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RESEARCH ARTICLE

Observational practice benefits are limited to perceptual improvements in the acquisition of a novel coordination skill

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Abstract There is disagreement about the effectiveness of observational practice for the acquisition of novel coordination skills and the type of processes involved in observation of novel movements. In this study, we examined learning of a bimanual 90° phase offset through comparisons of three groups; physical practice, observational practice and no practice ($n = 12$/group). Groups were compared before and after practice on perception and production scans of the practised pattern. The observation group was yoked to the physical group such that observers watched repeated demonstrations of a learning model. Although there were no positive effects of observational practice for physical performance measures, the observation group did not differ from the physical practice group and was more accurate than controls on perceptual discrimination measures after practice. We concluded that observation of a novel bimanual movement can aid perception but that physical practice is necessary for immediate physical performance benefits. These results are discussed in terms of cognitive mediation models of motor skill learning.

Keywords Modeling · Bimanual coordination · Motor learning · Visual perception

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Introduction

Motor skill acquisition often involves the transfer of information between an instructor and learner in an attempt to accelerate the learning process. One of the most common and efficient methods of transfer involves the use of demonstrations (Bandura 1986; McCullagh and Weiss 2001). The process by which an observer adapts his or her movements as a result of watching a model is known as observational learning (see Maslovat et al. 2010; Horn and Williams 2004; Hodges et al. 2007; Vogt and Thomaschke 2007 for recent reviews). A meta-analysis of the observational learning literature has shown that this process is more effective than practice alone (Ashford et al. 2006). However, the process and the conditions by which observation of an action produces learning benefits are still unclear. In an attempt to isolate the effects of observation, researchers have made a distinction between observational learning and observational practice (Vogt and Thomaschke 2007). While observational learning typically involves the alternation between demonstrations and physical practice, during observational practice the observer only watches a model as they acquire a skill. Observational practice thus affords the opportunity to test how observation alone affects the acquisition of motor skills. In the current study, we aimed to determine what is acquired during observational practice of a novel bimanual coordination skill through perceptual and behavioral measures of performance.

Different reasons have been proposed for the positive effects of observation. Recently, researchers have suggested that the observer's motor system is covertly activated during observation, so termed 'early mediation' (Vogt 2002; Vogt and Thomaschke 2007). Accordingly, any improvements in performing the motor skill after watching are attributed to the priming of the motor system during the observation stage. Alternatively, improvements due to observation have more traditionally thought to be strategic in nature, involving motor system activation only once physical practice has begun, so termed 'late mediation'. Trying to separate these two explanations has provided a significant challenge to researchers.

There is considerable evidence showing that observers are able to deduce cognitive strategies for performing through watching a model. Observational practice has shown to be as effective as physical practice during error recognition of a serial key press task (Black and Wright 2000; Black et al. 2005) and in adapting a learned strategy during a tracking task (Shea et al. 2000). Further, it appears that the strategy used by the model is adopted by the observer, regardless of whether it is most beneficial for task performance. In one study, observers watched a model demonstrate either a conservative or risky strategy during a ball-flicking task (Martens et al. 1976). The observers imitated the strategy of the model they observed, even though the more risky approach yielded poorer performance. Similarly, more recent results from Al-Abood et al. (2001) showed that observers mimicked the underarm throwing strategy employed by a model in a dart-throwing task. This was in comparison to the overarm strategy used by control participants, even though the type of strategy had no bearing on overall target success. Therefore, although demonstrations may function to constrain the strategy employed by the observer, this is not always an effective method, particularly if the strategy adopted by the observer is not directly related to task success.

Despite the acquisition of more cognitive strategic knowledge as a result of watching a model, there is also evidence that observation activates the motor system and that this process is responsible for positive learning effects (i.e., early mediation). Mattar and Gribble (2005) showed benefits of observational practice when participants watched a model learn to move a robotic arm in a perturbed, dynamic environment (see also Brown et al. 2009). Benefits were seen in terms of time savings for observers in comparison to actors when they first received physical practice performing in the new environment. While the authors could not conclusively rule out that observers developed a cognitive strategy during observation, the observers improved even when they were required to perform a cognitively demanding task during observation. The authors argued therefore, that learning occurred via implicit activation of the motor system. Similar conclusions were reached by Heyes and Foster (2002), who found that the degree of positive transfer following observational practice of a key-board sequence task was effector-dependent. Because of the specificity of learning to the observed limb, learning was believed to be a result of motoric encoding of the observed action rather than a more general strategic benefit.

Convincing evidence supporting motor involvement during observation has been provided through study of an area of the brain shown to be active during observation for imitation, known as the mirror neuron system (MNS). Researchers have shown similar cortical activation patterns during both observation and physical production of a movement, which has been attributed to the automatic elicitation of a motor representation of the action during observation (for reviews see Fadiga and Craighero 2004; Rizzolatti and Craighero 2004; Iacoboni 2005). There has, however, been some debate as to the presence or extent of motoric activation during observation for skills that are not within a person's motor repertoire and hence what might be considered true motor skill acquisition. For example, Calvo-Merino et al. (2005, 2006) showed that brain activation in areas associated with the MNS were significantly reduced or did not occur during observation of skills which were not typically performed by the observer (such as female moves for male dancers, see also Tai et al. 2004).

