IDENTIFYING THE BENEFITS OF OBSERVATIONAL PRACTICE IN THE ACQUISITION OF A NOVEL COORDINATION SKILL

A Thesis

by

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Submitted to the Office of Graduate and Professional Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

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August 2014

Major Subject: Kinesiology

ABSTRACT

The experiment undertaken was designed to reveal how split attention within an observational learning context influences perception and production processes. The task was producing a bimanual coordination pattern with a 90° relative phase lead of one hand over the other hand. Multi-resource observer group watched both of the model's arms and training animation. Single-resource observer groups watched either model's arm movements or a training animation. In the pre- and post-scanning trials, participants performed the task with pendula animation. After each trial, they performed a perceptual test. In the pre- and post-baseline trials, participants watched the pendula animation and then, re-produce the pattern. During the practice session, models tracked the training animation and their yoked observer saw this. The physical practice model improved at both physical performance and perceptual discrimination of the practiced task. The observer groups showed better performance in perceptual and physical performance test compared to the control group. This implies that observer's ability of extracting the relative phase information indicates a link from perceiving the model's movement to the coordination process required to producing the observed action. As a theory of observational learning, the visual perspective theory specifically accounts for the pick-up relative motion information (relative phase) through observation.

TABLE OF CONTENTS

Page

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

In the context of acquiring motor skills, observation and demonstration are commonly used techniques to facilitate motor learning (Maslovat, Hodges, Krigolson, & Handy, 2010b). Motor learning can be facilitated by providing the learner with expert performance demonstrations of specific patterns (Al-Abood, Davids, & Bennett, 2001; Blandin, Lhuisset, & Proteau, 1999; Hodges, Williams, Hayes, & Breslin, 2007). Motor learning through observation can also follow from watching a novice model learn a new motor skill (Black & Wright, 2000; Blandin et al., 1999; Buchanan & Dean, 2010; Buchanan, Ryu, Zihlman, & Wright, 2008; Buchanan & Wright, 2011).

Many studies have examined how observational learning facilitates physical performance (Cross, Kraemer, Hamilton, Kelley, & Grafton, 2009; Ellenbuerger, Boutin, Blandin, Shea, & Panzer, 2012; Gruetzmacher, Panzer, Blandin, & Shea, 2011). Another aspect of observation that has not been examined as extensively is the impact that observational learning has on the perceptual evaluation of the trained and similar untrained actions (Maslovat et al., 2010b). Research has shown that production capabilities (expert versus non-expert) influence the perception of action in skills such as dancing (Calvo-Merino, Glaser, Grèzes, Passingham, & Haggard, 2005; Calvo-Merino, Grèzes, Glaser, Passingham, & Haggard, 2006). One goal of this research is to reveal how observational training influences both production capabilities and perceptual evaluation processes. Extensive research has shown that split attention influences motor skill learning and actually constrains production capabilities (Kovacs, Buchanan, & Shea, 2009a; Shea, Buchanan, Kovacs, & Krueger, 2008). Another goal of this research will be to reveal how split attention within an observational learning context influences perception and production processes.

Theoretically, action observation is thought to effectively communicate relevant movement information from the model to the observer (Janelle, Champenoy, Coombes, & Mousseau, 2003; Maslovat, Hayes, Horn, & Hodges, 2010a; McCullagh & Weiss, 2001; Shea, Wright, Wulf, & Whitacre, 2000; Wulf, Raupach, & Pfeiffer, 2005). The basic idea is that watching a model allows the observer to develop a representation of the model's action. The issue is identifying the type of movement information represented. Johansson (1973) demonstrated that stereotyped movements (walking and running, etc.) presented in point-light form were automatically identified (within 400ms) through the motion of individual elements relative to each other. Based on the work of Johansson, Scully and Newell (1985) developed the visual perception perspective (VPP) of observational learning. The VPP theory asserts that modeling as a training protocol will be more obvious at the coordination stage when learners need to acquire new information about relationships between body parts and actions, rather than at the control stage when learners need to practice the skill of appropriately scaling the newly acquired coordination function (Scully & Newell, 1985). The immediate problem for a learner is coordinating the many degrees of freedom of the motor system. If actions are identified and described by the relative motion of the body and limbs, then this information is most probably essential for coordination and may be directly extracted and imitated following observational learning

(Scully & Newell, 1985). This direct extraction may simplify the coordination problem by identifying relevant degrees of freedom in the relative motion between limbs.

One-way to study the visual identification of relative motion and link it to observation and coordination is to manipulate the relative phase between limbs and joints. Relative phase (Φ) is defined as the spatiotemporal relationship between two joints or limbs during the performance of a cycle of movement. For example, two index fingers flexing and extending at the same time toward and away from the body midline is defined as an in-phase pattern of coordination with $\Phi = 0^\circ$ (or 360˚). Flexing one finger while the other extends toward and away from the body midline is defined as an anti-phase pattern with $\Phi = 180^\circ$. In-phase and anti-phase patterns are inherently stable coordination patterns and are often referred to as intrinsically stable patterns that do not require practice to generate (Haken, Kelso, & Bunz, 1985; Schöner, Haken, & Kelso, 1986; Schoner & Kelso, 1988). Other relative phase patterns, such as a 90˚ relative phase defined by one finger leading the other by a half-cycle of motion as the fingers flex and extend toward the body midline, are inherently unstable (except under very specific conditions (Kovacs et al., 2009a; Kovacs, Buchanan, & Shea, 2009b) and require extensive practice to produce (Lee, Swinnen, & Verschueren, 1995; Zanone & Kelso, 1992).

According to the VPP theory of observational learning, relative phase should act as a source of coordination information and therefore be perceptually available for pick-up in an observational learning context. The ability to learn a 90˚ relative phase pattern through observation has been examined (Buchanan & Dean, 2014; Buchanan & Dean, 2010; Hodges, Chua, & Franks, 2003; Hodges & Franks, 2001). For example, participants in

Buchanan et al (2008) were instructed to learn a rhythmic 90˚ relative phase pattern between their elbow and wrist joints of the right arm. The experimental groups consisted of a physical and yoked-observational pair and a control group. Each participant in the physical group practiced the to-be-learned pattern for 2 days while being watched by a participant in the observational group. The results showed that the physical group was distinguished by an improvement in relative phase performance. Results following a retention test showed that the observation group was closer at matching the performance of the physical group when compared to a control group in terms of relative phase. The authors concluded that relative phase may be picked-up through observation as a relative motion feature which can benefit early performance. Two studies by Buchanan & Dean (2010, 2014) examined observational learning of a 90˚ relative phase pattern using a bimanual circle tracing task. The models in both experiments were instructed to learn to trace a pair of circles with a 90˚ relative phase pattern between the arms, and observers watched the models practice for 2 days and were instructed that they would have to produce the relative phase pattern (90˚) at the end of the practice. In both experiments, observers were characterized by a significant performance benefit. To summarize, the results of these three studies, show that relative phase information plays a key role in linking together the production and perception of actions in observational contexts. The idea of extracting relative phase information through observation supports the VPP theory.

A recent study conducted by Maslovat et al. (2010), however, produced conflicting results compared to Buchanan & Dean (2010, 2014) about the efficiency of observational practice for the acquisition of novel coordination skills, such as producing a 90˚ relative phase pattern in a bimanual task. Maslovat et al (2010) found different outcomes with regard to the task goal of producing a bimanual 90˚ phase offset for three groups, a physical practice group, a yoked-observation group, and a control group. The task required elbow flexion and extension that produced horizontal motion of the forearms. The yoked-observers watched novice models train with an animated display of inverted pendulums that represented the motion of the two forearms in the horizontal plane (Fig. 1). The pendulums could be programed to oscillate at different relative phase patterns. The model trained with three frequencies (0.75, 0.85, and 1.0 Hz) at producing the 90˚ relative phase pattern. The observers saw this. The groups were compared pre- and post-test on perceptual and physical performance trials of the to-be-learned 90˚ relative phase pattern. The scanning test consisted of eight different relative phase patterns separated by 45˚ (e.g., 45˚, 90˚, 135˚, 180˚, 225˚, 270˚ and 315˚). The participants tracked the animated pendula and after each trial, were instructed to identify the relative phase pattern and leading hand.

Benefits of observational practice were not found in the physical performance of the required bimanual 90˚ relative phase, with the yoked-observers performing similar to the controls, and with both of these groups less accurate than the physical practice group. The observer group's perceptual ability in discriminating the lead hand and relative phase pattern attempted did not differ from the physical practice group and both were more perceptually accurate than the control group. The authors concluded that observational training via a model and animated 90˚ coordination pattern can aid perceptual learning, while not providing a benefit for physical performance. These results are consistent with cognitive mediation models of motor skill learning (Maslovat et al., 2010b). However, the

Maslovat et al (2010) study may have had a problematic training procedure that rendered observational training inefficient with regard to facilitating physical performance. The observers were able to view both the model and the animated pendulum display simultaneously and were not provided instructions on where to focus their attention during the observation trials. Thus, the model and animation may have competed for the observer's attention resources. This competition may have split the observer's attention processes and this may account for the observer's poor physical performance.

