



Mirror-hand selection is influenced by training perspective and model skill level in a motor-learning task

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Abstract

This study examined mirror and non-mirror arm selection processes in an observational learning context. Observer groups watched either a novice (instruction or discovery) or skilled model performing a bimanual task with the right arm leading the left arm. The models were viewed from a third-person perspective. Observers of the skilled model more often selected a mirror-image (left-hand) hand-lead in post-observations tests, while observers of the novice models more often selected a non-mirror image (right hand) hand-lead in post-observation tests. This is a novel finding regarding arm selection processes in a learning context, yet it is consistent with imaging data that has revealed specific neural areas linked to the selection of mirror and non-mirror imitation processes for first- and third-person viewing perspectives. The skilled model also supported more accurate and stable performance of the bimanual task in observers compared to the instruction and novice models. It is concluded that a skilled model supports attention focus being directed at pattern analysis, while novice models support attention focus being allocated to strategy identification first, followed by pattern analysis.

Keywords Bimanual · Lateralization · Coordination dynamics · Perception–action · Instructions · Relative phase

Introduction

Practice context can influence the speed of motor memory acquisition and the formation of key features of limb and body motions that support goal achievement. Identifying how variations in practice context influence the selection of specific action features is essential in facilitating the rate of return across practice, and this is true for training athletes, children, adults in exercise classes, and individuals recovering from neurophysiological trauma (e.g., stroke). The current experiment manipulated two features of a practice context, viewing perspective and model skill level, to identify the extent that one or both features influence the selection of hand-lead and hand motion direction in observers watching models train with a bimanual task. All observers watched models train from a third-person perspective which had the observer view the model face-to-face.

Studies examining motor control with action-observation (non-learning) and action-imitation tasks have demonstrated that viewing perspective influences motor performance. Motor evoked potentials are significantly larger when observers watch a model from a first-person perspective (Maeda et al. 2002), and spatial compatibility reaction times are shorter from a first person compared to a third-person perspective (Sebanz et al. 2003). In a mental imagery task, it has been shown that a first-person perspective resulted in more accurate estimates of movement times compared to a third-person perspective (Stevens 2005). Such findings suggest that first-person viewing should be the preferred perspective in observational training contexts. However, work has shown that observers produce similar movement times when imitating a model's reach generated from a first- or third-person viewpoint, and it was concluded that first- and third-person viewing perspective share a common cognitive representation (Anquetil and Jeannerod 2007).

Extensive research has explored action-observation and action-understanding processes within the context of the mirror-neuron system or action-observation network (AON) that supports the ability of humans to imitate actions, predict actions, and interpret actions of others (Rizzolatti and Craighero 2004; Cattaneo and Rizzolatti 2009; Cook et al.

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2014). Activity in the AON has been correlated with the learning of new dance sequences by expert dancers (Cross et al. 2006) and the emergence of different activity patterns (bilateral versus unilateral) when experts in one dance-type (ballet) view experts in another dance type (capoeira) (Calvo-Merino et al. 2005). Such findings suggest that the AON plays a role in learning novel actions as well as in the differentiation of learned and unlearned actions based on a person's motor repertoire. Neuroimaging studies have revealed specific neural areas that support action-observation processes from both first-person and third-person perspectives (Iacoboni et al. 1999; Shmuelof and Zohary 2006, 2008; Koehler et al. 2012). Action-imitation studies have demonstrated a preference for observers to match left side to left side and right side to right side when viewing a model from a first-person perspective (Franz et al. 2007). Observation from the third-person view, however, often produces a mirror matching, whereby an observer matches their left side to a models, right side, and vice versa. Activity in the anterior superior parietal lobule (aSPL) has been linked to first-person and third-person viewpoints of hand motions without imitation, suggesting an automatic action-simulation system that supports mirror and non-mirror-hand selection process (Shmuelof and Zohary 2006, 2008; Koehler et al. 2012). Moreover, context factors such as instructions, task complexity, and social interaction often produce greater ambiguity in the selection of mirror and non-mirror responses in observers when the model is viewed from a third-person perspective (Bianchi et al. 2014; Bardi et al. 2015; Freundlieb et al. 2016). Taken together, behavioral and neuroimaging research reveal flexibility in the selection of mirror and non-mirror-hand responses in imitation tasks, especially from the third-person viewpoint.