To try and understand the processes engaged during observational practice, a number of researchers have examined the effectiveness of demonstrations in the acquisition of novel, two-joint coordination movements (Buchanan and Dean 2010; Hodges and Franks 2000, 2001, 2002; Buchanan et al. 2008). Benefits from using a coordination task are that participants are typically unable to perform the movements without considerable practice and due to their novelty, they do not have any prior knowledge of an effective strategy which can be used to perform these movements. The acquisition of these types of coordination patterns can be studied in relation to existing performance capabilities, as well as in terms of transfer to non-practiced movement patterns (Zanone and Kelso 1997; Kelso and Zanone 2002), thus permitting insight into how learning is achieved and generalized.

In the examination of bimanual coordination, two inherently stable (i.e., intrinsic) movement patterns have been identified. These stable patterns include a strong symmetrical in-phase pattern (i.e., 0° relative phasing of the hands), and a somewhat weaker anti-phase pattern (i.e., 180° relative phasing of the hands). Because of the stability of these two patterns and the instability of relative phase patterns intermediate to these two attractors, researchers interested in motor learning have often required participants to learn a pattern half-way between in-phase and anti-phase, that is 90° relative phasing of the hands (e.g., Zanone and Kelso 1992a, 1997; Lee et al. 1995; Swinnen et al. 1997; Kovacs et al. 2009a). There is evidence that development of a 90° bimanual coordination pattern also results in positive transfer to the symmetrical pattern of coordination (i.e., 270° relative phasing where the opposite hand leads; Zanone and Kelso 1992b, 1997; cf. Maslovat et al. 2005) as well as positive transfer to other effector systems (Amazeen 2002; Kelso and Zanone 2002; Buchanan 2004; Buchanan et al. 2007). It is unclear whether this transfer is mediated by explicit, strategic processes, although the absence of effector specificity may suggest so (e.g., Heyes and Foster 2002).

Researchers who have studied the effectiveness of demonstrations during the acquisition of a 90° pattern have not found the observational process to be an effective medium (see Hodges and Franks 2000, 2001, 2002). There are two potential reasons for these results. First, is a lack of salient strategic information conveyed in a "correct" demonstration, especially when provided sparingly in an observational learning context. This would hinder any more cognitive mediated benefits from observing. Second, the novelty of the skill is expected to hinder or prevent motor system activation during observation (see Milton et al. 2008 for a review of this evidence). To address these strategic limitations, Buchanan et al. (2008) required observers to watch a learning model acquire a novel, unimanual coordination movement whereby the wrist and elbow joints were moving at a 90° offset. During these single limb movements, the lead–lag relationship between the limb segments may be more perceptually distinct as compared to a bimanual movement, providing more strategic information to the observer. For example, Breslin et al. (2005, 2006, 2009) showed that observers were better able to fixate, detect and replicate within-limb coordination of the arm after watching a cricket bowling action, than between-arm coordination (see also Collier and Wright 1995; Buchanan et al. 2008 for similar discussions about the differences between these types of coordination tasks). Further, Buchanan et al. allowed the models to adopt one of two possible strategies to produce the 90° movement (wrist leading or wrist lagging). Because the observers adopted the strategy of the model they observed, the authors concluded that the wrist lead–lag strategy was beneficially recognized and employed by the observers.

This cognitively mediated benefit as a result of observing was further underscored by a subsequent study involving observational practice of a 90° bimanual pattern, whereby the models were either allowed to explore various strategies or were constrained to a single strategy (Buchanan and Dean 2010). Actors who were constrained to a single strategy improved faster and performed better on retention tests than actors who practiced without these constraints. However, observers who watched the actors perform without strategy constraints were more accurate than those who watched a single strategy actor. The authors concluded that watching the exploration of various strategies was an effective learning technique, although they were not able to conclude whether these benefits were a result of cognitive strategic (late mediation) or motoric (early mediation) processes.

Strategic explanations associated with benefits from observing a model were originally proposed by Bandura (1971). According to his cognitive mediation model, behavior is stored in representational form which then mediates an action response. During observation, this cognitive representation is continually updated through comparisons between the observed act and the observer's internal representation of the act. Observation of multiple strategies would be expected to offer more distinguishing information than observation of a single strategy, acting to improve the effectiveness of this internal representation through distinctiveness and elaboration. However, observation of a single strategy would still provide information to the observer pertaining to what to do, as well as what not to do. This is especially true for observation of a learning model that would, presumably, show variability in demonstrations at least early in the acquisition period.

Evidence in support of the development of some sort of perceptual-cognitive representation preceding motor learning was shown by Carroll and Bandura (1982, 1990). Observers were able to distinguish between correct and incorrect versions of a desired motor skill before they were able to correctly perform the skill. This suggests that strategic or perceptual advantages were one of the immediate benefits of watching and that this cognitive-perceptual process mediated later performance of the motor skill. This ability to discriminate between correct and incorrect movement patterns as a result of observation was also shown in a bimanual coordination task by Hodges et al. (2003). However, this perceptual discrimination ability was only realized by participants who received both correct demonstrations and movement-based feedback about their own performance. As with the results of Buchanan et al. (2008) and Buchanan and Dean (2010), and in line with the cognitive mediation account of observational learning, it appears that the observer needs to see differences across performance attempts to improve and that the more varied these experiences are, the more effective is the perceptual-cognitive representation of the skill.

