in several regions, including the premotor cortex, supplementary motor area, putamen, internal capsule, and corpus callosum. Although this study provided the first evidence of brain structural differences between dancers and nondancers, an absence of any behavioral measure precluded the investigation of any brain–behavioral correlations.

A subsequent study by Nigmatullina *et al.* used MRI to study the structural brain correlates in dancers versus rowers (who had no dance experience) in relation to a task of vestibular function (in which participants turned a wheel to match the rotation they were experiencing as their chair turned).[28] Structural brain differences were found between groups, particularly in the posterior cerebellum, and were correlated with performance on the vestibular task as well as the amount of dance training in dancers. However, although this work correlated brain structure with behavior, the vestibular task used does not measure whole-body dance performance.

In order to investigate the brain structural correlates of dance in relation to actual dance performance, our laboratory recently used MRI to perform detailed gray- and white-matter analysis in expert dancers versus nondancer controls.[29,30] In addition, participants were tested on their ability to imitate whole-body movements with a dance video game. Preliminary results from cortical thickness analyses showed that dancers have thicker gray matter than controls in the superior and middle temporal gyri and precentral gyrus.[29] Preliminary results from diffusion tensor imaging (DTI) analyses showed that dancers have greater white-matter diffusivity in the corpus callosum, corticospinal tract, and superior longitudinal fasciculus.[30] Most importantly, dance video game performance was correlated with gray-matter thickness in the superior temporal gyrus as well as white-matter diffusivity in the corpus callosum, signaling the importance of these regions in dance performance.

Overall, the above studies suggest that long-term dance training is associated with brain plasticity in both gray- and white-matter regions associated with motor and auditory functions. In the future, longitudinal studies in dancers as well as short-term training studies in nondancers will allow us to distinguish between brain changes associated with training and possible preexisting differences in brain structure that may have predisposed certain individuals to pursue training.

In the final section we present new questions for future directions as well as the main implications of research on dance and the brain.

Future directions in dance and brain research

Specificity of dance training

As reviewed above, dance involves both athletic and artistic training and thus is distinct from other athlete groups. To date only two studies have compared the brain characteristics of dancers and athletes,[28,31] and no study has yet examined dance relative to another art form, for example, music performance. Similar to dance, musical training entails intensive practice of sensorimotor skills, and the type and duration of training can be quantified. Musicians and nonmusicians differ in terms of brain structure, function, and behavioral performance,[32] but no studies have yet examined the specificity of music versus dance training on the brain or behavior. Such studies are key to understanding what brain correlates or behaviors might be the same or different across types of training. To this aim, our laboratory recently compared brain structure and behavioral performance on a battery of auditory-motor tasks in dancers versus musicians.[29,30] Preliminary results revealed behavioral differences between groups, where dancers performed best on dance-related tasks and musicians performed best on music-related tasks. In addition, we found structural brain differences, particularly in terms of white matter, between dancers and musicians in several regions, including the corpus callosum, corticospinal tract, and superior longitudinal fasciculus.[30] These results promise to shed light on the specificity of dance versus music training on both the brain and behavior.

Is there a sensitive period for dance?

A sensitive period can be defined as a time during development in which the brain is most influenced by a specific type of experience.[33] The existence of a sensitive period has been demonstrated for various skills, such as language,[34] athletics,[35] and music.[36] For example, adult musicians who began training before age 7 years show behavioral[37] and structural brain differences compared to musicians who began training later and that could not be explained by differences in years of training.[38] Similar to music, formal dance training is a structured and intensive auditory-motor activity typically begun in young childhood. From this perspective, it is likely that a sensitive period would also exist for learning to dance, just as it does for music or language learning. However, no study has yet examined this important question. Our laboratory is currently investigating whether such a sensitive period may exist in dance learning in a large sample of dancers.

Dance-based interventions

Dance training and dance-movement therapy[39] have been found to correlate with positive behavioral effects in a variety of populations, including individuals with Parkinson's disease,[40–45] autism,[46] and various psychiatric conditions.[47,48] For example, Duncan and Earhart found improvements in symptom severity in individuals with Parkinson's disease following a tango dance intervention program that was not observed in a control group (who did not receive any intervention).[42] However, few studies have examined the brain functional correlates of dance interventions,[49,50] and no studies have investigated the brain structural correlates of dance-based therapies. Future studies on the brain and behavioral correlates of dance interventions are required in order to further understand and validate the true promise of dance therapy.

Conclusion

The main goal of this paper was to provide a focused review of research conducted to date in the field of dance and the brain. To this aim, studies were presented on the topics of action observation in dance, the functional neural correlates of dance performance, and structural brain plasticity associated with dance training. We suggest several future directions, including investigation of the specificity of dance training on brain structure and function, testing the existence of a sensitive period in the context of dance, as well as obtaining neuroimaging support for dance-based interventions. Dance and brain research holds great promise to provide a better understanding of expert and nonexpert auditory and motor brain–behavioral development and brain plasticity and can inform the development of dance-based therapy programs. Studying the neuroscience of dance will support a growing multidisciplinary field providing insight into the interactions between arts and the brain.

Conflicts of interest

The authors declare no conflicts of interest.

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