Overlearned motor responses are most often used to examine the selection of hand preference when observers imitate models as a function of perspective, and skill level is typically equivalent between model and observer. Imitation tasks minimize the learning process, and therefore, hand selection is typically not a variable that is defined as a novel feature of the skill that must be selected for the skill to be learned. In applied practice contexts, observers may have the option to watch demonstrations of motor skills from a variety of viewpoints before attempting the skill, and models can have a higher or equal skill level to the observer. The neuroimaging studies by Calvo-Merino et al. (2005) and Cross et al. (2006) used videos (of experts) showing sequences of action containing first- and third-person perspectives. Each factor, skill level, and viewing perspective should influence how motor skills are learned through observation and, therefore, possibly contribute to hand selection processes within a learning context. When it comes to model skill level, extensive research has shown that skilled and novice models

equally support observational learning of motor skills in a variety of tasks, bimanual (Martens et al. 1976; Hayes et al. 2008), discrete aiming (McCullagh and Caird 1990; Weir and Leavitt 1990), sequence aiming and key pressing tasks (Blandin et al. 1999; Blandin and Proteau 2000; Bird and Heyes 2005), and even robotic surgery training (Harris et al. 2017). The reason both models are thought to be beneficial is that each model type provides a different source of important information for the learner. Expert models are thought to convey information pertaining to strategy development, whereas novice models are thought to convey more salient information regarding error detection and correction processes (Rohbanfard and Proteau 2011b; Andrieux and Proteau 2013, 2014). Observer viewing perspective has been examined in imitation tasks quite often (Franz et al. 2007; Press et al. 2009; Garland and Sanchez 2013; Bianchi et al. 2014; Freundlieb et al. 2016), yet it has rarely been examined in motor-learning tasks with observation as a training context. At least one study has shown that both a first- and third-person perspective of an expert model performing a single-arm barrier knock down task supports motor skill learning through observation (Rohbanfard and Proteau 2011a). The task by Rohbanfard and Proteau (2001a), however, did not examine strategy selection or hand selection processes.

The current study was designed to reveal if model skill level and viewing perspective interact to influence the learning of motor skills through observation. The experiment sought to exploit the flexibility in hand selection found in imitation tasks from a third-person perspective by making hand selection, mirror or non-mirror, a key feature of the learning process. The task was to learn to trace two circles with a 90° relative phase offset between the hands through observation of a model. An earlier study with this task had three observer groups view either a skilled model, an instructional novice model, or a discovery novice model from a first-person perspective (Buchanan and Dean 2014). The skilled model used a right-hand lead and traced the circles with clockwise–counterclockwise (CW:CCW) motions of the arms (direction strategy) and produced the 90° pattern with small error and low variability (Fig. 1a). The instruction model was told to use a right-hand lead with a CW:CCW direction strategy, thereby starting training with large error and high variability that decreased over practice, yet the same strategy was always modeled. The discovery model was not instructed to use a specific hand-lead or a specific direction strategy. The discovery model switched between right-hand and left-hand leads and traced with multiple direction strategies (CW:CW, CCW:CW, etc.), and their performance of the 90° pattern had larger error and more variability compared to the other models. Over the last third of practice, the discovery model stuck with a right-hand lead using the CW:CCW strategy.