The development of visual discrimination in a bimanual coordination task is especially important because it has been implied that perception is coupled to, and essential for, accurate physical performance. In a series of studies, Bingham and colleagues (Bingham et al. 1999, 2001; Zaal et al. 2000; Wilson et al. 2005) provided evidence that visual perception of relative phasing between two stimuli followed a similar pattern to that observed for pattern production. Perception of in-phase movements were most accurate followed by anti-phase movements, with any other pattern judged unreliably (with poorest performance at 90°). The authors suggested that at least part of the problem with producing a novel relative phase pattern is the difficulty in correctly perceiving the movement. Therefore, it would be important to look at how observation affects both the perception and production of the movement pattern in order to make conclusions as to the processes encouraged by observational practice. Although we would not expect improvements on a motor task without corresponding perceptual improvements, we might expect perceptual improvements without corresponding changes in behavioral measures. Any perceptual discrimination improvements in the absence of behavioral improvements would support a late mediation or strategic account of observational practice, with physical practice necessary for behavioral benefits to be observed.

To test these ideas, we examined the changes in both physical performance and perceptual discrimination following physical and observational practice of a novel bimanual coordination skill. To ensure observers watched a novice model progress through the learning process observers were yoked to, and observed a participant in the physical practice group. We expected the physical practice group to improve at both physical performance and perceptual discrimination of the practiced task due to extensive physical (visuo-motor) practice and because of the close coupling seen between action capabilities and perceptual capabilities (Bingham et al. 1999, 2001; Zaal et al. 2000; Wilson et al. 2005). Although we expected variability in performance by the model over the course of practice, only one lead–lag strategy was conveyed by the visual metronome. Therefore, because observers watched a model that was not given the opportunity to explore different strategies, we did not expect the observational practice group to improve on the behavioral performance measures (Hodges and Franks 2000, 2001, 2002; cf., Buchanan and Dean 2010). However, based on Bandura's (1971) cognitive mediation model, we predicted that observers would improve on the perceptual discrimination measures. Repeated observation of a learning model should allow the observers the opportunity to determine correct and incorrect movement patterns in the absence of physical practice. This result would speak more to strategic or cognitively mediated processes of learning (late mediation), rather than more recent beliefs that observational practice activates the motor system during the observation process (early mediation) and that benefits are a result of this more direct route. We also examined physical and perceptual performance on the symmetry partner of the practiced task, whereby the opposite hand leads the pattern. Although physical practice can result in positive transfer to the symmetrical partner (Zanone and Kelso 1992b, 1997), it is unclear if observational practice would produce similar benefits. We did not expect the observational practice group to show transfer benefits in physical performance measures, although improvements in the perception of the symmetry partner might be expected if the benefits of observation are strategic in nature.

Methods

Participants and group assignment

A total of 36 university-aged [*M* 23.1 years, standard deviation (SD) 3.6 years] self-declared right handed participants (14 male, 22 female) were randomly assigned to one of three groups (12 per group): physical practice, observational practice, and control group. Participants performed either four sessions (physical and observation group) or two sessions (control group) on separate days spread over 1 week. All participants' first and last sessions were approximately half an hour and involved testing of physical performance and visual discrimination of various coordination patterns (including the to-be-learned pattern), providing a measure of performance before and following practice. In between these testing sessions, the physical and observation groups performed two acquisition sessions on consecutive days that were approximately 1 h in duration and consisted of repeated practice of a 90° phase offset bimanual coordination pattern. During acquisition, each participant in the observation group watched a participant in the physical practice group. In this way the observers were able to see repeated demonstrations of an actual participant learning the skill. All participants received remuneration ($35 CDN for physical and observation groups; $10 CDN for control group) and were naïve to the purpose of the experiment. The study was conducted in accordance with the ethical guidelines of the University of British Columbia.

Task and apparatus

The required coordination pattern was specified to the participant by two green vertical lines (10 in. in length) on a computer screen which moved in a 40° peak to peak movement range in the manner of an inverted pendulum (i.e., rotation around the bottom of the line). The task was to move two lightweight manipulanda, via horizontal elbow flexion and extension to follow the movements of these lines or pendula on the screen. Movement of the right line was to be mirrored by the right manipulandum while movement of the left line was to be mirrored by the left manipulandum. Presentation of different relative phase patterns of the pendula was controlled by altering the relative timing of the movements of the green lines.

A schematic of the apparatus and participant position is illustrated in Fig. 1. When physically performing

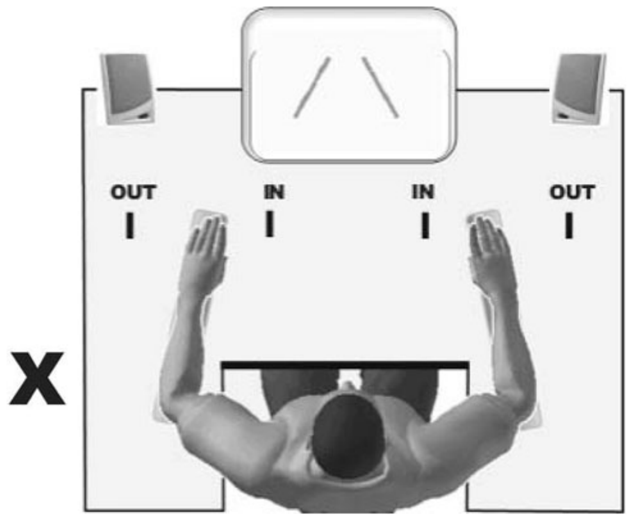

Fig. 1 Schematic display of apparatus set-up and design including location of monitor, speakers, and manipulanda (midpoint table markers not shown). The *X* indicates the location of the observer during acquisition trials