Several studies have recently examined the role of attention in bimanual coordination (Buchanan & Wang, 2012; Kovacs et al., 2009a; Kovacs & Shea, 2011). Kovacs and colleagues argued that too much perceptual information (auditory, visual) in a training setting can give rise to performance detriments with regard to producing a 1:1 bimanual coordination pattern with a 90˚ relative phase between the arms in the horizontal plane (Kovacs et al., 2009a). In the Kovacs and colleagues experiment, participants were provided a Lissajous plot with a circle. The on-line relative phase between the participant's arms was provided as a cursor in the Lissajous plot which was displayed directly to the front of the participant. The circle projected on the screen represents a perfect 90˚ relative phase pattern between one sine-wave plotted on the x-axis versus another sine-wave plotted on the y-axis with the same frequency. The dot plotted with the Lissajous circle provides visual feedback for the participant. The participants' task was to coordinate their arms in such a way as to move the dot around the circle, i.e., produce a 90˚ relative phase pattern. One group was paced by a metronome and another group was self-paced and neither group saw their arms. Participants that were self-paced showed better performance of the required coordination pattern after 5 minutes of practice compared to participants that were paced with the metronome. The authors concluded that attention and perceptual distractors have the possibility to disturb bimanual coordination (Kovacs et al., 2009a).

In another study, vision of the arms was manipulated to test attention demands when producing a 2:1 or 3:2 multi-frequency bimanual coordination pattern with the aid of Lissajous plot feedback (Kovacs, Buchanan, & Shea, 2010). To determine the influences of attention demands, vision of the arms was available for one group, while another group had vision of their arms blocked. Participants with no-vision of the arms showed effective performance after 5 min of practice when the Lissajous plot feedback was provided. Participants that had vision of their arms in combination with the Lissajous plot feedback showed deteriorated performance. The findings suggest that some difficulty in producing multi-frequency bimanual coordination patterns may be linked to too much perceptual (vision) information that leads to split attention (Kovacs et al., 2010). The role of attention and perceptual distractors has recently been shown to have an impact on producing bimanual coordination patterns under a variety of contexts that manipulated visual perception (Buchanan & Wang, 2012; Kovacs et al., 2009a; Kovacs & Shea, 2011).

To facilitate observational practice benefits on physical performance, it may be necessary to provide a training context whereby attention is not split and can lead to physical performance improvements. The current study had three different observer groups. The first observer group was a multi-attention resource group. This group was yoked to a group of models trained with a display consistent with Maslovat et al. (2010), they saw a live model and an animation simultaneously (model-ani observer). The second and third observer groups were single-attention resource groups. The second observer group was yoked to a group of models that were trained with the animation, this group of observer only watched the model's arms and did not see the pendulum training animation (model-observer). The third observer group was not yoked to a live model and was exposed to the training pendulum animation (animation-observer). These three groups allow for the examination of observational learning benefits on perceptual and motoric process with regard to attention processes. Two hypotheses will be tested with regard to attention resources and demands. The first hypothesis is that the physical practice group will improve at both (A) physical performance and (B) perceptual discrimination of the practiced task due to extensive physical practice and because of the close coupling seen between action capabilities and perceptual capabilities (Bingham, Schmidt, & Zaal, 1999; Maslovat et al., 2010a). The second hypothesis is that the single-attention resource observer groups will show greater benefits for physical performance compared to the multi-attention resource observer group if splitting attention plays a significant role in the acquisition of motor skills through observation. Based on the Maslovat et al (2010), all observer groups are predicted to show improvement in perceptual discrimination. To test these hypotheses, changes in both physical performance and perceptual discrimination were examined following physical and observational practice of a novel bimanual coordination skill.

Another issue related to the Maslovat et al. (2010) study is testing protocol. The evaluation of learning was based on performance in the scanning trials. The scanning trials, while containing the 90° target pattern at 1Hz, may not have been a representative test of the observational training context. The observers in the Maslovat et al. (2010) study saw a single pattern produced by a model and animation at multiple frequencies. A second pre- and post-test was added in this experiment that required the participants to watch the pendula animation and then re-produce the pattern that they saw. Participants saw and performed nine trials of pre-and post-practice baseline tests that consisted of three patterns (0˚, 90˚, and 180˚) repeated three times for each pattern. This may provide a better test of the observation training. This is due to the fact that the baseline trials test what the observers saw during the training session with the same frequency.

2. METHOD

2.1 Participants

College students (N= 42) received class credit for participation in the experiment. The participants had no prior experience with the experimental task and were not aware of the specific purpose of the study. Self-declared right handed participants were randomly assigned to be a model, an observer, or a control participant. The Texas A&M University IRB approved the experimental protocol and consent form in accordance with the Helsinki Declaration. Each participant signed a written consent form prior to participation.

2.2 Task and apparatus

The task for the models and observers was to learn to produce a 90˚ relative phase pattern between the arms. The task required elbow flexion-extension to move the forearms rhythmically on the horizontal plane. The required relative phase pattern was represented or defined by two vertical lines on a screen which moved 45˚ from peak flexion to peak extension in the manner of inverted pendulums (Fig. 1A). Movement of the right line was to be mirrored by the right arm (RA) while movement of the left line was to be mirrored by the left arm (LA). The animation was used during baseline trials, scanning trials (control, model, observers) and during training trials (model and observers).

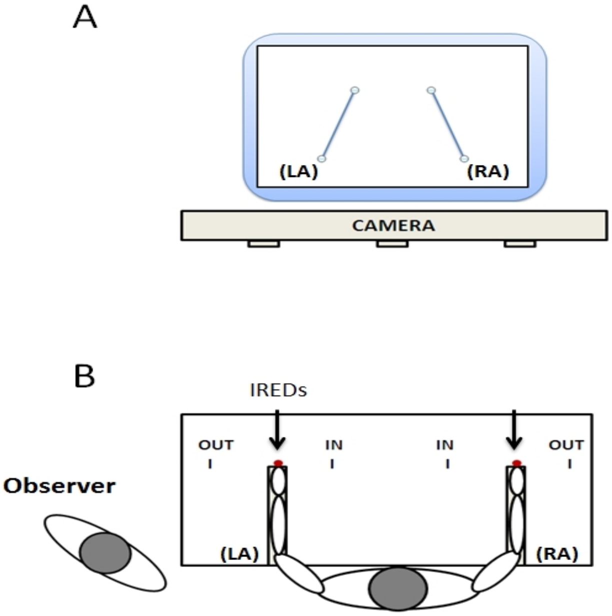

Figure. 1 Illustration showing location of screen, camera, and participants. Infra-red markers identified by arrows. A) Animated pendula representing both arms. B) position of model and observer.

When physically performing, participants sat at a table and their forearms and hands were supported by manipulanda with the elbow joint aligned with the axis of rotation and the hands pronated (Fig. 1B). The required movement amplitude was specified by “in” and “out” markers on the table for each arm. An Optotrack Certus camera was used to collect the angular position of two Infra-red diodes (IREDs) placed on the tips of the manipulanda (Fig. 1B).

2.3 Groups

There were 5 groups in the current study: controls, models, model-ani observers, model-observers, and animation-observers. The control group performed baseline and scanning runs on day 1 and day 3. The models were involved in baseline and scanning runs on day 1 and day 3 and performed two days of physical training. All observer groups performed baseline and scanning runs on day 1 and day 3. The model-ani observers and the model-observers were yoked to a model for the two days of training. The model-ani observers were able to watch the model's arms and pendula animations and the model-observers only watched the model's arms. The animation-observers were not yoked to a model and only watched the pendula animations during the training sessions.

2.4 Procedure

2.4.1 Baseline and scanning

All participants began the day1 testing session with a set of pre-training "baseline trials" to measure their intrinsic ability to produce relative phase patterns of 0°, 90°, and 180° (Table 1). During these baseline trials, participants first watched the pendula on the screen complete 16 cycles, and then had to perform the movement without pendula aniamation. The day 3 session ended with a set of post-training baseline trials for all participants. After the baseline trials, participants performed a scanning run to measure perceptual discrimination and motor capability with respect to a variety of relative phase patterns.

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

Condition	Trials	Display	Pattern
Day 1			
Baseline	9	Pendula no track	0˚ , 90˚, 180˚
Pre-test	24	Pendula track	Random presentation of three trials each of : 0˚, 45˚, 90˚, 135˚, 180˚, 225˚, 270˚, 315˚
Acquisition	20	0.85Hz Pendula track	90˚
	10	Lissajous	
Day 2			
Acquisition	20	0.85Hz Pendula track	90˚
	10	Lissajous	
Day 3			
Post-test	24	Pendula track	Random presentation of three trials each of : 0˚, 45˚, 90˚, 135˚, 180˚, 225˚, 270˚, 315˚
Baseline	9	Pendula no track	0˚ , 90˚, 180˚

Each participant performed a pre-training scanning run on day 1 and a post-training scanning run on day 3. During the "scanning runs", participants performed by tracking with the pendulums. Each trial lasted 16 s. There were three trials each of eight different relative phase patterns (Φ) separated by 45˚ (Table 1.). The pendulums oscillated at a frequency of 1 Hz. These trials were presented in a random order, such that a single pattern was never repeated three times in a row

The data from pre- and post-test trials were used as an assessment of performance enhancement as a function of physical practice and observational practice. The models and yoked-observer groups and the animation observer group started training after the scanning run. The control group was dismissed after the scanning run and returned two days later to do the scanning and baseline trials again.