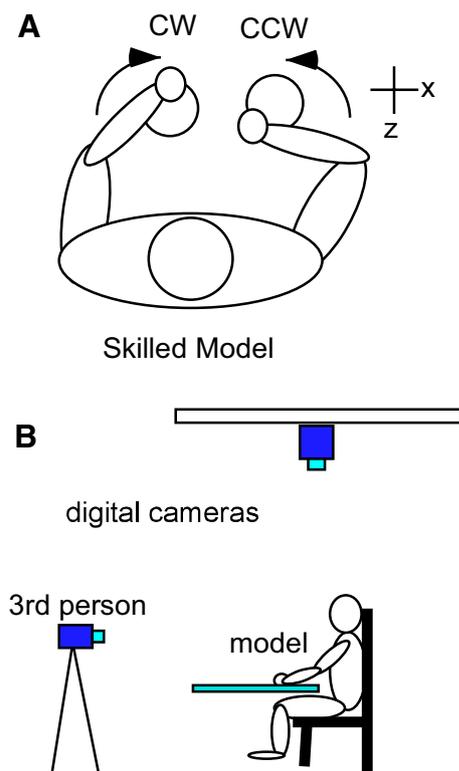


Fig. 1 Task description and experimental setup. **a** Representation of the strategy and bimanual task produced as viewed from a first-person perspective. The arms are drawn to show a right-hand lead with a direction strategy of CW:CCW (left arm, right arm). **b** Setup to record model training. In this experiment, the observers viewed the model from the third-person perspective

In the Buchanan and Dean (2014) study, a pre-observation test of the observers did reveal a bias for selecting a right-hand lead when first attempting to trace the circles with a 90° offset. In a post-observation test, a right-hand lead was selected as follows across trials: 91% for observers of the instruction model, 69% for observers of the skilled model, and 88% for observers of the discovery model. As with the hand-lead, there was no tendency to select the CW:CCW direction strategy over other combinations. After observation, the CW:CCW direction strategy was selected 100% of the time by the observers of the skilled and instructional models and 69% of the time by observers of the discovery model. These results demonstrate that hand-lead selection and arm motion direction strategy were influenced by model skill level and the consistency in modeled direction strategy within a first-person perspective training context. The observers of the skilled and instructional models showed significant improvement at the 90° pattern in a post-observation test, a finding consistent with previous work revealing that both model types support observational learning. The Buchanan and Dean's (2014) study extended the previous work by revealing that strategy instructions (instructional

model) that limit strategy exploration (discovery model) can also create an advantage for the observer.

With the current experiment, the same models and bimanual circling task just outlined were employed with the primary difference being that observers watched the models from a third-person perspective. As outlined, there is little research providing data to make predictions regarding how model skill level will interact with the third-person perspective within an observational learning context, where hand-lead selection is a primary component of the learning process. Our previous study, however, does suggest that novice and skilled models constrain observers in different ways that influence hand-lead selection and direction strategy usage. If novice models support the development of error correction/detection processes, then seeing a specific hand-lead emerge over practice in a novice model may facilitate the selection of the same hand-lead even from a third-person perspective. If this is the case, observers of novice models (instructional and discovery) may select more often a right-hand lead (non-mirror) after observing from the third-person perspective. If skilled models support the rapid identification of a successful strategy, then a skilled model demonstrating a well-defined and easily observable strategy, in this case a right-hand lead, may allow observers to focus more on the coordination pattern and less on the strategy. This scenario may lead observers of a skilled model to the selection of a mirror-match response when observing from a third-person perspective, which would be a left-hand lead in the current task.

Materials and methods

Participants: model and observer training

The protocol and consent procedure were approved by the human subjects board at Texas A&M University. Informed consent was obtained from the observers ($n = 24$) and models ($n = 2$) (MN age = 21.9 years., std. dev. = 2.1 years.). There were three observer groups ($n = 8$) that were classified based on the model viewed: instructional (Ins), discovery (Dis), and skilled (Sk1). Participants were students from the Health and Kinesiology department and received academic credit for participating. Students were naive to the study's purpose being both self-reported and classified as right-arm dominant.

Two digital video cameras recorded models training from first- and third-person perspectives (Fig. 1b). The models traced circle templates with hand-held styli (Buchanan and Dean 2014). Infrared LEDs were mounted on the styli and tracked with an OPTOTRAK® camera system (Northern Digital, Inc.) at a sampling rate of 100 Hz. A Lissajous template with a dot representing the motion between the

hands was used to train the models by providing concurrent and terminal feedback. The models were instructed that the left arm moved the cursor up and down and that the right arm moved the cursor left and right. The instructional and discovery models started their training by producing three in-phase and three anti-phase bimanual tracing patterns. The models were told to trace the left-hand circle CW and right-hand circle CCW to produce in-phase, and to trace the left-hand circle CW and right-hand circle CW to produce the anti-phase pattern. These patterns familiarized the models with the tracing task in general. Before producing the in-phase and anti-phase patterns, the models were shown what the motion of the dot would look like in a Lissajous plot (diagonal lines). After viewing the Lissajous plot for each pattern, the models produced the in-phase and anti-phase trials and were shown the Lissajous plot for each of the three trails with a terminal format.