coordination patterns, participants were seated approximately 30 in. in front of a 17-in. color monitor (VGA 640 × 480 pixels, 60 Hz refresh). Attached to the table on each side of the monitor were the manipulanda. Participants' arms and hands were secured with Velcro straps to the manipulanda with the elbow joint aligned with the axis of rotation and the hands pronated. The required movement amplitude was 20° (resulting in a 40° peak to peak movement range), specified by "in" and "out" markers on the table for each arm, which translated to a 15 cm movement on the computer screen. Angular position was recorded using two optical encoders (Dynapar, E20-2500-130), one attached to the shaft of each manipulandum. Three-axis Quadrature Encoder interface cards (Advantech, PCL-833) enabled high-speed sampling of angular position at a rate of 1,000 Hz and a spatial resolution of 0.036°/bit. A computer motherboard was used to generate the audio metronome tones. The metronome signal was amplified by a speaker on each side of the monitor (Multi-Media, Model #EP-691). During observation trials, the observer was seated in a chair approximately 1 m in height so that they could view both the performer's hands and computer screen. The observer's hands were loosely strapped to their thighs to ensure no physical movement of the limbs occurred during observation trials. During all trials both observers and performers had full vision of their hands.

Testing protocols

Details of group procedures including number of trials and specific feedback are described below and displayed in Table 1. Participants in all three groups began with a single testing session on day 1 that involved a "scanning run" to measure performance on a variety of relative phase patterns (i.e., pre-test). These procedures were also adopted on day 4 after all practice trials had been completed (i.e., post-test). Participants performed 24 trials each lasting 20 s, consisting of 3 trials of 8 different relative phase patterns comprising the entire range of possible patterns, separated by 45° (i.e., 0°, 45°, 90°, 135°, 180°, 225°, 270°, and 315°). These trials were presented at a rate of 1 Hz in a pseudo-random order, such that a single pattern was never repeated three times in a row. Following each trial, participants were asked to determine which pattern they had just performed by a rating system that designated whether the limbs were moving in a symmetrical (i.e., in-phase, 0°) or alternating fashion (i.e., anti-phase, 180°), or if the right or left hand was leading the movement by one-quarter, one-half or three-quarters of a cycle (see Fig. 2 with the corresponding relative phases shown in brackets). Following the pre-test scanning run a single 20 s trial was presented whereby participants attempted to perform a 90° relative phase movement at 1 Hz. In this trial the pendula on the computer screen disappeared after 5 s and the participant was required to continue to perform the movement without any visual information (i.e., faded feedback). This trial allowed for assessment of performance without the guide of the pacing pendula. This trial was also completed post-practice on day 4, at the end of the post-test scanning run. No augmented feedback about performance was provided during the pre-test or post-test trials.

Following the pre-test scanning were two acquisition sessions on day 2 and 3. During practice, a physical practice participant was paired with an observational practice participant. Participants in the physical practice group performed 80 trials per day (16 blocks of 5 trials, 20 s per trial) of a 90° relative phase pattern with the right hand leading (with the yoked observational practice participant watching). To facilitate improvement in the physical practice participants, feedback and speed of movement were manipulated. For the first day of acquisition, participants performed four blocks of trials with pendula presented at 0.75 Hz, followed by a single block of trials with Lissajous feedback and a metronome of 0.75 Hz. The next four blocks involved pendula presented at 0.85 Hz, followed by another single block of Lissajous feedback at 0.85 Hz. The last six blocks were performed with pendula presented at 1 Hz (the speed of the pre- and post-test scanning runs). No metronome was used for the pendula trials as movement frequency was manipulated by the speed of the moving lines.

Lissajous feedback involved a real-time displacement–displacement plot of the two limbs, with movements of the right manipulandum producing horizontal movements of

Table 1 Summary of testing conditions including number of trials, display shown, feedback, and pattern performed

Condition	Trials	Display	Feedback	Pattern
Day 1 (all groups)				
Pre-test	24	1 Hz Pendula	None	Random presentation of three trials each of: 0°, 45°, 90°, 135°, 180°, 225°, 270°, 315°
Faded feedback	1	5 s of 1 Hz Pendula	None	90°
Day 2 (physical and observational groups only)				
Acquisition	20	0.75 Hz Pendula	Terminal RMSE	90°
	5	0.75 Hz Lissajous		
	20	0.85 Hz Pendula		
	5	0.85 Lissajous		
	30	1 Hz Pendula		
Day 3 (physical and observational groups only)				
Acquisition	20	0.85 Hz Pendula	Terminal RMSE	90°
	5	0.85 Hz Lissajous		
	55	1 Hz Pendula		
Day 4 (all groups)				
Post-test	24	1 Hz Pendula	None	Random presentation of three trials each of: 0°, 45°, 90°, 135°, 180°, 225°, 270°, 315°
Faded feedback	1	5 s of 1 Hz Pendula	None	90°

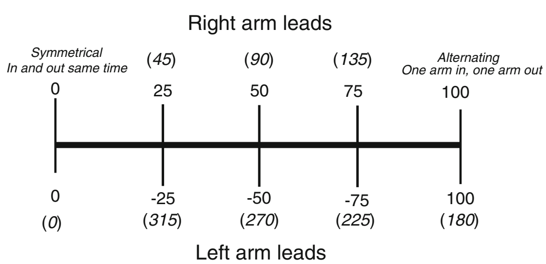

Fig. 2 Display for relative phase perceptual discrimination. Note relative phases shown in *brackets* for information only (not shown to participants)

the cursor on the screen and movements of the left manipulandum producing vertical movements of the cursor on the screen. Participants saw a circular Lissajous template projected on the computer screen and the actors' movement was superimposed over the template (60 Hz refresh rate), showing the current position of the actor and the previous 500 ms of movement. Actors were asked to complete an entire cycle of movement for each metronome pulse. This feedback method has repeatedly been shown to be effective in encouraging acquisition of this difficult coordination movement (e.g., Swinnen et al. 1997; Hodges and Franks 2001; Kovacs et al. 2009a; Maslovat et al. 2009). Therefore, we interspersed these trials with the pendula trials in order to ensure that the actors were correctly performing the coordination movement and that the observers were watching correct trials by the end of the 2 days of practice.

