Dance and the Brain

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Summary

The ubiquity of dance across cultures, ages, and history make it an "embedded" art form. Most of us already have significant dance experience by adulthood. This commonality of dance, therefore, shifted our research away from normative studies that attempt to show that dance is good for a person or their brain, that it makes one smarter, is worth learning, or that some types of dance make one smarter than others.

Instead, our studies concerned the mechanisms that allow us to learn to dance, and the concurrent learning-related changes in the brain. Prior behavioral research on observational learning suggests that physical and observational learning share many common features. Neuroimaging research on action observation has identified brain regions, including premotor, inferior parietal, and temporal regions, that are similarly active when performing actions and when watching others perform the same actions. The present study investigated the sensitivity of this "action observation network" (AON) to learning that is based on observation, compared to physical rehearsal.

Participants were trained for five consecutive days on dance sequences that were set to music videos in a popular video game context. They spent half of daily training physically rehearsing one set of sequences, and the other half passively watching a different set of sequences. Participants were scanned with fMRI (functional magnetic resonance imaging) prior to, and immediately following, the week of training.

Results indicate that premotor and parietal components of the AON responded more to trained, relative to untrained, dance sequences. These results suggest that activity in these brain regions represents the neural resonance between observed and embodied actions. Viewing dance sequences that were only watched (and not danced) also was associated with significant activity in the brain's premotor areas, inferior parietal lobule, and basal ganglia.

These imaging data, combined with behavioral data on a post-scanning dance test, demonstrate the emergence of action resonance processes in the human brain that are based on purely observational learning, and identify commonalities in the neural substrates for physical and observational learning.

A critical outcome of our research is that learning by observing leads to action resonance and prediction that is the same as occurs with physical learning. This strong link between learning by doing and learning by observing at the neural level might benefit from early exposure to dance, where the consistencies between training methods could be acquired.

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Introduction

Many avenues exist for learning dance. For example, learning how to flamenco dance could be achieved in several different ways. One could learn the steps by following a verbal description of where, when, and how to move through space, by following step patterns traced on the floor, by trial and error, or by observing a dancer who knows the movements and performing the movements alongside this individual.

Behavioral research on action learning conducted during the past half-century suggests that the final option, learning from observing and simultaneously reproducing another individual's movements, results in the quickest and most accurate learning (e.g., (Sheffield, 1961; Schmidt, 1975; Bandura, 1977, 1986; Blandin et al., 1999; Blandin and Proteau, 2000; Badets et al., 2006).

This past research has demonstrated that not only is observation of a model helpful for learning (Blandin et al., 1999), but also that physical practice is more beneficial than mere observation of new movements (Badets et al., 2006). The current research was directed at exploring the separate and combined contributions that observing and practicing have on acquiring a novel movement sequence. Additionally, using functional neuroimaging, we characterized the neural underpinnings of observational learning, with or without the added benefit of physical practice.

Early behavioral investigations by Sheffield (1961) led to the proposal that observation of a model improved motor learning by means of providing a "perceptual blueprint," or a standard of reference for how the task to be learned should be performed. Carroll and Bandura elaborated upon these ideas by proposing that this "perceptual blueprint" improves learning by providing a means for detecting and correcting performance errors as well (Carroll and Bandura, 1987, 1990). Behavioral studies that compare observational and physical learning support this idea (Zelaznik and Spring, 1976; Doody et al., 1985; Carroll and Bandura, 1990; Lee et al., 1990; Blandin and Proteau, 2000) (for a review, see Hodges, 2007).

In one such study, Blandin and Proteau (2000) asked participants to perform a task that involved executing a speeded out-and-back movement pattern with the right arm while avoiding obstacles. Participants either physically rehearsed without observing a model perform the action, observed a novice performing the task before attempting to perform the task themselves, or observed an expert performing the task before attempting the task themselves. Observation of either type of model enabled participants to develop error detection and correction skills as effectively as physical practice.

