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Generalization of action knowledge following observational learning

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Both observational and physical practices support the acquisition of motor skill knowledge in the form of spatiotemporal coordination patterns. The current experiment examined the extent that observation and physical practice can support the transfer of spatiotemporal knowledge and amplitude knowledge associated with motor skills. Evidence from a multijoint limb task revealed that knowledge about spatiotemporal patterns (relative phase) acquired by observers and models can be generalized exceptionally well within the trained arm (right) and across to the untrained arm (left). Transfer of relative phase occurred even when untrained combinations of joint amplitudes were required. This indicates that observation and physical practice both lead to the development of an effector-independent representation of the spatiotemporal knowledge in this task. Both observers and models showed some transfer of the relative amplitude knowledge, with observers demonstrating superior transfer for both a trained and untrained-arm transfer test, while the models were limited to positive transfer on an untrained-arm transfer test. The representation of movement amplitude knowledge is effector-independent in this task, but the use of that knowledge is constrained by the specific practice context and the linkage between the elbow and wrist.

1. Introduction

That we can learn many complicated behaviors by observing others is well known. Acquiring knowledge through observation has been examined with regard to many skills including, writing and reading (Braaksma, Rijlaarsdam, van den Bergh & van Hout-Wolters, 2004; Ezell & Justice, 2000), rule based categorization (Ashby, Maddox & Bohil, 2002), social situations (Bandura, 1986), and motor skill acquisition (Carroll & Bandura, 1982). An important feature associated with acquiring knowledge, whether through observation or physical training, is our ability to transfer the acquired knowledge to new tasks. Transferring knowledge following acquisition is a fundamental technique used to determine the abstractness or flexibility of the knowledge representation in many skill areas (Foreman, Stanton-Fraser, Wilson, Duffy & Parnell, 2005; Ischebeck, Zamarian, Schocke & Delazer, 2009; Jessup, 2009). If observation serves as a means of knowledge acquisition, then the extent to which observation can benefit knowledge transfer needs to be identified.

Observation can benefit physical performance of novel motor skills by accelerating the acquisition of knowledge that underlies the control of that motor skill. Specifically, observational learning has been shown to benefit the acquisition of motor strategies (Buchanan & Dean, 2010; Martens, Burwitz & Zuckerman, 1976), sequence knowledge (Bird & Heyes, 2005), relative timing knowledge (Black, Wright, Magnuson & Brueckner, 2005), and even mechanical knowledge about environmental objects (Mattar & Gribble, 2005). What is less clear about learning motor skills through observation is the extent to which it can benefit the transfer of acquired knowledge to novel situations? This study was designed to reveal if observational learning and physical practice of a motor skill will lead to similar capabilities regarding the acquisition and transfer of spatiotemporal knowledge and amplitude knowledge that define the motor skill.

In order to determine if the processes underlying observational learning support the transfer of acquired knowledge, it is important to first identify movement information that can be learned and transferred following physical practice. A variety of studies, utilizing rhythmic tasks, have shown that a practiced and learned relative phase pattern can be transferred following physical practice (Amazeen, 2002; Buchanan, 2004; Kelso & Zanone, 2002; Zanone & Kelso, 1997). For example, Kelso and Zanone (2002) trained participants to perform a 90° relative phase pattern using either forearm flexion–extension motions or knee flexion–extension motions. Both the arm-trained and knee-trained groups were able to transfer the relative phase to the untrained appendages, knees to arms and arms to knees. Using a single limb task, research has shown that training participants to produce a 90° relative phase between the elbow and wrist with the forearm (right or left) supine can lead to transfer of the 90° pattern within the limb by rotating the forearm prone and across to the untrained limb (left or right) (Buchanan, 2004). Transfer of relative phase knowledge by models occurs independently of the muscles, limbs and joints used

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during the training process. This implies an effector-independent representation of the newly learned relative phase pattern. Can a relative phase pattern, a form of spatiotemporal knowledge, be learned through observation and then transferred?

Recent research employing a single limb elbow–wrist coordination task (Buchanan, Ryu, Zihlman & Wright, 2008) and a bimanual task (Buchanan & Dean, 2010) has shown that observers can develop a representation of a 90° relative phase pattern without physical practice (Hodges, Chua & Franks, 2003; Hodges & Franks, 2001). The ability of observers to accurately produce and to perceptually distinguish spatiotemporal patterns (Maslovat, Hodges, Krigolson & Handy, 2010) without physical practice indicates that relative phase acts as an informational variable linking together the production and perception of actions (Bingham, Schmidt & Zaal, 1999; Kelso, 1994; Zaal, Bingham & Schmidt, 2000). The single limb elbow–wrist task required a wrist displacement of 48° and an elbow displacement of 80°. In a retention test, the observers produced equal joint amplitudes whereas models produced larger elbow compared to wrist amplitudes as required. This suggests two possibilities with regard to the observational learning system and amplitude knowledge. First, the observational system was not able to distinguish the different amplitudes, implying that joint amplitude scaling requires physical practice in order to properly distinguish and modulate joint torques (Scully & Newell, 1985). Second, observational learning can facilitate the pick-up of amplitude knowledge in that observers understand that different joint amplitudes are required for specific conditions. However, mechanical factors associated with the control of wrist and elbow motion, such as the regulation of interactive torque between joints (Dounskaia, Swinnen, Walter, Spaepen & Verschueren, 1998), may constrain the application of that knowledge when tested without extensive physical practice (Buchanan, Zihlman, Ryu & Wright, 2007).