The second day of acquisition consisted of 4 blocks of pendula presented at 0.85 Hz, 1 block of Lissajous feedback at 0.85 Hz, followed by 11 blocks of pendula presented at 1 Hz. At the end of all acquisition trials, numerical terminal feedback was provided on the computer screen for 7 s showing the root mean squared error (RMSE) of relative phase for the entire trial (i.e., error information based both on mean and SD in relative phase). This information was available to both the physical and observational practice participant.

Data analysis

Physical performance measures

Continuous measures of relative phase were calculated at a rate of 1,000 Hz for all complete cycles of movement within the final 15 s of each trial. Relative phase of the left arm in relation to the right was calculated for each point after the speed and position of the limbs was re-scaled to the interval [−1, 1]. The phase angles were calculated using the methods described by Scholz and Kelso (1989), and then quantified using circular statistics (Mardia 1972) from which two measures of performance were determined. Absolute error (AE) of relative phase provided an index of accuracy and was determined by calculating the AE of each relative phase value and then taking a grand mean for each trial. Within-trial SD of mean relative phase was used as a measure of consistency.

To determine if improvement occurred for the physical practice group, we analyzed relative phase AE during acquisition for the blocks of trials with pendula presentation only. Although 32 total blocks were performed during acquisition, the 3 blocks involving Lissajous feedback were removed, resulting in a 29 block univariate, repeated measures analysis of variance (ANOVA). To compare physical performance on the to-be-learned (90°) pattern as a function of practice, we used each participant's three-trial mean from the pre- and post-scanning runs. We also analyzed each participant's three-trial mean AE and SD for the 270° pattern.[1] Relative phase AE and SD were independently analyzed via a three group (physical, observation, control) × two block (pre-test, post-test) ANOVA with repeated measures on the last factor. We analyzed the single trial of faded feedback in a similar manner.

Alpha level for the entire experiment was set at 0.05, with partial eta squared (η_p^2) values reported as measures of effect size. Significant results for the repeated measures ANOVAs were examined post hoc via Tukey's honestly significant difference (HSD) test to determine the locus of the differences. The Greenhouse–Geisser Epsilon factor was used to adjust the degrees of freedom for violations to sphericity (Greenhouse and Geisser 1959).

Perceptual performance measures

We separately analyzed the proportion of trials where participants either correctly identified the pattern (regardless of whether they determined which hand was leading), or the leading hand (regardless of whether they determined the correct pattern). As with the physical performance measures, we calculated each participants' mean based on the three 90° and 270° trials during pre-test and post-test sessions. Data from these trials were subjected to an arcsine square root transform before analysis to correct for violations to normality and analyzed in a three group (physical, observation, control) × two block (pre-test, post-test) ANOVA, with repeated measures on the last factor.

[1] Additional analyses were performed comparing all eight relative phase patterns across the pre- and post-test for AE and SD of relative phase. For AE a group × pattern × test (pre vs. post) effect was observed, $F(14,231) = 4.46$, $P < 0.001$, $\eta_p^2 = 0.21$. Post hoc analysis of this interaction showed that only the physical practice group improved on the 45° and 90° pattern from pre to post-test. No improvements across practice were noted for the observational practice and control groups for any patterns. For SD no groups showed decreased variability for any patterns as a function of practice, despite a significant three-way interaction, $F(14,231) = 2.31$, $P = 0.005$, $\eta_p^2 = 0.12$.

Results

Physical performance measures

The physical practice group improved at the 90° pattern during acquisition, as shown by a significant block effect for relative phase AE, $F(28,308) = 14.76$, $P < 0.001$, $\eta_p^2 = 0.57$. Relative phase error for the group decreased from a maximum of 73.0° during the first block to a minimum of 19.9° on the twentieth block.

Figure 3 illustrates the relative phase AE for the 90° pattern, for all three groups during the pre-test and post-test sessions. AE was generally higher overall for the control group (*M* 76.6°), but only in comparison to the physical practice group (*M* 50.6°), which was confirmed by a main effect for group, $F(2,33) = 7.10$, $P = 0.003$, $\eta_p^2 = 0.30$ and follow up post hoc tests. Although there was a general decrease between the pre-test (*M* 77.5°) and post-test (*M* 51.6°) as shown by a main effect for block, $F(1,33) = 33.54$, $P < 0.001$, $\eta_p^2 = 0.50$, importantly there was also a group × block interaction, $F(2,33) = 11.56$, $P < 0.001$, $\eta_p^2 = 0.41$. Post hoc analyses yielded no significant group differences in the pre-test, but a significant group effect in the post-test due to the physical practice group having less error than both the observational practice and control groups. Post hoc comparison across pre-test and post-tests confirmed only the physical practice group showed a significant decrease in error ($P < 0.001$). The only significant finding in the analysis of within-trial SD of relative phase was a block effect $F(1,33) = 5.39$, $P = 0.027$, $\eta_p^2 = 0.14$, which was due to a general decrease in variability from the pre-test (*M* 29.1°) to the post-test (*M* 24.1°).

