



## Have I grooved to this before? Discriminating practised and observed actions in a novel context



Dilini K. Sumanapala<sup>a</sup>, Laurel A. Fish<sup>a</sup>, Alex L. Jones<sup>a,b</sup>, Emily S. Cross<sup>a,\*</sup>

<sup>a</sup> *Social Brain in Action Laboratory, School of Psychology, Bangor University, Bangor, Gwynedd, LL57 2AS Wales, United Kingdom*

<sup>b</sup> *Department of Psychology, Swansea University, Swansea, SA1 8EN Wales, United Kingdom*

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### ABSTRACT

Learning a new motor skill typically requires converting actions observed from a third-person perspective into fluid motor commands executed from a first-person perspective. In the present study, we test the hypothesis that during motor learning, the ability to discriminate between actions that have been observed and actions that have been executed is associated with learning aptitude, as assessed by a general measure of physical performance. Using a multi-day dance-training paradigm with a group of dance-naïve participants, we investigated whether actions that had been regularly observed could be discriminated from similar actions that had been physically practised over the course of three days, or a further set of similar actions that remained untrained. Training gains and performance scores at test were correlated with participants' ability to discriminate between observed and practised actions, suggesting that an individual's ability to differentiate between visual versus visuomotor action encoding is associated with general motor learning.

### 1. Introduction

When learning a new motor skill, observing a model can facilitate the acquisition of complex new movement patterns, such as those required for sport, dance, or playing a musical instrument. Although numerous studies directly attribute gains in motor performance to physical practice (Lee, Swinnen, & Serrien, 1994; Savion-Lemieux & Penhune, 2004; Walker, Brakefield, Morgan, Hobson, & Stickgold, 2002; Wulf & Schmidt, 1997), other studies indicate that some aspects of motor information can be learnt by observing a model before any physical attempts have been made (Blandin, Lhuisset, & Proteau, 1999; Carroll & Bandura, 1985, 1987; Hodges, Williams, Hayes, & Breslin, 2007; Horn, Williams, & Scott, 2002). However, few studies have addressed whether an increased ability to retain the visual profile of observed movements is associated with a similarly increased ability to perform these movements following physical or observational experience. For instance, individuals who retain detailed visuospatial information regarding observed movements (e.g., placement of limbs in time and space, the physical relationship between different limbs, the timing and rhythm of movements) may be better able to access this information during subsequent attempts to perform these actions, thus leading to superior performance abilities. Alternatively, the level of detail with which a visually experienced action is encoded in long term memory may be unrelated to motor learning and performance ability if an

individual is unable to adapt this information into corresponding motor commands. If the former scenario is supported by empirical evidence, measures addressing an individual's ability to retain movement information acquired through observation might provide a vital index of how well this individual could learn to perform complex new movements in new learning scenarios. In addition, if this relationship between action memory and performance aptitude is borne out, tests of action memory could be used to differentiate between individuals who learn actions best through observational experience, physical experience, or a combination of both in order to cater to individual learning needs.

Leading theoretical accounts of how we make sense of other people moving around us in a social world suggest that action understanding is achieved by a sensorimotor resonance process whereby observed actions are mapped onto corresponding components of an observer's existing motor repertoire (Gallese, 2003; Gallese, Keysers, & Rizzolatti, 2004; Rizzolatti, Fogassi, & Gallese, 2001). In general, this correspondence between perception and action has been linked to action understanding as well as action learning (Buccino et al., 2004; Catmur, Walsh, & Heyes, 2007). Meta-analyses of action observation studies using neuroimaging document common regions of premotor and parietal cortices that are active during action observation as well as action execution (Caspers, Zilles, Laird, & Eickhoff, 2010; Grèzes & Decety, 2001). These overlapping regions may contribute to the

\* Corresponding author.

E-mail address: [e.cross@bangor.ac.uk](mailto:e.cross@bangor.ac.uk) (E.S. Cross).

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formation of action memories by integrating kinematic and visuospatial information learnt through observation as well as execution.

Studies that report observational learning of novel movement patterns in the absence of concurrent physical practice demonstrate that sensory feedback is not essential for learning certain aspects of new movement profiles (Black & Wright, 2000; Kohl & Shea, 1992; Maslovat, Hodges, Krigolson, & Handy, 2010). In a task requiring participants to trace dynamic patterns using a computer mouse, observing another learner led to improvements in a subject's own movement trajectories, even without prior or concurrent physical practice (Hayes, Elliott, & Bennett, 2013). Specifically, using a between-subjects design, these authors demonstrated that the observation group improved between pre- and post-test when these participants were yoked to participants in a physical practice group, indicating that motor information regarding the intended tracing motions could be acquired through observation alone. The value of observational experience on subsequent motor performance has also been demonstrated using paradigms that require participants to perform immediately following observation as well. Mattar and Gribble (2005) found that participants who observed videos of individuals learning to manipulate a robotic arm were themselves able to immediately manipulate the arm better than control participants who had no prior observational experience. Additionally, performance accuracy was improved if the direction of force generated by the robotic arm (clockwise or counter-clockwise) in the execution condition matched the force-field seen during observation. In contrast, observing manipulations of the robotic arm in an opposite direction to the field encountered during execution led to poorer execution compared to receiving no observational experience, indicating that observational experience inconsistent with what is expected during physical performance can also *reduce* subsequent performance. Collectively, these studies suggest that observational experience can engage the motor system in a manner that can either facilitate or attenuate performance gains across a variety of physical tasks, depending on the contextual congruency between observation and execution.