Following each scanning trial, participants were asked to discriminate each pattern with a rating system that distinguished which hand was leading and what pattern they had performed (Maslovat et al. 2010). The perceptual performance test consisted of two parts as a way to measure the participants' perceptual discrimination ability. Participants were instructed to discriminate the leading arm and coordination pattern in each trial during the scanning runs. Prior to performing the scanning run, the experimenter provided an explanation about the leading arm and the different relative phases. When the right arm led, the right side pendula was placed in peak position ("IN" or "OUT") prior to the left arm, and when the left arm led peak positioning was just the opposite way. In-phase (0˚) and anti-phase (180˚) patterns are neutral patterns with no arm lead. If the leading arm reached the peak position a little earlier than the contralateral arm, the trial was classified as a ¼ cycle lead. When the leading arm was placed in peak position and the opposite arm was located halfway between flexion-extention, this pattern was classified as a ½ cycle lead pattern. Lastly, if the leading arm reached peak position well ahead of the opposite arm then this pattern was defined as a ¾ cycle lead pattern. When the right arm (pendulum) led by ¼, ½, and ¾, the corresponding relative phases were defined as 45˚, 90˚, and 135˚, respectively. When the left arm (pendulum) led by ¼, ½, and ¾, the corresponding relative phases were defined as -45˚, -90˚, and -135˚, respectively. The proportion of correctly identified relative phase patterns (p_{pat}) and leading hand (p_{hl}) trials based on the three trials for each pattern during the pre- and post-scanning runs was calculated. The percentage values were transformed to an arcsine square root value to adjust for violation of normality ($\Phi_{pat} = arcsine(sqrt(p_{pat}))$, $\Phi_{hl} = arcsine(sqrt(p_{hl}))$. Statistics were performed on the transformed values of Φ_{pat} and Φ_{hl}.

2.4.2 Model training

There were two training sessions separated by 24 hours (Table 1). In the training sessions, models practiced 30 trials per day of the 90˚ relative phase pattern with the right hand leading. There were two blocks of 15 trials. The first 10 trials were pendula animation with models tracking and the last 5 trials were Lissajous plot trials. The Lissajous plot trials required participants to trace a circle template presented on the screen, showing the on-line movement of the participant. The circle template presented on the screen represented the target relative phase pattern of 90˚. The Lissajous plot presented a real time angle-angle plot of the two arms, right arm flexion-extension motion moved the cursor horizontally and left arm flexion-extension motion moved the cursor vertically.

2.4.3 Observer training

The model's arm movements and the screen displaying the pendula were visible to the model-ani observer (Fig. 1). The model-ani observers were told to watch both the computer screen and model's arms. This group saw the Lissajous plot during those training trials. The model-observer group did not watch the computer screen, they only saw the models arms and did not see the Lissajous plot during the training trials. The animation-observer group only saw the pendula animation during the practice trials in both sessions. The animation-observer group watched the 30 pendula trials and were instructed to focus on the pendula motion throughout an entire trial. Each model-ani observer, model-observer and animation-observer were informed that they would have to perform the task in the last session.

2.5 Data collection and analysis

An OPTOTRAK Certus 3D camera (Northern Digital Ontario, Canada) was used to record the position of two infra-red light emitting diodes (IREDs) mounted on the ends of the manipulanda (Fig. 1B). The Certus camera has three pre-calibrated lenses with a resolution of 0.1 mm in x and y and 0.15 mm in z at a distance of 2m. The IREDs were sampled at 100 Hz and filtered (Butterworth, 10 Hz) before computing an elbow angular time series for both limbs. All dependent measures were calculated using Matlab 7.0 (Mathworks, Inc.).

2.5.1 Relative phase

To identify the spatial-temporal coordination of the limbs' motion, the continuous relative phase (Φ_c) between the two limbs was computed. In order to compute the continuous relative phase, the two elbow angle time series were mean centered and rescaled between -1 and 1 and the velocity of each time series was computed and scaled between -1 and 1. The phase angle (θ) for each limb (RA, LA) was computed for each sampled point (i) as follows: $\theta_i = tan^{-1}\,[(dX_i/dt/\,X_i\,)]$ with X_i representing normalized limb position and $\mathrm{d}X_i/dt$ normalized velocity. The continuous relative phase was derived by subtracting the phase angle of the left limb (θ_l) from the phase angle of the right limb (θ_r), $\Phi_c = \theta_{RA} - \theta_{LA}$, with $+\Phi_c$ indicating a right hand lead and $-\Phi_c$ indicating a left hand lead. An absolute value of Φ_c ($\Phi_{AE} = ABS(required - |\Phi_c|)$) and standard deviation of Φ_c were used to characterize goal attainment, with the standard deviation of relative phase providing an assessment of performance stability.

2.6 Statistics

The dependent measures (Φ_{AE}, Φ_{SD}, Φ_{pat}, and Φ_{hl}) were analyzed with ANOVAs. Simple effects analyses were performed on interactions, and all post hoc comparisons were conducted using Tukey's HSD test ($\alpha = .05$). The variable group is a between factor, pattern and test are within factors in all repeated measures ANOVAs.

3. RESULTS

3.1 Practice: Models

To show how the models' performance changed as a function of practice, we looked at the two days of training trials of the 90˚ pattern in terms of relative phase bins. The number of trials within relative phase bins of 45˚ (e.g., 90˚, bin 65.7˚ to 112.5˚.) based on the value of Φ_c were calculated across all participants. The number of trials that were binned as the 90˚ relative phase pattern for the models increased from day 1 to day 2 and the number of trials that were binned as 135˚ and 180˚ decreased from day 1 to day 2 (Fig. 2).

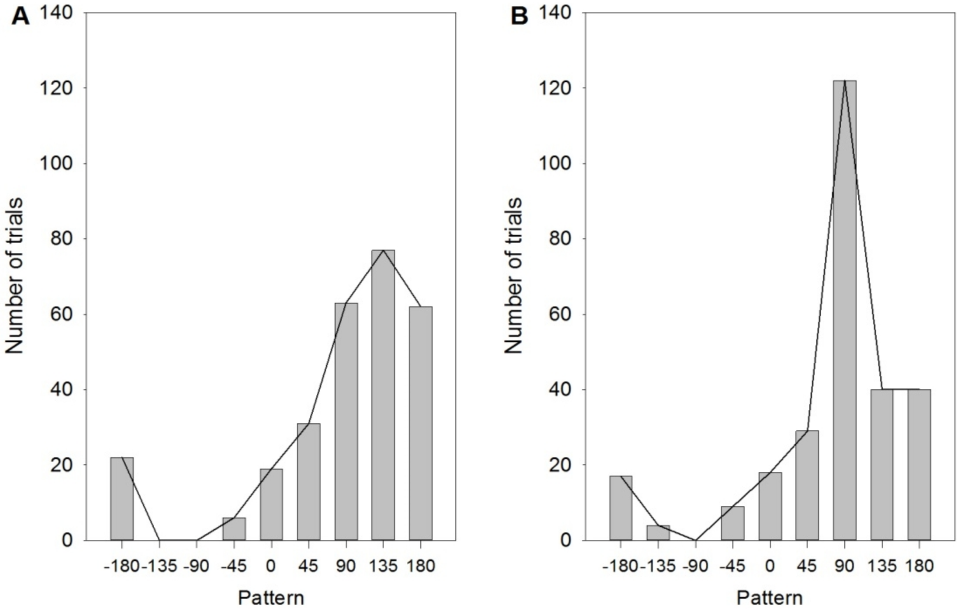

Figure. 2 Relative phase distributions for the two days of 90˚ relative phase practice trials. (A) day 1, (B) day 2.

The Φ_{AE} and Φ_{SD} data from the 20 practice animation tracking trials were each analyzed with a 2 day × 2 block ANOVA. The analysis of the Φ_{AE} data revealed a significant effect of day ($F_{(1,556)} = 8.85$, $p < 0.05$) and a day × block interaction ($F_{(1,556)} = 4.287$, $p < 0.05$) (Fig. 3A). The day 1 Φ_{AE} value decreased from block 1 to block 2. The Φ_{AE} value from the day 1 block 1 practice trials was significantly larger than the day 2 block 1 practice trials. The block effect ($p > 0.1$) was not significant for the practice trials Φ_{AE} data set.

The analysis of the Φ_{SD} data showed a significant day × block interaction ($F_{(1,556)} = 7.615$, $p < 0.01$) (Fig. 3B). Post-hoc tests revealed significantly lower Φ_{SD} values for day 2 block 2 practice trials compared to day 1 block 2 practice trials. The difference between day 2 block 1 and day 2 block 2 was not significant ($p > 0.4$). No other significant effects were found ($p > 0.09$).