The faded feedback trial comparisons yielded similar results to those above. For relative phase AE, a significant group effect, $F(2,33) = 5.03$, $P = 0.012$, $\eta_p^2 = 0.23$ was

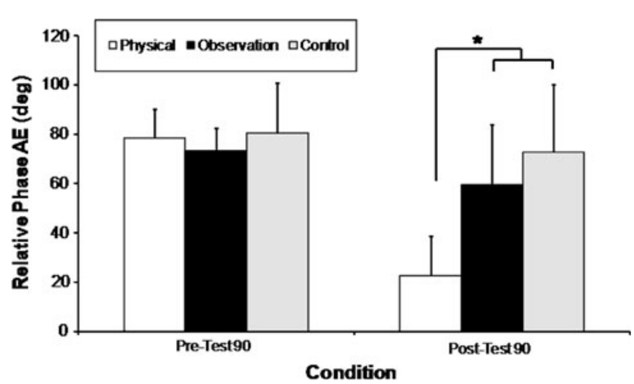

Fig. 3 Relative phase AE (SD) for pre- and post-test 90° trials, separated by group. An *asterisk* denotes a significant difference between the physical practice group and both the observational practice and control groups in the post-test

due to a significantly higher error for the observational practice group (*M* 77.6°) in comparison to the physical practice group (*M* 51.1°) only. A block effect was also found due to less error in the post-test (*M* 49.9°) compared to the pre-test (*M* 83.1°), $F(1,33) = 22.59$, $P < 0.001$, $\eta_p^2 = 0.41$. The group × block interaction was not significant, $F(2,33) = 3.07$, $P = 0.060$, $\eta_p^2 = 0.16$, although a similar trend as detailed above was shown, such that the physical practice group showed the greatest decrease in error between the pre-test (*M* 79.9°) and post-test (*M* 22.3°). No significant effects were found for relative phase SD. There was no evidence of positive transfer to the 270° pattern as seen by a lack of change in AE from pre-test (*M* 82.6°) to post-test (*M* 87.3°), $F < 1$. Further, none of the effects involving group were significant. Similarly, SD failed to show any effects related to consistency improvements on the 270° pattern.

To more specifically determine what had changed or been acquired as a function of practice, we looked at the pre- and post-test trials of the 90° pattern in terms of relative phase bins. The percentage of time spent within relative phase regions of 30° (i.e., −15° to 15°, 15°–45°, 45°–75°, 75°–105°, etc.) were calculated for each trial. Pre- and post-test means for each relative phase bin are shown in Fig. 4 in order to give a description of change for each group. The physical practice group showed a change from a pre-test bimodal distribution of intrinsic in-phase (0°) and anti-phase (180°), to a post-test unimodal distribution around the target pattern (90°). Although the observational practice group showed a change in distribution following practice such that in-phase movements were no longer performed, this did not result in greater time spent around the to-be-learned pattern. The control group continued to show a bimodal distribution around 0° and 180°, although the peak around 0° had shifted closer to the 180° pattern. To more generally examine if participants utilized any strategic knowledge regarding the correct lead–lag relationship, we also analyzed the pre- and post-test trials of the 90° pattern in terms of time spent with a right-hand lead (i.e., relative phase between 15° and 165°). Only the physical practice group showed a significant increase ($P > 0.001$) from pre-test (*M* 31.3%) to post-test (*M* 92.5%). Neither the observational practice group (pre-test, *M* 42.7%; post-test, *M* 60.2%) nor the control group (pre-test, *M* 32.5%; post-test, *M* 46.8%) showed a significant change across practice.

Perceptual performance measures

Figure 5 illustrates the proportion of patterns correctly recognized by the three groups for the 90° pattern during the pre-test and post-test sessions. Pattern discrimination accuracy improved from the pre-test (*M* 31%) to the post-test (*M* 69%) as evidenced by a main effect for block $F(2,33) = 33.26$, $P < 0.001$, $\eta_p^2 = 0.50$. Importantly, a main effect for group $F(2,33) = 5.14$, $P = 0.011$, $\eta_p^2 = 0.24$, and a group × block interaction $F(2,33) = 6.72$, $P = 0.004$, $\eta_p^2 = 0.29$ showed that pattern discrimination accuracy depended on the group assignment. The control group (*M* 35%) showed lower accuracy overall in comparison to the physical practice (*M* 56%) and observational practice (*M* 61%) groups. As evidenced by the two-way interaction, these differences were a result of

