Brain and Cognition 77 (2011) 231–236

Contents lists available at SciVerse ScienceDirect

Brain and Cognition

journal homepage: www.elsevier.com/locate/b&c

Captured by motion: Dance, action understanding, and social cognition

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ARTICLE INFO

Article history:
Accepted 1 August 2011
Available online 30 August 2011

Keywords:
Dance
Action
Perception
Body
Movement

ABSTRACT

In this review article, we summarize the main findings from empirical studies that used dance-related forms of rhythmical full body movement as a research tool for investigating action understanding and social cognition. This work has proven to be informative about behavioral and brain mechanisms that mediate links between perceptual and motor processes invoked during the observation and execution of spatially–temporally coordinated action and interpersonal interaction. The review focuses specifically on processes related to (a) motor experience and expertise, (b) learning and memory, (c) action, intention, and emotion understanding, and (d) audio-visual synchrony and timing. Consideration is given to the relationship between research on dance and more general embodied cognition accounts of action understanding and social cognition. Finally, open questions and issues concerning experimental design are discussed with a view to stimulating future research on social-cognitive aspects of dance.

1. Introduction

The rhythmical patterning of body movements in dance is a common practice that arises under diverse social circumstances across human cultures worldwide. Indeed, dance is a prime means of human expression that may have originated in rudimentary form as early as 1.8 million years ago, when the bipedal anatomy of Homo ergaster enabled full body movements that enhanced the capacity for gestural communication and body language (Mithen, 2005). Dance therefore has the potential to be not only beautiful in the esthetic sense, but also bountiful in what it reveals about cognition, action, and human interaction. Despite this potential, dance has only recently begun to be featured in research investigating the behavioral and brain bases of human social communication (but see Goodchilds, Roby, & Ise, 1969; Gruen, 1955; Maas & Johansson, 1971a, 1971b).

In this article, we review empirical studies that used dance as a research tool for action understanding and social cognition, and discuss their findings and implications for these fields. More specifically, this review covers studies that employed various forms of dance and rhythmical full body movements in order to investigate perception–action links. Our focus is on perceptual, cognitive, and motor processes manifested while observing and performing dance rather than on aspects of motor control related to biomechanics or rehabilitation (see Rosenbaum, 2010, for a general overview of this field). Our review thus complements previous reviews of cognitive and neuroscientific approaches to dance (Bläsing, Puttke, & Schack, 2010; Brown & Parsons, 2008), the neuroaesthetics of dance (Cross & Ticini, 2011), and psychological approaches to contemporary dance and choreography (Stevens & McKechnie, 2005). Despite the recentness of these publications, the field is growing rapidly and numerous studies have appeared that are not included in previous reviews. This increasing number of empirical studies, which signals augmented interest in the use of dance as a means of exploring the perceptual, motor, and social capacities of the human body, highlights the need for a compendium of published research to provide a platform on which further developments can be grounded.

The following review of studies of dance perception and performance includes sections on (a) motor experience/expertise, (b) learning and memory, (c) action, intention, and emotion understanding, and (d) audio-visual synchrony and timing. Finally, in the concluding remarks, we examine the reported findings in relation to embodied cognition accounts of action understanding and social cognition, as well as issues concerning experimental design.

2. Dance as a research tool for perception and action: literature review

Research in past decades has identified tight relationships between motor and perceptual processes that support close links between action execution and action observation. Much of this work has been guided by the 'common-coding' principle, which holds that perception and action are represented in a common format and thus share resources in functional brain architecture (Hommel, Müsseler, Aschersleben, & Prinz, 2001; Prinz, 1990). Perception–action links have been explored at the level of both behavior and

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doi:10.1016/j.bandc.2011.08.005

the brain by applying a wide variety of methodological techniques, ranging from psychophysical experiments and motion capture recordings to brain imaging and single cell recording. The latter neuroscientific techniques have revealed that similar brain areas are activated when perceiving an action – via visual, auditory, or multiple channels – and when executing the same action. These areas, which include the premotor cortex, the supplementary motor area, the primary somatosensory cortex, and the inferior parietal cortex, have collectively been dubbed the 'mirror system' (Rizzolatti & Craighero, 2004). More recently, additional networks related to social cognition and/or top-down processing (i.e., inferential and theory-of-mind processes) have been identified (Grafton, 2009). A heuristic framework incorporating the common coding principle, the mirror system, and social-cognitive networks will be of assistance in describing and discussing the various experimental approaches that have been employed to investigate the processes and neural substrates involved in cognitive, emotional, and social aspects of dance.