Other work by Blandin and colleagues (1999) establishes that the quality of the model matters. Beneficial learning comes from observation of an expert model and not a novice model during the acquisition of a novel motor task (Blandin, Lhuisset, & Proteau, 1999). Recent data from psychophysics and EMG (electromyography) data lend additional evidence in support of observational learning, as reported in a study by Mattar and Gribble (2005). They demonstrated that participants' learning performance of a novel, complex motor task was facilitated after they observed another individual learning to perform that same task, compared to watching another individual perform the task without learning, or learning to perform a different task (Mattar and Gribble, 2005).

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What follows from these and other studies (Barzouka et al., 2007; Bouquet et al., 2007) is the idea that observational and physical learning have similar outcomes on behavior, as evidenced by the outcome of training. However, as Blandin and colleagues note (1999), "this does not mean that all cognitive processes involved during physical practice are also taking place during observation or that observation does not engage participants in some unique processes not taking place during physical practice" (p. 977).

The work presented above provides a behavioral foundation for exploring areas of overlap and divergence between observational and physical learning. However, it is difficult to determine with only behavioral procedures the degree of correspondence of cognitive processes subserving these two types of learning. Behavioral and EMG (electromyography) studies (study of electrical activity of both muscle and nerve) alone cannot satisfactorily address the underlying neural mechanisms, whereas the addition of functional neuroimaging enables us to determine whether observational and physical learning modify the same, or different, neural substrates.

Research Design

In the current research, we investigated this hypothesized overlap of cognitive mechanisms for observational and physical learning through concurrent use of behavioral and neuroimaging procedures. If we found that both types of learning engage the same areas of the brain, then we can infer that both observational and physical learning engage comparable cognitive processes. Conversely, the emergence of different areas of neural activity based on learning would imply that distinct cognitive processes underlie each of these two types of learning.

We investigated observational learning by training novice dancers to perform complex dance movement sequences while manipulating training elements. Specifically, we determined whether observational and physical learning resulted in quantitatively similar or different behavioral performance and patterns of neural activity, and examined how adding an expert model to the training procedure influenced behavior and neural activity. Due to the complexity and unfeasibility of having participants actually perform dance sequences in the scanner (but see Brown et al., 2006), we instead chose to train participants to perform the movement sequences with videos outside the scanner, and then asked them to observe the training videos during the scanning sessions, as shown in Figure 1.

A growing body of evidence indicates that action observation during imaging can be used as a surrogate marker for studying the neural systems