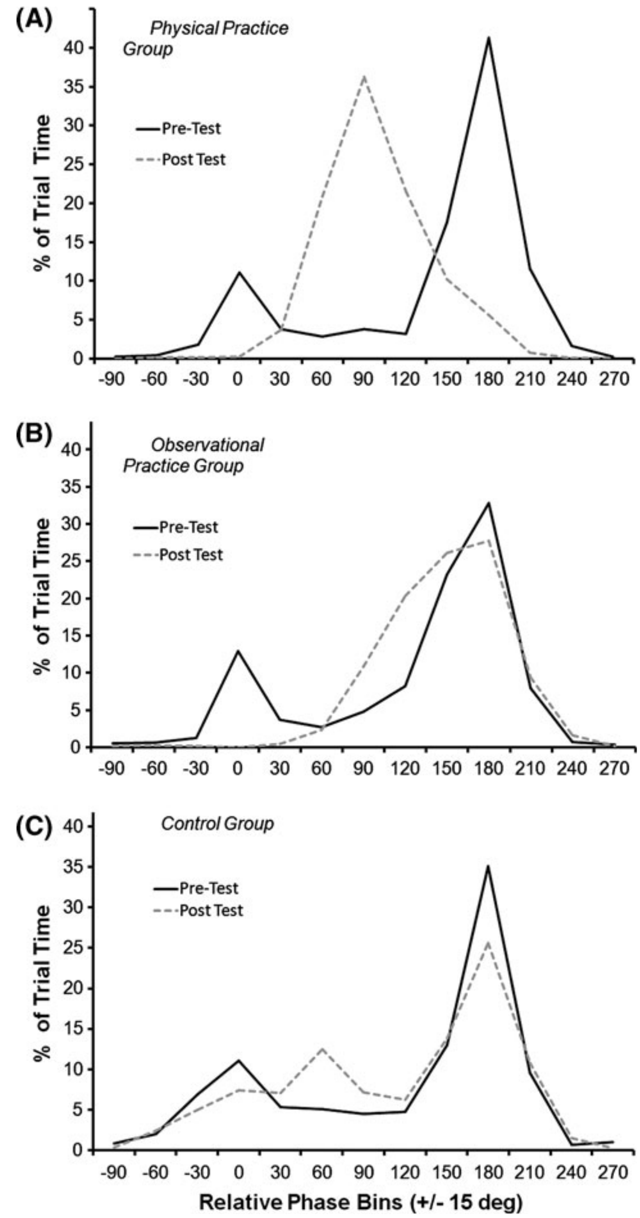

Fig. 4 Relative phase distribution for pre- and post-test 90° trials, separated by group. Note the shift in the physical practice group away from in-phase (0°) and anti-phase (180°) movement toward the to-be-learned pattern (90°). Also note the shift of the observational practice group away from in-phase (0°)

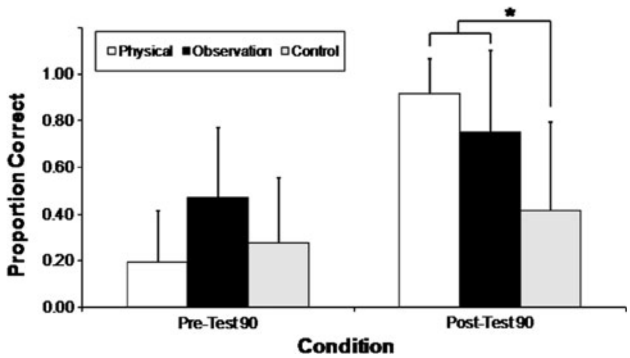

Fig. 5 Proportion of correct pattern discrimination (SD) for pre- and post-test 90° trials, separated by group. An *asterisk* denotes a significant difference between the control group and both the physical practice and observational practice groups in the post-test

significant group effects in the post-test only, with the physical and observational practice groups being more accurate than the control group but not significantly different from each other. However, only the physical practice group showed an increase in accuracy across the testing sessions ($P < 0.001$) in comparison to the observational practice ($P = 0.067$) and control groups ($P = 0.196$). In terms of participants' ability to discriminate the correct leading hand, there were no significant differences across the three groups. The only significant effect was a main effect for block, $F(2,33) = 4.20$, $P = 0.049$, $\eta_p^2 = 0.11$, which was due to a general improvement in accuracy across the pre-test (44%) and post-test (61%).

Participants also improved from pre-test (*M* 31%) to post-test (*M* 64%) at pattern recognition for the 270° pattern as evidenced by a main effect for block $F(1,33) = 23.72$, $P < 0.001$, $\eta_p^2 = 0.42$, but there were no significant effects involving group (physical practice pre-test *M* 25%, post-test *M* 78%; observational practice pre-test *M* 44%, post-test *M* 69%, control group pre-test *M* 25%, post-test *M* 44%). The only significant effect for hand determination for the 270° pattern was a group × block interaction $F(2,33) = 4.21$, $P = 0.023$, $\eta_p^2 = 0.20$. Although post hoc analyses yielded no significant group differences in the pre-test or post-test, comparisons across the pre- and post-tests showed that only the physical practice group improved in their ability to discriminate ($P = 0.010$).

Discussion

In order to test what is acquired through observational and physical practice and whether behavioral improvements are mediated by improvements in cognitive discrimination, we analyzed physical and perceptual measures of performance following practice of a novel bimanual coordination skill. By yoking an observational practice group with a physical practice group, participants were able to observe a learning model throughout acquisition. Despite significant opportunities to watch a paired participant improve at the 90° movement pattern, we did not find any physical performance benefits for the observational practice group as a result of this type of practice. While the physical practice group showed relatively large decreases in performance error, the observational practice group performed in a similar manner to the control group who did not watch or practice the movement pattern. Therefore, we did not find evidence supporting an early mediation account of observational practice, whereby performance benefits would be expected immediately as a result of motoric activation during the observation stage. This finding is in line with conclusions from research where participants have been trained on a similar skill in an observational learning protocol. In these studies, demonstrations interspersed with practice failed to improve performance relative to discovery learning conditions (Hodges and Franks 2000, 2001, 2002).