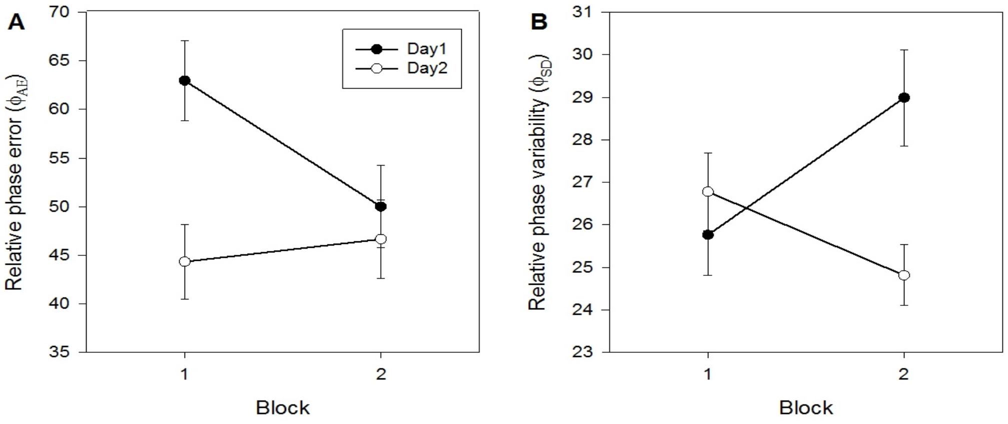

Figure. 3 Mean absolute error of relative phase (A) and standard deviation of relative phase (B) from the practice trials are plotted as function of block.

3.2 Scanning

In the scanning trials, the participants tracked with the pendula animation. Figure 4 illustrates the distribution of the relative phase (Φ_C) values produced by the models and controls during the pre- and post- practice scanning trials only for the 90˚ pattern. The control group was characterized by a strong attraction toward an anti-phase pattern (180˚) across the two days (Fig. 4A). The models had a larger number of trials with a mean of Φ_C closer to the 90˚ relative phase pattern on day3 compared to day1 (Fig. 4B).

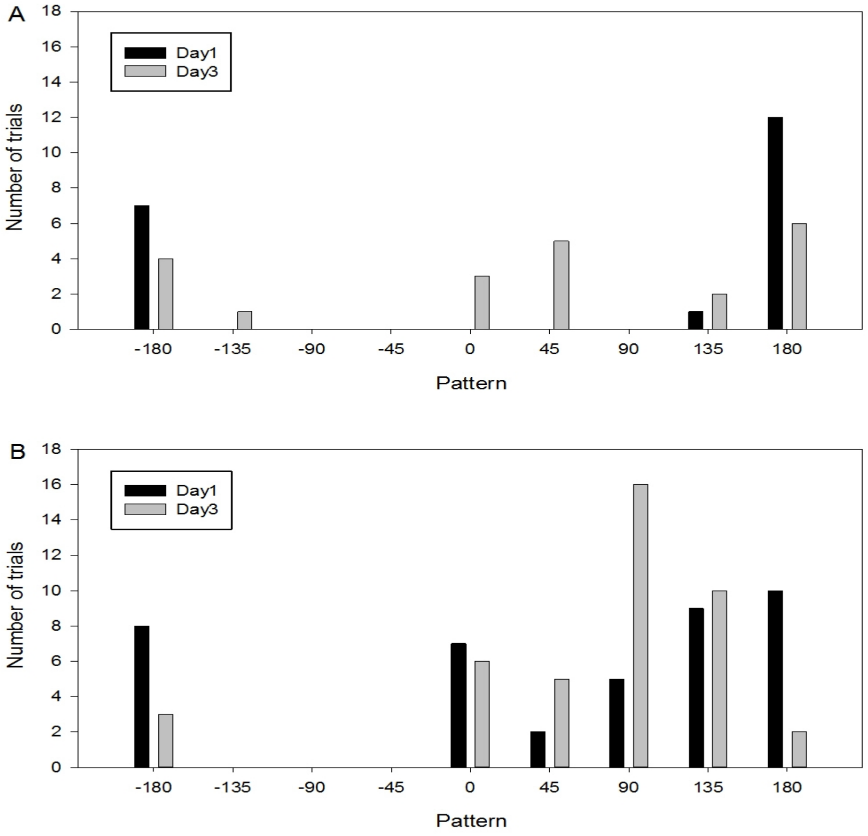

Figure. 4 Relative phase distributions for the pre- and post-practice scanning trials performed by controls (A) and models (B).

The distributions of relative phase patterns produced by the three observer groups during the pre- and post- practice scanning trials only for the 90˚ pattern are shown in Figure 5. The model-ani observer group showed a decrease in the expression of patterns binned as 135˚ and 180˚, and an increase in the number of trials binned as the 90˚ pattern. The animation-observer group showed a decrease in the number of trials binned as the 180˚ pattern, and an increase in the number of trials binned as 135˚, and the change in the number of trials binned as a 90˚ pattern was not large. The model observer group showed a decrease in trials binned as the 0˚ and 180˚ patterns. The number of trials binned as 45˚ and 135˚ increased for this group and the number of trials binned as 90˚ did not change.

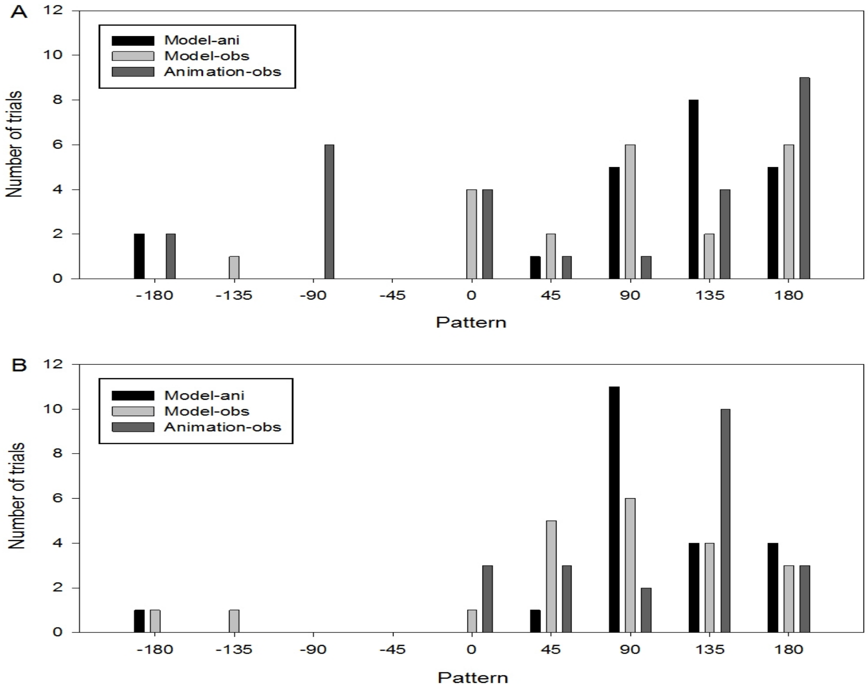

Figure. 5 The three observer groups relative phase distributions for the pre- (A) and post-practice (B) scanning trials.

3.2.1 Models and control

The Φ_{AE} and Φ_{SD} data from the pre- and post-practice scanning trials for the 90˚ pattern performed by the models and controls were analyzed with a 3 group × 2 day ANOVA. The analysis of the Φ_{AE} data found a significant main effect of group ($F_{(2,120)} = 15.77, p < 0.001$) and day ($F_{(1,120)} = 17.69, p < 0.001$). The two-way interaction of group × day ($F_{(2,120)} = 3.69$, $p < 0.05$) was also significant. Significantly lower Φ_{AE} values characterized both the model groups compared to the controls on day 3 (Fig. 6A). There was no significant difference between models and control on day 1. The model groups' Φ_{AE} values decreased from day 1 to day 3.

The analysis of the Φ_{SD} data revealed a significant main effect of group ($F_{(2,120)} = 4.28, p < 0.05$). The two-way interaction of group × day ($F_{(2,120)} = 11.03, p < 0.001$) was also significant. On day 1, the models from the model-observer group had significantly higher Φ_{SD} values compared to the other two groups. However, on day 3, there was no significant group difference. The models from the model-ani group and the controls did not show a change in variability from day1 to 3 (Fig. 6B).

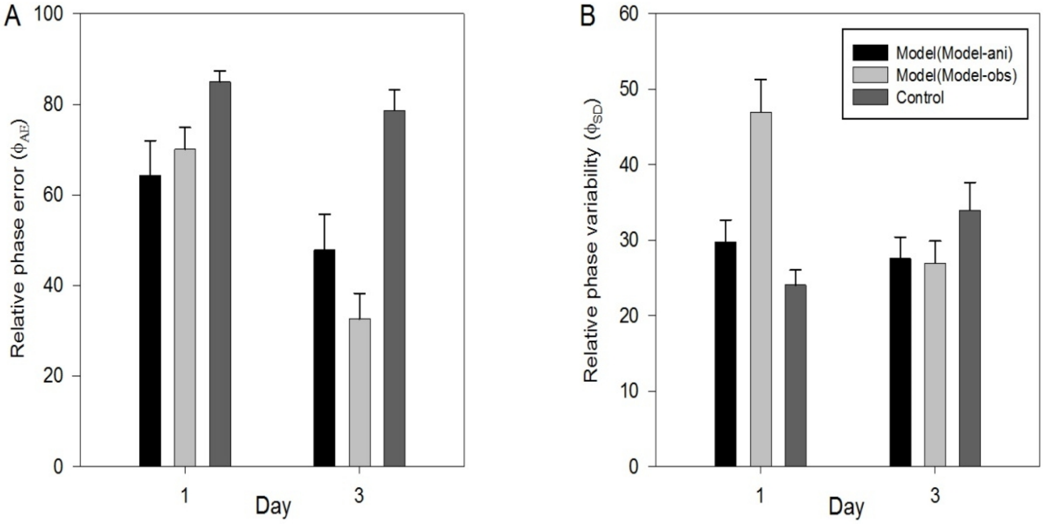

Figure. 6 (A) Mean absolute error of relative phase and (B) standard deviation of relative phase from the pre- and post-practice scanning trials for models and controls are plotted.