2.1. Motor experience and expertise

Dance often requires highly refined motor skills and competency, as well as augmented knowledge of how one's own body moves. As such, it lends itself well to the investigation of motor performance and expertise. Calvo-Merino, Glaser, Grèzes, Passingham, and Haggard (2005) capitalized on this by examining whether specific brain areas become active preferentially when people observe dance movements that they are experts in. To this end, functional Magnetic Resonance Imaging (fMRI) was used to compare activation patterns associated with changes in cerebral blood flow in ballet and capoeira[1] dancers as they watched video clips of either ballet or capoeira movements. The authors found increased activation of areas associated with the mirror system—including the premotor and parietal cortices, and the superior temporal sulcus—when individuals in each group observed dance movements with which they had motor expertise. It was concluded that a person's action-observation system is tuned to his or her individual motor repertoire.

A subsequent fMRI study (Calvo-Merino, Grezes, Glaser, Passingham, & Haggard, 2006) found further support for this conclusion in the comparison of brain activations of male and female ballet dancers who watched video clips of gender-specific movements performed by either male or female dancers. The results showed increased activity in premotor, parietal, and cerebellar cortices when men observed male-specific and women observed female-specific movements. Dance expertise has also been found to be associated with stronger ventral premotor cortex activation when viewing familiar ballroom dance movements, whereas internal viewpoint observation (vs. external viewpoint) activated more the dorsal premotor cortex (Pilgramm et al., 2010). The increased activation of ventral premotor cortex in experts might therefore reflect their ability to match visuospatial information onto their own motor representations, while the dorsal premotor cortex activation may be related to watching actions from a person's own perspective.

In another study (Orgs, Dombrowski, Heil, & Jansen-Osmann, 2008), electrical signals reflecting neural activity were recorded from the scalp using electroencephalography (EEG) as professional dancers and non-dancers observed video displays of contemporary dance and everyday movements. Dance expertise was found to modulate event-related desynchronization in alpha and lower beta frequency bands in the EEG signal as a function of movement type. Specifically, the power of the signal in the 7.5–25 Hz range was reduced in dancers when they watched dance movements, suggesting that these rhythmic oscillations in brain activity may be related to observation-action matching functions carried out by the mirror system.

To investigate the influence of the creative demands of dance on brain functioning, Fink, Graif, and Neubauer (2009) conducted an EEG study in which expert and novice dancers were required to imagine that they were performing an improvised dance or a waltz. It was hypothesized that EEG alpha activity, which typically increases as a function of the creative demands of a task, should be relatively high when imagining a novel improvised dance in comparison to a more stereotyped waltz. The results supported this hypothesis, indicating that tasks that allow more free-associative thinking are accompanied by alpha activity that is more pronounced in frontal, frontotemporal, and centrotemporal brain regions compared to activity during tasks involving lower creative demands. Professional dancers also showed generally stronger alpha activity than novices.

Intensive dance training has effectively been employed as a model for investigating brain plasticity. One study has revealed decreased gray and white matter volume in brain areas associated with motor functions in professional ballet dancers relative to non-dancers (Haenggi, Koeneke, Bezzola, & Jäncke, 2010). These differences in brain structure complement findings that expertise in a particular domain is often associated with a reduction of neural activity in brain areas underpinning the control of the given skill (Haslinger et al., 2004).

At a behavioral level, it has been shown that expertise in ballet (in terms of professional experience and/or gender) is associated with higher perceptual sensitivity to subtle differences in movement kinematics when observing point-light displays of dancers (Calvo-Merino, Ehrenberg, Leung, & Haggard, 2010). Similarly, the role of motor experience is highlighted in self-recognition studies that show higher sensitivity for one's own than others' movements when observing brief episodes of dance performances in various musical styles (e.g., pop, jazz, folk) (Loula, Prasad, Harber, & Shiffrar, 2005; Sevdalis & Keller, 2009, 2010, 2011). Furthermore, studies of eye movements have revealed shorter fixation times and faster saccades in experts than novices when viewing a contemporary dance performance, suggesting that expertise may facilitate the anticipation of body movements (Stevens et al., 2010).

2.2. Learning and memory

Extensive training is necessary for achieving the high motor competency required to control the spatiotemporal unfolding of one's own body movements in relation to music and to other individuals during dance. Studies of the process of learning to dance has led to insights into how such skills are acquired, and the perceptual and motor mechanisms that underlie them. In a seminal study, Cross, Hamilton, and Grafton (2006) had expert dancers learn novel, complex modern dance sequences over a 5-week period. Brain activity was recorded using fMRI each week while the dancers observed the sequences performed by a model dancer. The results showed that brain activations in premotor and parietal areas were enhanced by the ability to perform the observed movements (i.e., if the observer had previously rehearsed the sequence, compared to sequences that had not been rehearsed), suggesting that experience dependent action simulation accompanied the perception of the dance movements.

In another study (Cross, Kraemer, et al., 2009b), novice dancers were trained on complex techno dance sequences over 5 days either with or without concurrent physical practice; i.e., some sequences were learnt via active rehearsal and others by passive observation. The comparison of brain activity when viewing the

[1] Capoeira is a Brazilian art form that combines dance and martial arts maneuvers.