Despite the lack of physical performance benefits, the observers did show benefits in terms of cognitive-perceptual measures of performance and their ability to discriminate the learned pattern. At the end of acquisition the observational practice group was able to distinguish the practiced pattern as well as the physical practice group, and more accurately than the control group. This is consistent with Bandura's (1971) cognitive mediation model of observational learning, whereby repeated observations are believed to promote a better internal representation of the action, even in the absence of physical practice. Difficulties in perception of relative phase have been linked to difficulties in the production of relative phase. Specifically, it has been hypothesized that a lack of perceptual detection of deviations from the intended movement does not allow participants to correct their movements, and thus hampers their ability to acquire a new coordination pattern (Bingham et al. 1999, 2001; Zaal et al. 2000; Wilson et al. 2005). Thus, the ability of the observers to distinguish between different relative phase patterns may still represent a positive learning effect even though physical performance of the pattern did not improve. Improved perceptual discrimination without physical practice has recently been demonstrated by Calvo-Merino et al. (2010). Expert ballet dancers were compared to novices in the discrimination of point light displays of ballet movements. Expertise differences were found for movements that were common to both genders, as well as those that were only practiced by one gender. For the single gender movements, expertise differences were found for the gender that did not physically practice the skill but had extensive visual expertise.

This result suggests that visual experience alone is sufficient to show an improvement in perceptual discrimination.

When we take a closer look at the data from our study we can see that the perceptual benefits for the observational practice group were indeed reflected in the relative phase distribution data and hence suggestive of strategically mediated improvements. Observational practice resulted in a decrease in the amount of time around in-phase movements (0° relative phase), suggesting that participants were aware that this was not the desired movement (see Fig. 4). Elsewhere it has been shown that learning of this novel coordination movement proceeds by a break away from more stable, yet undesired movement behaviors or “attractors” (e.g., Zanone and Kelso 1992b; Lee et al. 1995). Despite the potential benefits of this strategic knowledge, it did not result in more time around the desired 90° relative phase pattern, perhaps as a result of knowing what was not required.

Although we never tested participants in a physical practice reacquisition session to determine whether there would be time savings in later acquisition of this observed movement, we have reason to suspect this would be the case. First, observers were better able to discern the desired movement pattern in the post-test as compared to control participants showing some benefits of observation had occurred, although limited to the perceptual-cognitive level. Second, others have shown time savings from watching a model during later physical practice (e.g., Mattar and Gribble 2005). Although these latter authors argue that learning was due to the extracting of information at the level of motor execution (i.e., how to make movements rather than what movements to make), it is possible at least some of the benefit was due to cognitive or strategic mechanisms.

Overall, our results provide little evidence for positive transfer to performance of the symmetrical partner (270°). In the examination of physical performance measures, no improvement was found for any group in terms of reduced error or variability. This result is contrary to findings by Zanone and Kelso (1992b, 1997) and is likely due to differences in the type of feedback available during practice and the absence of more descriptive or qualitative feedback regarding relative phase in our experiment (see also Maslovat et al. 2005). All three groups did, however, show an improvement in pattern discrimination for the 270° pattern, but the lack of group differences suggests that this improvement was not due to physical or observational practice as neither group outperformed the control group. While there was a group difference observed for recognition of which hand was leading, only the physical practice group significantly improved on this measure. Thus the observational practice group did not outperform the control group on either pattern or hand recognition for the symmetry partner of the observed pattern. Although we have argued for strategic benefits as a result of observational practice, it does not appear that these benefits were general enough to apply to other coordination patterns. It is possible that this lack of transfer of perceptual benefits may at least partially relate to the position of the observer. During observation, participants were always positioned to the left of the model, thus only able to see the movement from one perspective (Fig. 1). This may have resulted in a limitation in the generalization of any strategic benefits.

Based on our data we argue that observation is limited in its effectiveness as a motor learning medium for these types of dual-limb coordination tasks and that benefits as a result of watching are primarily cognitive-perceptual in nature. However, it is possible that observation conditions, in comparison to physical practice, created difficulties in attention allocation (see Kovacs et al. 2009a, b, 2010). Observers were able to watch both the moving pendula on the computer screen (correct model) and the person performing the task (learning model). This may have led to attention being split between two information sources, which would not have occurred for the physical practice participants. However, either (or both) source(s) of information would be potentially beneficial for the observer, conveying information about the desired relative phase, as shown on the computer or demonstrated by the participant, as well as online errors in performance, which could be ascertained through comparisons of the two sources of information. Furthermore, observers were encouraged to be actively engaged in watching the model and trying to (privately) estimate the error score presented at the end of each trial. Observers also received a high number of demonstrations (160 trials) and showed a similar level of accuracy as the physical practice group when tested on perceptual discrimination of the practiced task. Thus we believe that the lack of improvement for the observers was unlikely a result of divided attention.

In conclusion, we have provided evidence that while observation of a novel coordination movement can improve cognitive-perceptual performance in comparison to control conditions, physical practice is necessary for improved behavioral performance. It has been suggested that for covert motor simulation to take place during observation, the performer must be trying to improve on an already learned skill, rather than acquiring a motor skill de novo (Milton et al. 2008). The data from the current study support this view, showing limits as a result of observation without physical practice and providing support for a late mediation account (in terms of perception to action transfer) of the observational learning process (Vogt and Thomaschke 2007). Although physical performance did not improve with observation, the additional measurement of perceptual discrimination allowed us insight into other possible benefits of observational practice and the mediating processes. Improved perceptual recognition may still represent significant advances in the understanding of a coordinated novel visuo-motor task, even though overt performance does not improve. These results may also help explain some of the disparate results found in studies examining the benefits of observation in the acquisition of a novel skill. When strategic knowledge can only be applied with limited effectiveness to the solving of a motor task, observational practice will not show the same performance improvements as would be apparent from tasks where a particular strategy leads to the solving of the motor problem.

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