Evidence for the neurophysiological substrates that could support physical performance gains stemming from observational experience come from studies demonstrating common regions of cortical activity engaged when participants view actions that have been previously observed or executed (Calvo-Merino, Grèzes, Glaser, Passingham, & Haggard, 2006; Cross, Kraemer, Hamilton, Kelley, & Grafton, 2009). In a study that investigated the effects of a week-long dance-training intervention on action performance and perception, Cross et al. (2009) found that activity in premotor and parietal regions while observing dance movements was linked to the prior training context of each movement. Specifically, both physically practised and passively observed movements evoked premotor and parietal cortices to a greater degree than untrained movements during action observation. Since engagement of premotor and parietal cortices is frequently associated with visuomotor learning (Binkofski et al., 1999; Jonides et al., 1993), Cross et al. (2009) suggest that engagement of these regions when viewing actions that had been passively observed reflects their involvement in learning, even when no concurrent motor practice was present. In contrast to the findings reported by Cross et al. (2009), Calvo-Merino et al. (2006) demonstrated that after years of formal training, classical ballet dancers showed much greater engagement of parietal and premotor regions when observing movements learnt through extensive physical practice compared to similar movements that had only been visually experienced. Although action understanding can be achieved by visual means, both studies demonstrate the possibility of selective and specific action encoding within sensorimotor brain regions as a function of an individual's prior experience. The overall novelty of actions featured in the paradigm by Cross et al. (2009) may have given rise to similar cortical engagement for physically practised and observed actions during an early stage of motor learning. In contrast, Calvo-Merino et al.'s (2006) paradigm addressed action perception following years of formal dance training, possibly tapping into greater

differentiation of visuomotor compared to visual experience at the neural level. Together, the work by Cross et al. (2009) and Calvo-Merino et al. (2006) raises important questions concerning the impact of differentiated sensorimotor experience on neurocognitive engagement during action observation.

Findings from a recent dance-training paradigm similar to that used by Cross et al. (2009) add weight to the notion that the manner in which actions are experienced shapes their subsequent perception. In this study, auditory experience alone (i.e., listening to the soundtrack that could be paired with a dance sequence) was associated with weak engagement of premotor and parietal brain regions following training, while additional layering of visual and physical experience led to marked increases in activation within the same cortical regions (Kirsch & Cross, 2015). The increased neural response for each additional sensory modality was interpreted as evidence for increasing action embodiment as a consequence of multi-modal action experience during learning. The fact that physical experience was associated with the strongest engagement of parietal and premotor brain regions may be unsurprising, given that physical experience is consistently linked to greater performance gains relative to observational experience alone (Black & Wright, 2000; Cross et al., 2009; Maslovat, Hodges, Krigolson, & Handy, 2010). These results may be due to the fact that direct, physical engagement of the motor system facilitates detailed learning of temporal and kinematic features of a task in a manner that is unmatched by observational experience (Ellenburger, Boutin, Blandin, Shea, & Panzer, 2012; Gruetzmacher, Panzer, Blandin, & Shea, 2011; although see Hayes, Roberts, Elliott, & Bennett, 2014, for compelling evidence of complex kinematic information being learned from observation in the absence of motor signals).

In support of this notion, other studies have demonstrated the aspects of performance that are least served through observational practice compared to physical practice. In a study involving a serial reaction time task, observational practice of key sequences led to poorer intermanual transfer, since an intermanual version of a sequence bears limited visual similarity to the observed model (Osman, Bird, & Heyes, 2005). In a separate study, Bird and Heyes (2005) found that observational practice of a tapped finger sequence was effector dependent, given that sequence production with untrained digits led to poorer performance. All together, these findings suggest that in order to benefit most from observational training, a model must demonstrate the task in a manner that is visually compatible with how the observer might reproduce the movement.

In order to accurately translate observed movements into motor commands, an observer must differentiate between his or her own physically executed movements and those executed by a model. One's ability to discriminate differences between observed and performed actions on the basis of differences in sensorimotor engagement could be intricately linked with overall performance ability - a relationship that, to our knowledge, has not yet been empirically examined. We hypothesised that dance-naïve participants who showed the best performance ability after a week of observational and physical practice with previously novel dance movements would also be better at discriminating between observed, practised, and untrained dance actions within a training-modality categorisation task. Such a pattern of findings would suggest that aptitude with learning to physically execute coordinated, whole-body movements is also associated with heightened abilities to encode and recall visuomotor experience specific to individual movements. The establishment of such a relationship could lead to the development of metrics that assess individual skill in sensorimotor differentiation, which could in turn be useful in classifying individual movement learning aptitudes.

## 2. Method

### 2.1. Participants

Thirty participants with no prior history of dance training or

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