3.2.2 Observers and controls

The Φ_{AE} and Φ_{SD} data from the pre- and post-practice scanning trials for the 90° pattern performed by observers (model-ani observer, model-observer, and animation observer) and controls were analyzed with a 4 group × 2 day ANOVA. The analysis of the Φ_{AE} data found significant group ($F_{(3,160)} = 12.823$, $p < 0.001$) and day ($F_{(1,160)} = 8.507$, $p < 0.01$) effects (Fig. 7A). All observers' Φ_{AE} values (model-ani observer. 41.95°, SD = 32°; model-observer. 50.95°, SD = 35.85°; animation-observer. 63.27°, SD = 38.3°) were significantly lower than the controls (81.81°, SD = 16.76°). The model-ani observer's Φ_{AE} value was significantly lower than the model-observer and animation observers. All groups had decreases in Φ_{AE} values from day 1 to 3 (Δ = day $1\Phi_{AE}$ − day $3\Phi_{AE}$): 1) animation observer Δ26˚, 2) model observer Δ13˚, 3) model-ani observer Δ11˚, and 4) control Δ6˚. The group × day interaction in the Φ_{AE} data set was not significant ($p > 0.5$).

The analysis of the Φ_{SD} data from the scanning trials for the 90˚ pattern yielded no significant main effects of group or day or any interaction between these variables (*ps* > 0.2) (Fig. 7B).

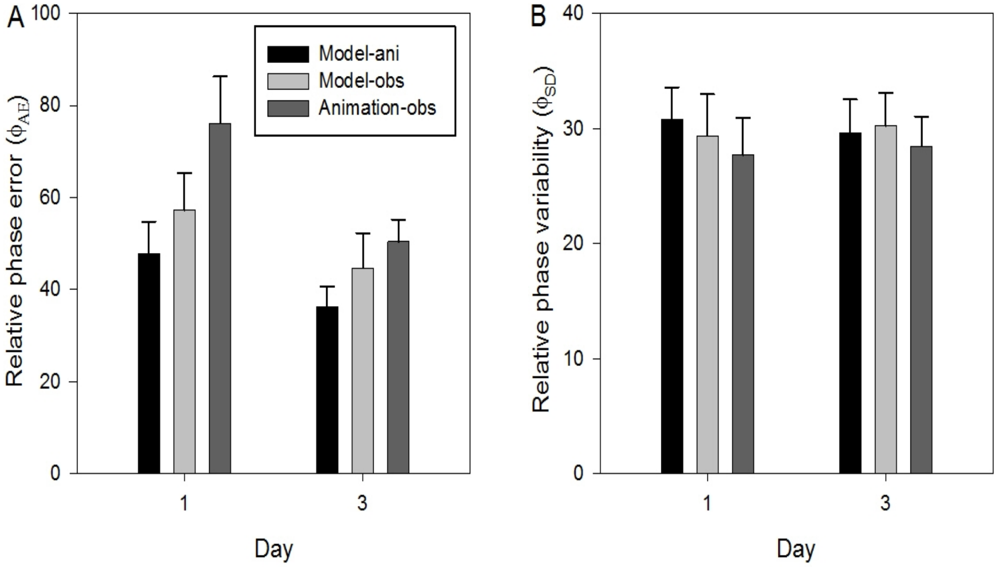

Figure. 7 Relative phase error $\boldsymbol{\Phi_{AE}}$ (A) and standard deviation of relative phase $\boldsymbol{\Phi_{SD}}$ (B) from the pre- and post-practice scanning trials for observer groups are plotted.

3.3 Perceptual test

After each scanning trial the participants performed two perceptual performance tests that distinguished which hand was leading and what pattern they had performed. The proportion of correct trials that participants either correctly discriminated the relative phase pattern (Φ_{pat}) and leading hand (Φ_{hl}) were analyzed separately.

3.3.1 Models and controls

The proportion of patterns correctly discriminated by the models and controls for the 90° pattern during the pre- and post-perceptual test were analyzed with a 3 group × 2 day ANOVA. The analysis of the proportion of correct trials for pattern discrimination revealed no significant main effects or interactions between these variables (*ps* > 0.09). However, both model groups showed improvement in pattern discrimination from day 1 to day 3, whereas the control group showed a decrease (Fig. 8A). To test for changes in the model groups' perceptual performance through practice, paired t-tests were conducted with the models' proportion of correct trials. The models from the model-ani and model-observer groups showed a significant increase in accuracy of pattern discrimination (t =-2.931, $p < 0.05$).

The analysis of the proportion of correct data for hand discrimination revealed significant main effects of group ($F_{(2,36)} = 5.775$, $p < 0.05$) and day ($F_{(1,36)} = 6.251$, $p < 0.05$). The hand discrimination accuracy improved from day1 to day3. The models' score was higher than the controls. The two-way interaction of group × day was not significant ($p = 0.076$) (Fig. 8B.).

3.3.2 Observers and Controls

The proportion of patterns correctly discriminated by the three observer groups and controls for the 90° pattern during the pre- and post-perceptual test were analyzed with a 4 group × 2 day ANOVA. The main effect of day was significant ($F_{(1,48)} = 8.637$, $p <$

0.05). Perceptual performance improved from day1 to day3. The two-way interaction of group × day was also significant ($F_{(3,48)} = 2.976\ p < 0.05$). Post-hoc tests revealed that the animation-observer groups' pattern discrimination ability was significantly improved from day 1 to day 3. Even though the model-observer showed improvement in pattern discrimination, it was not significant (Fig. 8C.). The main effect of group was not significant ($p > 0.1$).

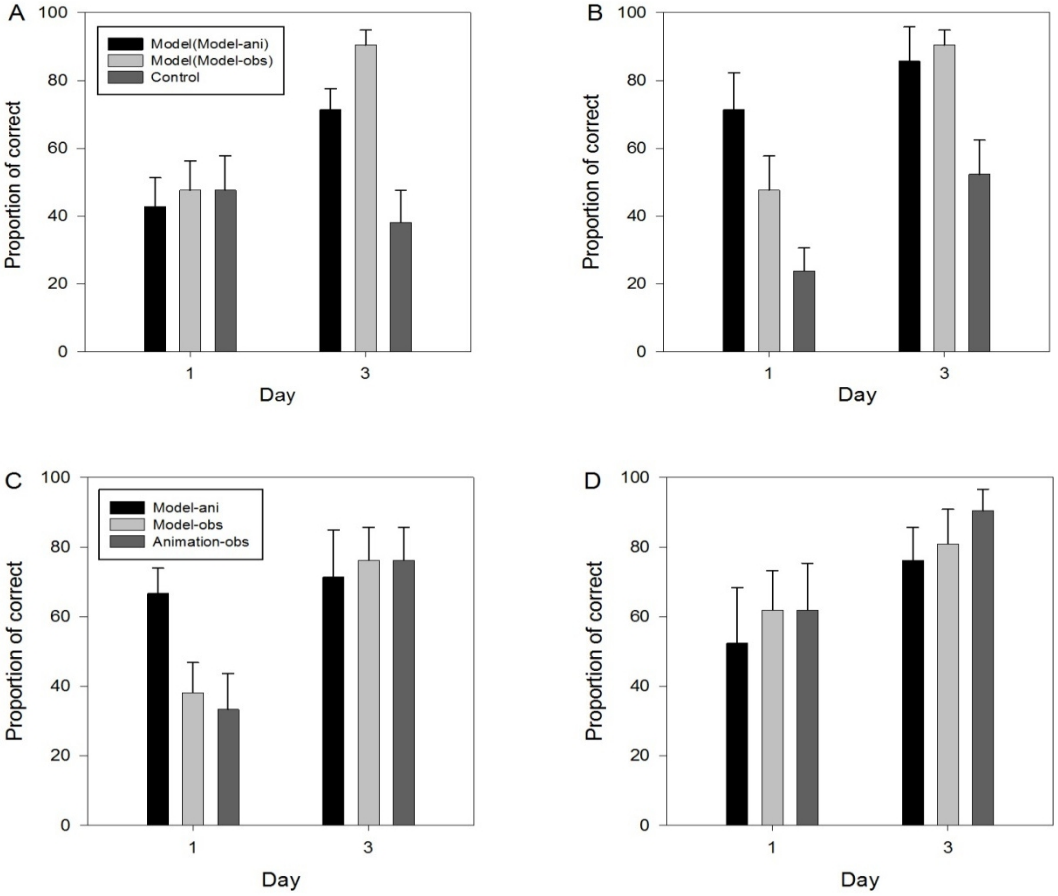

Figure. 8 Proportion of correct pattern (A, C) and leading hand (B, D) distinguished for pre- and post-perceptual test. A, B) the two model groups and control, C, D) the three observer groups.

The analysis of the proportion of correct data for hand discrimination performed by observers and controls revealed significant main effects of group ($F_{(3,36)} = 5.77, p < 0.05$) and day ($F_{(1,36)} = 9.6337$, $p < 0.05$). The model-observer and the animation observer showed better performance in hand discrimination than the model-ani observer and control. All groups' hand discrimination accuracy was improved from day 1 to day 3 (Fig. 8D).