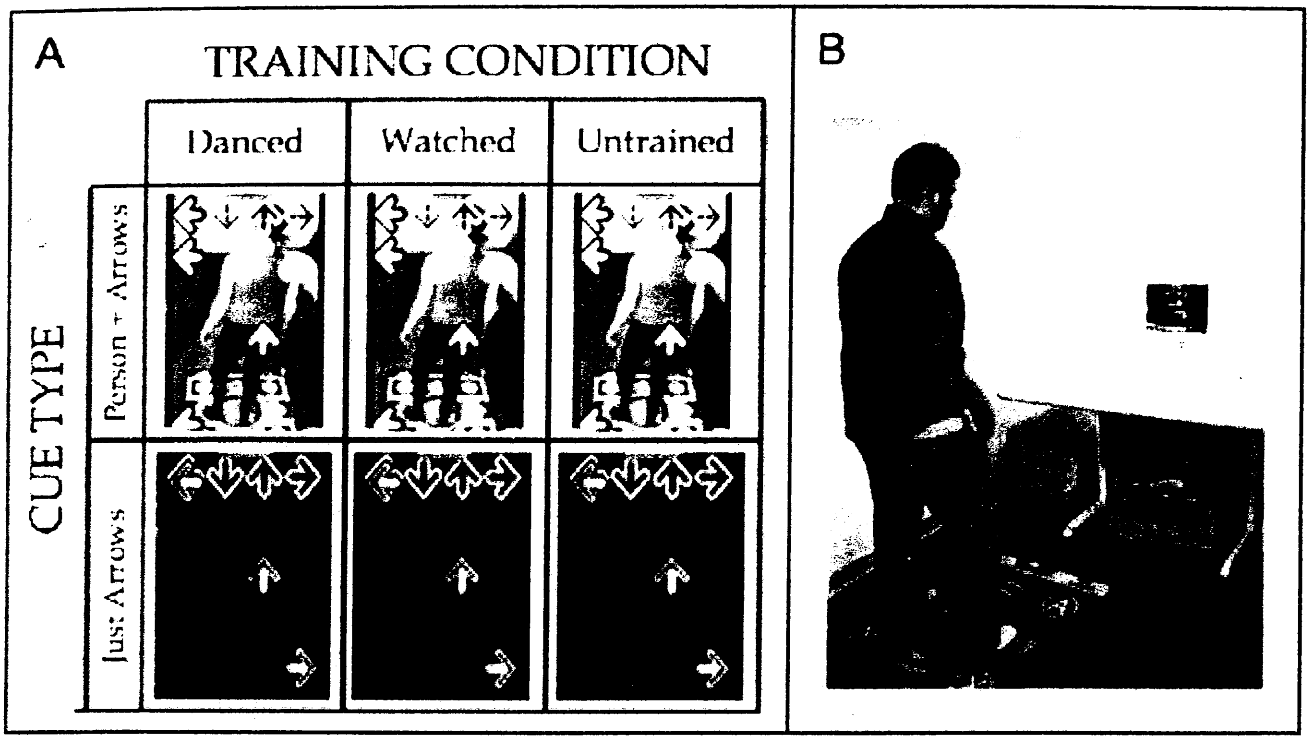

Figure 1. Part A: Schematic representation of the study design. The findings from this report focus on overlaps between the danced and watched training conditions, whether a small figure is present in the instruction or not. Part B: Training apparatus. On a dance pad connected to a computer, participants step on arrows arranged in the four cardinal directions (front, back, right, and left) in time with arrow cues on the screen. Each dance sequence is linked with a particular song.

involved in physical skill. Numerous studies have demonstrated that action observation models can be used to characterize the neural substrates for action understanding and action learning (e.g., Decety and Grezes, 1999; Brass et al., 2000; Buccino et al., 2001; Grezes and Decety, 2001; Rizzolatti and Craighero, 2004). These experiments identify a distinct set of brain regions that are active both when observing and when performing actions, referred to as the "mirror neuron system" or, more broadly, the "action observation network"(AON).

For the purposes of this research, we use the term "action observation network" over "mirror neuron system," since this latter term is more general and encompasses all of the brain regions involved in action observation processes, not simply the two main mirror neuron regions (inferior parietal and premotor cortices). The brain regions that are generally included in the AON include the supplementary motor area (SMA), the ventral premotor cortex (PMv), the inferior parietal lobule (IPL), and posterior superior temporal sulcus/middle temporal gyrus (pSTS/pMTG) (Stephan et al., 1995; Decety, 1996; Grafton et al., 1996; Rizzolatti et al., 1996; Binkofski et al., 2000).

In line with the present experiment, several past studies have demonstrated the feasibility of using dance learning and observation as a paradigm for investigating the properties of the AON (Calvo-Merino et al., 2005; Calvo-Merino et al., 2006; Cross et al., 2006). The first such study was conducted by Calvo-Merino and colleagues. They investigated the specificity of the AON to observing one's own movement repertory, compared to an unfamiliar and untrained movement repertory (Calvo-Merino et al., 2005). In this study, expert ballet dancers, capoeira dancers, and non-dancer control participants passively viewed ballet and capoeira dance clips while undergoing fMRI scanning.

The authors reported significantly greater activity within the AON, including bilateral PMv and IPL activity, right superior parietal lobe, and left STS, when dancers observed the movement style of which they were expert. From this, Calvo-Merino and colleagues concluded that the AON is able to integrate one's own movement repertoire with observed actions of others, thus facilitating action understanding.

A related study from our laboratory investigated the possibility of creating an action simulation de novo in a group of expert modern dancers and exploring how this new learning might be reflected within AON activity (Cross et al., 2006). For this study, we measured patterns of neural activity within 10 dancers as they learned a complex new modern dance work over a six-week period. While being scanned, the dancers observed short clips of the new dance work they were learning, and of non-rehearsed, kinematically similar control dance sequences. After each clip concluded, participants rated their ability to perform each movement sequence. The critical contribution of this study was that, as the dancers' expertise with the rehearsed dance sequences increased, activity within the brain's PMv and IPL tracked parametrically with their perceived expertise.