Relative phase characterizes the spatiotemporal features of between joint coordination. As two joints move through a flexion–extension cycle, relative phase provides an estimate of the time difference between similar spatial positions of the joints, e.g., maximum flexion. This time difference, however, is independent of the actual joint amplitudes. In other words, a relative phase pattern of 90° can be produced with both joints moving through 20° or 40° of motion, or one joint moving through 40° and the other through 20° of motion. As just reviewed, observers are able to reproduce a relative phase pattern but not an amplitude difference, whereas models can acquire both aspects of coordination. This indicates that relative phase and joint amplitudes are represented independently. The current experiment will examine the acquisition and transfer of these independent knowledge types through observation. The issue of transfer following observation needs further investigation in light of several recent studies utilizing single limb tasks that have shown observers cannot transfer acquired knowledge.

Through physical practice individuals can learn to produce a straight line trajectory under a variety of mechanical and visuomotor perturbations that are applied to the arm when reaching from a central location to target locations (Criscimagna-Hemminger, Donchin, Gazzaniga & Shadmehr, 2003; Sainburg, 2002; Sainburg & Wang, 2002; Shadmehr & Mussaivaldi, 1994; Wang & Sainburg, 2004a,b). Observers after watching a model adapt their reach to force field perturbations applied to the hand produce a straighter hand path when first encountering the perturbation compared to a group of controls (Mattar & Gribble, 2005). Can observers transfer the acquired force field knowledge? Mattar and Gribble (2005) examined the transfer issue by exposing observers to a clockwise perturbation after viewing a model learn to adjust to a counterclockwise perturbation. Observers did not adapt the knowledge gained about the counterclockwise perturbation to the clockwise perturbation; instead, the observers employed the knowledge of the counterclockwise perturbation and performed worse than controls first exposed to a clockwise perturbation. This finding suggests an effector-dependent or task-dependent representation was developed by the observers in the force field task. In other words, the observers extracted information about the impact that a specific directional force in a mechanical environment had on reaching, and the knowledge extracted was not usable in a similar but novel context. Although the amplitude knowledge regarding the distance to move was the same across the different force field directions, the different force field direction would require different muscle timing patterns for the same target locations. This suggests that the task did not directly test the transfer of the temporal information gained by the observers, in turn, poor transfer performance was observed.

That observers are constrained to an effector-dependent representation of an action has also been demonstrated in serial reaction time tasks (Bird & Heyes, 2005; Osman, Bird & Heyes, 2005). Bird and Heyes (2005) found that observers could out perform a group of controls (no practice and no observation) on a trained sequence that required pressing six keys with the ring, middle, and index finger of each hand. Observers were not able to transfer the knowledge gained about the sequence from the fingers to the thumbs, even when considering the difference associated with a six digit versus two digit performance of the task (Bird & Heyes, 2005). Together, the studies by Mattar and Gribble (2005) and Bird and Heyes (2005) suggest that observers develop an action representation tied to the effectors used by the model or specific conditions the models train under. Such findings appear at odds with the assumption that observation leads to a symbolic representation independent of the components (muscles and limbs), that in turn, would result in an effector-independent representation supporting positive transfer (Bandura, 1986; Bandura & Jeffrey, 1973; Carroll & Bandura, 1987). This suggests that action understanding has a strong motor component and the lack of transfer after observation may be the rule and not the exception.

Why did the above studies not find transfer following observation? One reason may be that the transfer task did not tap into the knowledge representation developed by the observers. In the current experiment, the transfer tests are designed to specially tap into the temporal and amplitude knowledge representation developed by the models and observers. If the motor system can support transfer of a physically practiced relative phase pattern, will the observational system that can extract relative phase information also support transfer of relative phase? If action observation cannot support the production of required amplitudes, does this imply that no amplitude information is extracted during observation? To find answers for the above questions, a single limb elbow–wrist task was employed with all models training with the dominant right-arm. Observers watched models train on a 90° relative phase with a required joint amplitude ratio of wrist (48°) to elbow (80°) angular displacement equal to 0.6. After two training days, the models, observers and a group of controls performed a retention test and three transfer tests designed to reveal the effector-dependent or independent nature of the representation of relative phase and joint amplitudes that was formed through observation and physical practice. The retention test is the same pattern that the models trained with during practice. Previous work has shown that observers are able to reproduce the required phase but not the required amplitude ratio in this task, and the same results should emerge in the current task (Buchanan et al., 2008). Based on previous work, it is hypothesized that the models will transfer the acquired relative phase pattern and outperform the observers and controls on each transfer test. Moreover, observers are expected to outperform the controls on the retention test (Buchanan, et al., 2008; Mattar & Gribble, 2005; Osman, et al., 2005). How will the observers perform in the transfer tests? Based on the results from Mattar and Gribble (2005) and Bird and Heyes (2005), transfer of relative phase may not occur. However, if relative phase is an abstract informational variable, and if the transfer tests allow for the use of the actual spatiotemporal knowledge gained by the observers, then it is predicted that transfer will occur.