3.4 Baseline

In the baseline trials, participants saw the pendula animation and then re-produced what they had seen. Figure 9 illustrates the distribution of the relative phase (Φ_C) values produced by the models and controls during the pre- and post- practice baseline trials only for the 90˚ pattern. The control group showed an attraction toward the anti-phase pattern (180˚) (Fig. 9B). The models had a larger number of trials with a mean of Φ_C closer to the 90˚ relative phase pattern on day 3 compared to day1 (Fig. 9B).

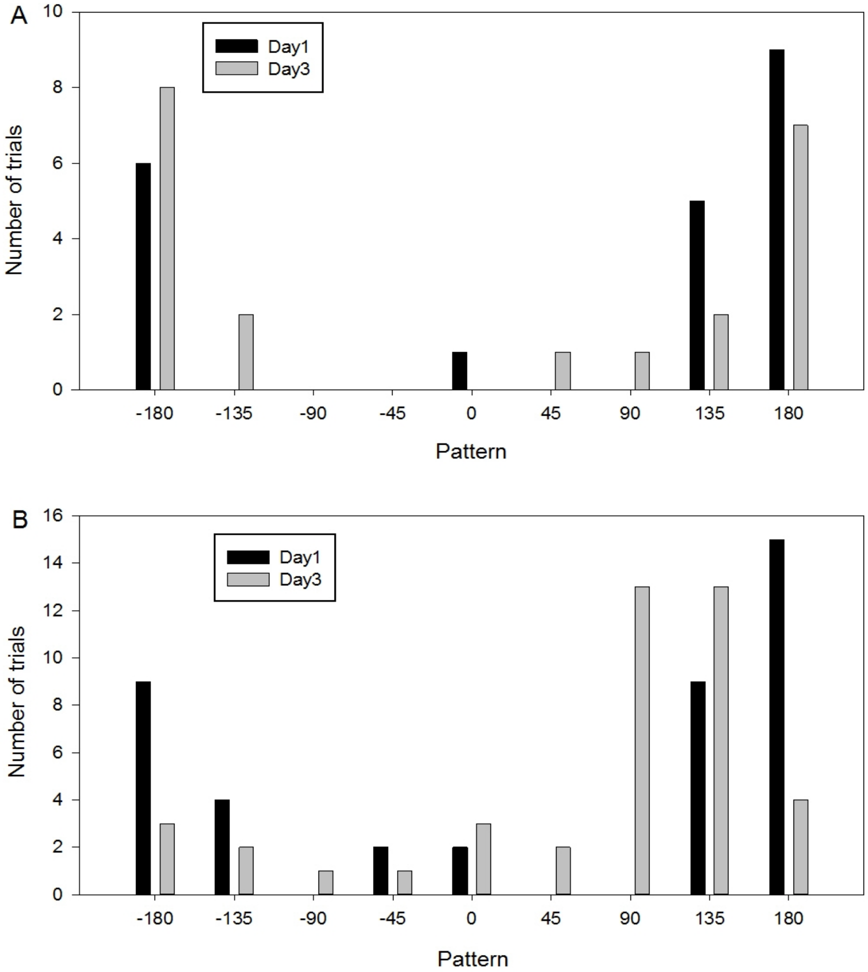

Figure. 9 Relative phase distribution for the pre- and post-practice baseline trials performed by controls (A) and models (B).

The distributions of mean relative phase values (Φ_c) produced by the three observer groups during the pre- and post- practice baseline trials only for the 90˚ pattern are shown in Figure 10. That the model-ani observer group was characterized by a decrease in the number of trials classified as 135˚ and an increase in the number of trials binned as the 90˚ pattern. The model observer group did not produce 0˚ or left-hand leading patterns on day

3, and the number of trials classified as 90˚ increased, while the number of trials classified as 180˚ decreased for this group. The animation-observer group showed a decrease in the number of trials classified as the 180˚ pattern and an increase in the number of trials binned as the 90˚ and 135˚ patterns.

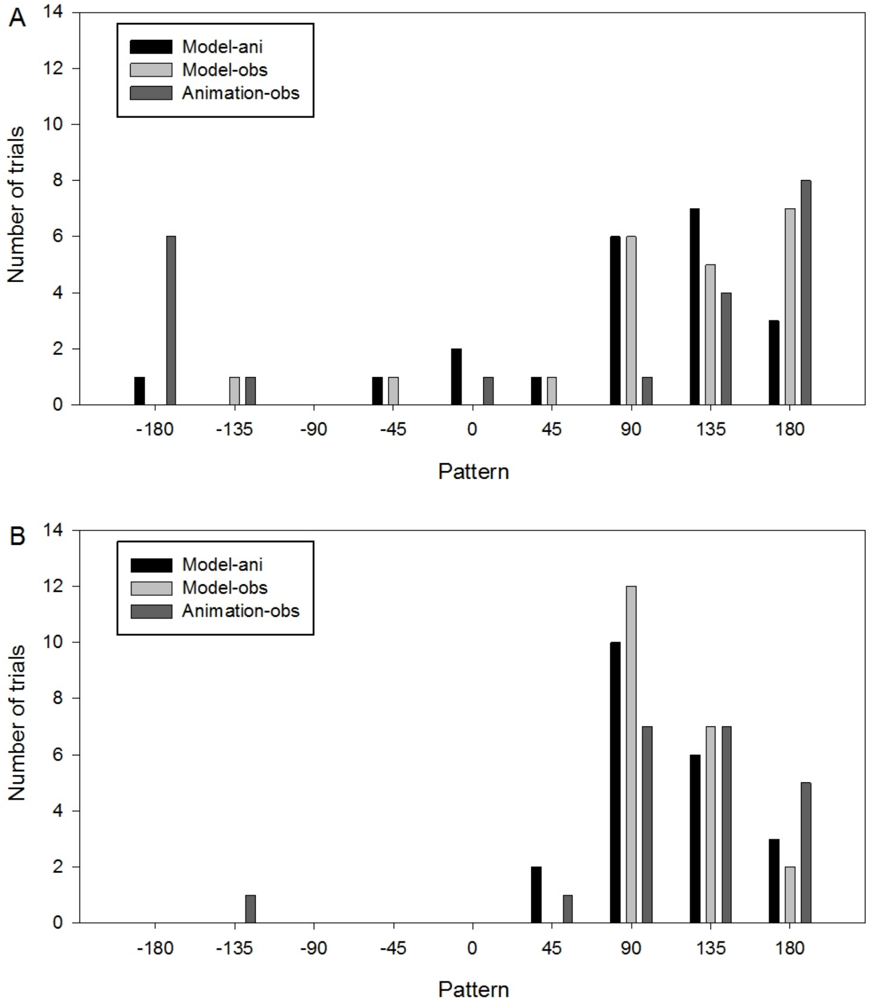

Figure. 10 The three observer groups relative phase distribution for the pre- and post-practice baseline trials.

3.4.1 Models and control

The $\Phi_{AE}$and Φ_{SD}data from the pre- and post-practice baseline trials performed by the two model groups and controls were analyzed with a 3 group × 2 day × 3 pattern (0˚, 90˚, and 180˚) ANOVA. The analysis of the Φ_{AE} data found significant effects of day ($F_{(1,360)} = 6.421$, $p < 0.05$) and pattern ($F_{(2,360)} = 320.771$, $p < 0.001$). The two-way interactions of group × day ($F_{(2,360)} = 3.907$, $p = 0.021$) and day × pattern ($F_{(2,360)} = 9.642$, $p < 0.001$) were significant. The three-way interaction of group × day × Pattern ($F_{(4,360)} = 4.305$, $p < 0.01$) was significant (Fig. 11A-C). The post-hoc test of the day × pattern interaction showed that the Φ_{AE} value for day 3 (64.84˚) was significantly lower than day 1 (87.93˚) only for the 90˚ pattern. The post- hoc comparison of the group × day × pattern interaction focused on the 90˚ pattern and only on the models. Note in Figure 11B that the control group's Φ_{AE} value increases from day 1 to day 3. To test for changes in the model groups' Φ_{AE}values for the 90˚ target pattern, a 2 group × 2 day ANOVA was conducted. A significant main effect of day ($F_{(1,80)} = 13.329$, $p < 0.001$) was found. The model groups showed significant decreases in the Φ_{AE} value from day 1 to day 3. The two-way interaction of group × day was not significant ($p > 0.05$).

The analysis of the Φ_{SD} data revealed significant day ($F_{(1,360)} = 7.55$, $p < 0.05$) and pattern ($F_{(2,360)} = 322.325$, $p < 0.001$) main effects. The two-way interactions of group × day ($F_{(2,360)} = 6.043$, $p < 0.01$) and day × pattern ($F_{(2,360)} = 8.647$, $p < 0.001$) were significant. The three way group × day × Pattern interaction ($F_{(4,360)} = 5.51$, $p < 0.001$) was also significant (Fig. 11D-F). The most stable pattern was 0˚ followed by the 180˚

pattern, and the 90° pattern was the least stable pattern (Fig. 11D-F). The post-hoc test of the group × day × pattern interaction revealed no significant change in the 0° and 180° patterns. Note in Figure 11E that the control group's Φ_{SD} values for the 90° pattern increases from day 1 to day 3. To take a closer look at the change in the 90° pattern for the models, a 2 group × 2 day ANOVA was conducted. The main effect of day ($F_{(1,120)} = 16.74$, $p < 0.001$) was significant. The model groups' Φ_{SD} values were significantly smaller on day 3 compared to day 1. The main effect of day and two-way interaction of group × day were not significant ($p > 0.8$).