A second study by Calvo-Merino and colleagues (Calvo-Merino et al., 2006) examined the influence of visual, compared to motor, experience on AON activity during action observation. In order to parse visual familiarity from physical experience, expert men and women ballet dancers observed videos of movements learned only by their sex, only by the opposite sex, or moves that are performed by all dancers. The motivation behind this procedure was to determine whether equally robust action resonance processes may be elicited by observation of movements that are equally visually familiar, because men and women dancers train together, but unequal in terms of physical experience.

The authors reported that when effects of visual familiarity are controlled for (i.e., when dancers watched moves from their own movement repertoire, compared to moves that they frequently saw, but never physically performed), evidence for action resonance based on pure motor experience was found in inferior parietal, premotor, and cerebellar brain cortices. The authors conclude that actual physical experience is a necessary prerequisite for robust activation in these areas of the AON. This study provides an excellent point of departure for the present study, as we also are interested in measuring how purely observational experience is represented in the AON.

Taken together, these prior dance studies provide robust evidence for changes within the AON with the presence (or emergence) of execution competency. The current study built upon this foundation by addressing open questions about the sensitivity of this network to real and observational learning.

To that end, the objectives of this study were to determine how movement training influences activity within the AON, and how observational learning (such as when one simply watches the dance instructor without imitating the movements) is represented within the AON. By addressing these questions through the use of both behavioral and neuroimaging measures, we aim to better characterize the processes that underlie the various ways that people acquire new movements.

Results

Behavioral Training

Participants' performance on the rehearsed dance sequences improved across days, $F(2.15, 29.97) = 45.1$, $p < 0.0001$. In terms of behavioral performance for training with videos that included an expert human model, participants performed better when a model was present, $F(1, 15) = 10.16$, $p < 0.003$.

Behavioral Retest

Results from the post-scanning dance retest—where participants performed three songs they had trained on during the week, three that they had passively watched, three untrained songs, and three entirely novel songs—demonstrated a main effect of training experience, $F(3, 39) = 4.6$, $p = 0.008$. Pairwise comparisons revealed statistically significant differences between trained and untrained sequences ($p = 0.001$) and between trained and novel sequences ($p = 0.002$). Because performance was so similar between the untrained and novel sequences, our discussion for the post-scan dancing data focus only on differences between stimuli that were danced, watched, and untrained. Between these stimuli types, there was a linear trend of experience, with participants performing the best on sequences they danced, an intermediate level on those they passively observed, and the poorest on untrained sequences, $F(1, 13) = 29.85$, $p < 0.0001$.

Imaging Effects of Dance Training

The first set of imaging data analyses focused on locating brain regions within the action observation network that demonstrated a significant main effect of training during the post-training scan session. In order to assess the response of the AON to actions that have been rehearsed, whole-brain analyses were performed comparing the relative BOLD fMRI imaging responses while participants watched and listened to the set of videos that they had danced for five days ("danced"), and another set of videos for which they had received no training ("untrained").

A t-test revealed a main effect of training, regardless of cue type, in several areas of the action observation network, including bilateral ventral premotor cortex, left inferior parietal lobule, supplementary motor area/pre-SMA, and mid STS. These results indicate that premotor and parietal components of the AON responded more to trained, relative to untrained dance sequences, suggesting that activity in these regions represents the neural resonance between observed and embodied actions.

Imaging Effects of Observational Learning

A separate set of imaging analyses focused on locating brain regions within the action observation network that demonstrated dissociable responses with respect to training type (whether the sequences were physically rehearsed, passively observed, or untrained). Viewing dance sequences that were only watched (and not danced) also was associated with significant activity in premotor areas, inferior parietal lobule, and basal ganglia, as shown in Figure 2.

Concluding Comments

Overall, our results indicate that at the neural level, learning by observing and physical learning lead to the same action resonance and prediction. This strong link between learning by doing and by observing suggests that early exposure to dance might enhance this link, through consistencies between the training methods.