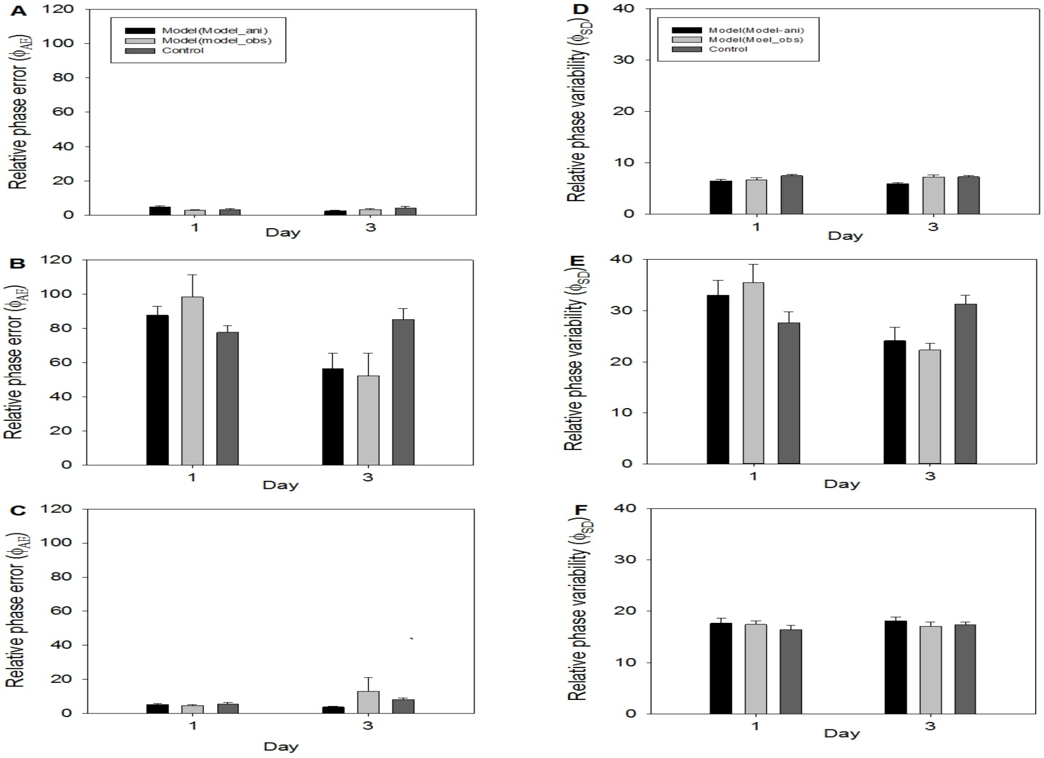

Figure. 11 Mean absolute error of relative phase (A= 0°, B= 90°, C= 180°), standard deviation of relative phase (D-F) from the pre- and post-practice baseline trials for models and controls are plotted.

3.4.2 Observers and controls

The Φ_{AE} and Φ_{SD} data from the pre- and post-practice baseline trials performed by the three observer groups (model-ani observers, model-observers, and animation –observers) and controls were analyzed with a 4 group × 2 day × 3 pattern (0°, 90°, and 180°) ANOVA. The analysis of the Φ_{AE} data found significant main effects of group ($F_{(3,480)} = 15.42$, $p < 0.001$), day ($F_{(1,480)} = 15.52$, $p < 0.001$), and pattern ($F_{(2,480)} = 397.782$, $p < 0.001$). The following two-way interactions were also significant, group × day ($F_{(3,480)} = 4.304$, $p < 0.01$), group × pattern ($F_{(6,480)} = 12.004$, $p < 0.001$) and day × pattern ($F_{(2,480)} = 16.191$, $p < 0.001$). The three-way interaction of group × day × Pattern ($F_{(6,480)} = 3.008$, $p = 0.007$) was also significant (Fig. 12A-C). The post- hoc comparison of the group × day × pattern interaction focused on the 90° pattern for the observers only. To test for changes in the observer groups' Φ_{AE} values from the 90° target pattern, a 3 group × 2 day ANOVA was conducted. Significant main effects of group ($F_{(2,120)} = 4.361$, $p < 0.05$) and day ($F_{(1,120)} = 22.052$, $p < 0.001$) were found. The model-ani observer's Φ_{AE} value was significantly lower than the model-observer and the animation-observer group. The observer groups showed significant decreases in the Φ_{AE} value from day 1 to day 3. The two-way interaction of group × day was not significant ($p > 0.05$).

The analysis of the Φ_{SD} data revealed a significant effect of pattern ($F_{(2,480)} = 355.625$, $p < 0.001$) and a significant day × pattern interaction ($F_{(2,480)} = 3.697$, $p = 0.026$) (Fig. 12D-F). The post-hoc comparison of the day × pattern interaction showed that the 90˚ pattern's Φ_{SD} for day 3 was significantly lower than day 1 (Fig. 12E). The values of Φ_{SD} for 0˚ and 180˚ did not change from day1 to day3 (Fig. 12D,

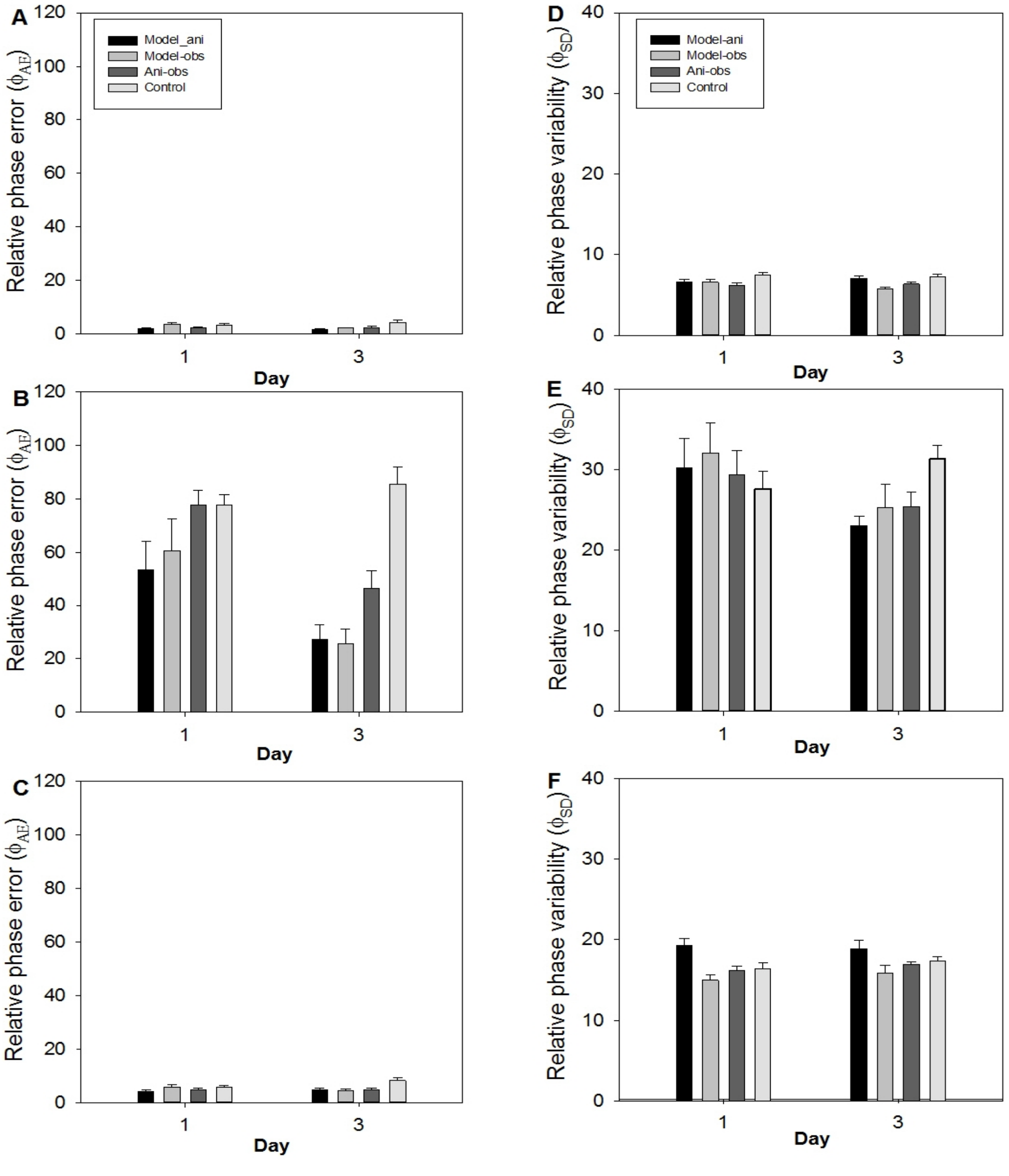

Figure. 12 Mean absolute error of relative phase (A-C), standard deviation of relative phase (D-F) from the pre- and post-practice baseline trials for observers and controls are plotted.