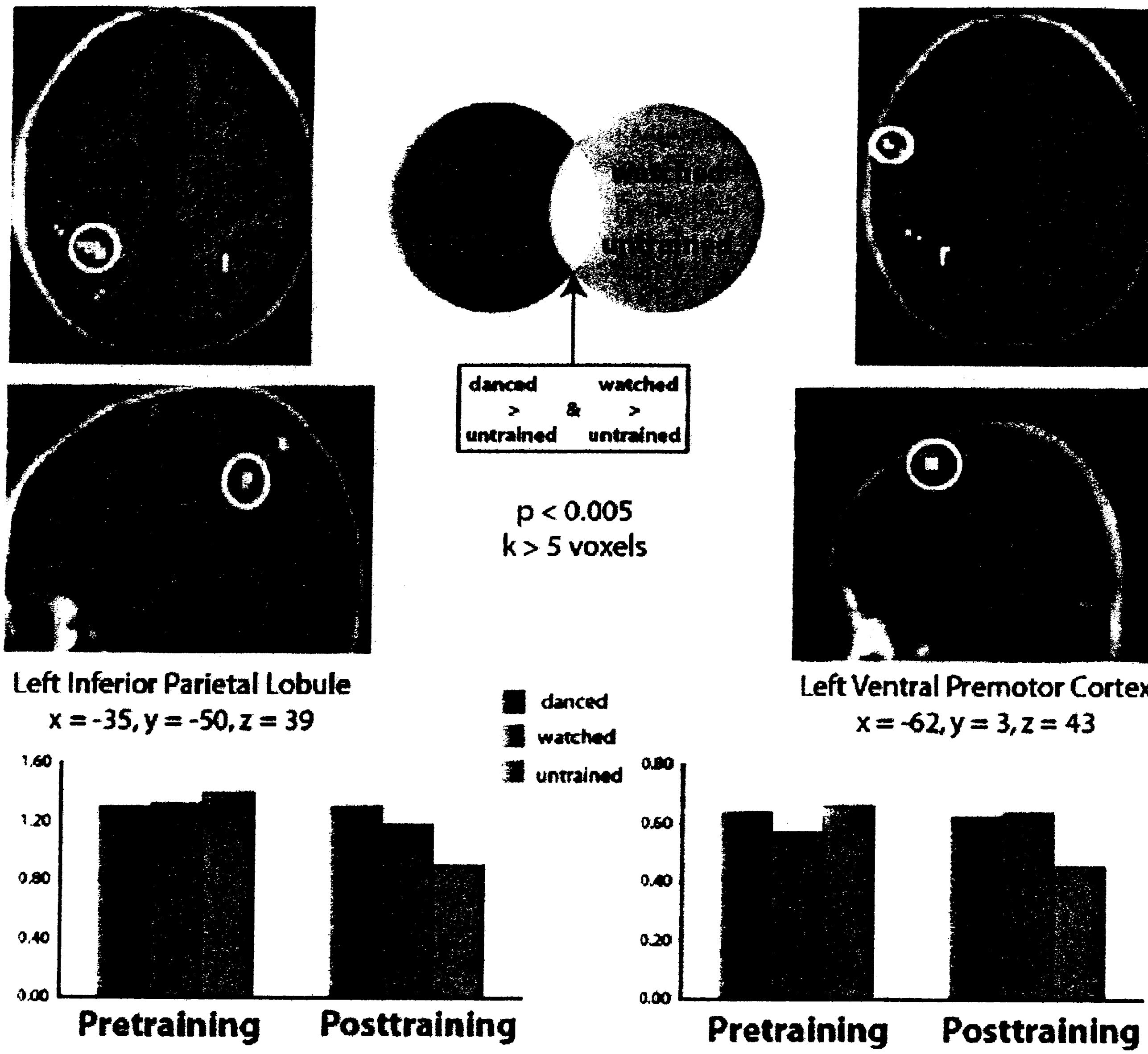

Figure 2. Overlapping areas that are engaged for action understanding after training by doing (danced) or training by watching.

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