F). The three observer groups' Φ_{SD} values decreased from day 1 to day 3. On the other hand, the controls Φ_{SD} increased from day 1 to day 3. To test for changes in observer groups' Φ_{sd} value for the 90˚ target pattern, a 3 group × 2 day ANOVA was conducted. A significant main effect of day ($F_{(1,120)} = 6.577, p < 0.05$) was found. The observer groups showed significant decrease in the Φ_{sd} value from day 1 to day 3. The two-way interaction of group × day was not significant ($p > 0.05$).

4. DISCUSSION

With regard to attention resources and demands on attention processes in the context of observational practice, two hypotheses were tested. The results provide support for the first hypothesis that the physical practice group would improve at both physical performance and perceptual discrimination of the practiced task. However, the results did not support the second hypothesis that stated the single-attention observer groups would show a greater benefit for physical performance compared to the multi-attention observer group if splitting attention plays a key role in the acquisition of motor skills through observation.

4.1 Hypothesis 1 and 2

In terms of hypothesis one, the model groups were characterized by a significant improvement in physical performance compared to the control group from day 1 to day 3 in the baseline trials as well as the scanning trials. These results are consistent with Maslovat et al (2010) and with previous studies comparing models and controls within observational learning contexts (Buchanan et al., 2008; Buchanan & Wright, 2011). The model groups were characterized by an increase in perceptual performance across days. This result is in line with the result from the Maslovat et al (2010) study that showed improvement in perceptual performance by the models with regard to the trained relative phase pattern. The above results provide support for hypothesis one.

With respect to hypothesis two, the model-ani observer group shows the smallest change in Φ_{AE} across days in the scanning trials, while the other two observer groups have larger changes in Φ_{AE} values. The model-ani observer group had the smallest error on day 1 as well as day 3, compared to the other observer groups. There was no difference in observer groups across days based on Φ_{SD} values. Similar to the results from the scanning trials, the model-ani observer group had the smallest change in Φ_{AE} across days in the baseline trials, while the other two groups had larger changes in Φ_{AE} values. There was no difference in the observer groups across days based on Φ_{SD}. In sum, the scanning and baseline data do not support hypothesis two. However, the results are different from Maslovat et al. (2010) in that the same group (model-ani observer) as used by Maslovat et al. did get better at physical performance. The three observer groups in the current study all showed improvement in physical performance.

According to the results of the perceptual performance test, the model-ani observer group had the smallest increase in Φ_{pat}, yet started higher and ended only slightly smaller than the other observer groups. All three groups show similar changes in Φ_{hl} , and for this one the model-ani observer group is smaller than the animation-observer group. The controls are below or at chance. This data is consistent with Maslovat et al. (2010) in that observation did benefit perceptual (visual) process with regard to identifying the target relative phase pattern. However, the data do not support hypothesis two.

4.2 Relative phase: perception and production

The results from the current study with regard to the observer groups' data implies that perception and production processes may not be affected by split attention within an observational learning context. The live models for the yoked observers may have contributed to create the representation of observed action at least in this experimental setting. This result is different from previous research that examined attention resource and demands (Buchanan & Wang, 2012; Kovacs et al., 2009a; Kovacs & Shea, 2011). According to the previous research, too much perceptual (vision) information leads to split attention that can decrease the stability of coordination patterns. In this context, both the model's arm movement and training animation represented the target relative phase pattern. This may have been a benefit since the observers were told to focus on both. It is clear what the observers were told to focus on in the Maslovat et al. (2010) study. If the observers focused only one the display, this may account for the lack of improvement in physical performance. In the current experiment, the observer group that only viewed the animation had the largest error in both day 3 tasks. The observer group that only watched the model was characterized by significant improvement in this study. In the Maslovat et al. (2010) study, if their observers focused more on the model than the animation, then an improvement in performance should have occurred, but it did not.

In terms of movement stability, the observer groups show a decrease in the Φ_{sd} value for the 90° target pattern only for the baseline trials, while there is no difference in observer groups across days. On the other hand, the Φ_{sd} values for the 0° and 180° patterns were not different from each other across practice. The 0° pattern was more stable than 180° pattern and the 90° pattern was the least stable pattern. Previous research revealed that the perception of bimanual patterns reflects the production of those patterns. For instance, in-phase ($\Phi = 0^{\circ}$) and anti-phase ($\Phi = 180^{\circ}$) are perceived as the most coordinated patterns, while other relative phase patterns, such as $\Phi = 90^{\circ}$, are perceived as less coordinated based on visual information (Bingham et al., 1999; Zaal, Bingham, & Schmidt, 2000). Some studies have been conducted that show learning of a 90˚ relative phase pattern through observation (Buchanan & Dean, 2014; Buchanan & Wright, 2011; Hodges et al., 2003; Maslovat et al., 2010a). This implies that relative phase acts as an informational variable that links together perceptual and motor processes in observational context. Both models and observers showed an improvement at recognizing the trained 90˚ pattern and hand lead. This shows that improving physical performance facilitates visual perception of actions. The ability of observers to reproduce the target relative phase pattern suggests that the relative phase information can be extracted through observation. Several studies have revealed that the relative direction of motion is the information that supports the ability of people to discriminate relative phase differences between moving objects (Wilson, Collins, & Bingham, 2005; Wilson, Snapp-Childs, & Bingham, 2010). In other words, extracting the target relative phase was dependent on identifying the relative motion direction of the arms. The overall improvement in hand-lead for the 90˚ trained pattern shows relative phase and relative motion identification improve when the ability to perform a pattern with greater stability emerges through practice.

The observer groups showed larger changes in Φ_{AE} values from pre- to post-practice scanning trials compared to the control group as well as the baseline trials and the perceptual performance test. The novel finding from this experiment is that observational practice can provide the benefits for not only perceptual but also physical performance when the observers train with a yoked model. Recently, Maslovat et al. (2010) assumed that the benefit of observational practice was limited to perceptual learning and that physical practice was still needed to improve the physical performance of bimanual skills.

The finding that emerged in the current test shows that physical performance of a complex bimanual skill can benefit from observational practice. The goal of both experiments was to learn and to produce the 90˚ relative phase pattern between both arms. In the Maslovat et al. (2010) study, observers watched both the model's performance and pendula animation simultaneously during the practice trials with three different movement frequencies. The experiment context was exactly the same as the current study in that the pendula animation set both the right-hand lead and required relative phase pattern. The crucial difference in the impact of observation between the two studies may reside in the training context. In the Maslovat et al. (2010) study, the observers saw a model train on the 90˚ target relative phase at multiple frequencies. This experimental setup may have led to a facilitation only of the perceptual process instead of action process that must underlie motor skill learning. In the current experiment, the observers watched the model train on the 90˚ target relative phase with only one frequency that was the same frequency as the actual learning test.

Through observational practice, the observer groups showed large decreases in performance error compared to the control group that did not practice the target relative phase pattern. Relative phase has been conceptualized as spatiotemporal information that defines the relationship between two joints or limbs when producing and perceiving a coordination pattern. The observer's ability of extracting that information indicates a link from perceiving the model's movement to the coordination process required to producing the observed action. In other words, relative phase information plays a key role in linking together the production and perception of actions in observational contexts.

According to the visual perspective theory of observational learning, relative phase can be perceptually available for pick-up through observation (Scully & Newell, 1985). The concept of picking-up relative phase information through observation is based on Johansson's research that used point light displays (Johansson, 1973). This idea is supported by numerous studies using point light forms that examined the relative motion between joints and limbs (Cutting & Kozlowski, 1977; Kozlowski & Cutting, 1977; Pinto & Shiffrar, 1999). The ability of observers to pick up the relative motion information has been examined by various kinds of tasks such as a rhythmic elbow and wrist motion (Buchanan et al., 2008), bimanual circle tracking task (Buchanan & Dean, 2014; Buchanan & Dean, 2010), and dart aiming task (Al-Abood et al., 2001). As a theory of observational learning, the visual perspective theory specifically accounts for the pick-up relative motion information (relative phase) through observation.

The current study had two different types of pre- and post-test, one was scanning trials and the other was baseline trials. With regard to the scanning trials, participants tracked the pendula animation simultaneously. The scanning trials focused more on an on-line vision-action process. The participants may have utilized their short-term memory to produce the target relative phase pattern. On the other hand, the baseline trials regarded the participants to view a pattern and then re-produced the pattern without the visual information. The baseline trials were focused more on the production processes and tuning into the long-term memory related to the target relative phase pattern. A study by Ronsse and colleagues revealed that participants that trained with augmented visual feedback to produce a 90˚ relative phase pattern became dependent on this feedback for performance.

However, a second group that were not exposed to visual feedback but were trained with auditory feedback performed equally well with or without augmented feedback by the end of the practice (Ronsse et al., 2011). The current results show that observational learning can support performance improvements in testing contexts with and without augmented feedback present.

5. CONCLUSIONS

The physical practice models improved at both physical performance and perceptual discrimination of the practiced task due to extensive physical practice and because of the close coupling seen between action capabilities and perceptual capabilities (Bingham et al., 1999; Maslovat et al., 2010a). The observer groups showed better performance in perceptual and physical performance test compared to the control group. The three observer groups showed improvement in movement accuracy and stability of the 90˚ target pattern, yet both 0˚ and 180˚ were still more stable than 90˚ pattern. The current study could not control whether observers stayed focused on the model's performance or pendula animation during the practice sessions. Future research needs to examine how the strength of attention influences the learning of difficult bimanual coordination patterns.

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