After the in-phase and anti-phase trials, the models received further instruction. The models were shown a circle template in the Lissajous plot and told that this template represented the pattern that they would practice. The motion of the dot around the plot was demonstrated and it was emphasized to the models that the practice pattern was different from the in-phase and anti-phase patterns. The instructional model was given the following description on producing the bimanual pattern of 90° : trace the right-hand circle CCW and the left-hand circle CW with a $\frac{1}{4}$ cycle lead of the right arm to left arm. The $\frac{1}{4}$ cycle lead corresponds to the left-arm's position lagging $\frac{1}{4}$ of a circle behind the right-arm's position when tracing (Fig. 1a). The discovery model was told one hand must lead the other hand by a $\frac{1}{4}$ cycle to produce the 90° pattern. The discovery model was not instructed to use a specific hand to produce the lead. The discovery model was told that the circles could be traced in any direction, CW or CCW, and was not told to use a specific rotation strategy. The models attempted the 90° pattern for three trials and were provided terminal feedback to insure an understanding of the instructions. The models trained on the 90° pattern for 3 days with 32 trials per day and tracing frequency was paced at 1 Hz (auditory) with 16 beats per trial. Concurrent and terminal feedback were alternated every two trials with the first two trials each day being concurrent feedback. A single model was used to develop the instructional novice model and skilled model training DVDs for observers.

From the practice trials, two novice model training DVDs for each model (instructional, discovery) were created. DVD 1 shown on observer training day 1 consisted of a model's 32 trials from day 1 and first 16 trials from day 2. DVD 2 shown on observer training day 2 contained a model's second 16 trials from day 2 and the 32 trials from day 3. The trials were presented in the sequence that they were performed. To generate two skilled model DVDs, the ten most accurate

(smallest error) trials from the instructional model's third practice session were selected. The skilled model DVDs were composed of a random sampling and random ordering of the ten best trials in groups of eight to create two 48 trial DVDs with one DVD a day presented for observer training. The model's terminal feedback trials were shown to the observers using the Lissajous plot.

In session one, all observers performed the in-phase and anti-phase patterns (3 trials each) in the same manner as the models and were also introduced to and performed the 90° pattern (3 trials) in the same way as the discovery model. After the 90° trials, the styli were removed and the first observational training DVD was presented. Day 2 saw the presentation of the second training DVD. Observers did not perform in the second session. Observers watched the training DVDs on a 28" monitor positioned above the Optotrak camera while sitting in the same position as the model and were instructed to watch the model with the intent to learn the pattern practiced by the model. The observers were not instructed to match a model's arms' rotation direction or hand-lead. Day 3 consisted of post-observation tests with observers' first performing in-phase and anti-phase without feedback, and then attempting the 90° pattern for a set of trials without feedback.

Data analysis

The xz time series from two IREDS mounted on the hand-held styli were filtered (Butterworth, 10 Hz cutoff, dual pass). All dependent measures were computed with routines written in Matlab R2014a (MathWorks). The coordination between the arms was quantified with a continuous relative phase (φ_C) calculated between the LA stylus (θ_l) and RA stylus (θ_r), $\varphi_C = \theta_r - \theta_l$. The φ_C time series was used to derive three performance measures per trial: (1) the percentage of φ_C values within a bandwidth of $\pm 45^\circ$ (BW45) around 90° ; (2) the percentage φ_C of values within a bandwidth of $\pm 22.5^\circ$ (BW22) around 90° ; and (3) root mean square (RMS). The BW45 and BW22 measures represent coordination accuracy (Wilson et al. 2010), while coordination stability was assessed with the RMS measure. Based on these performance measures, the DVDs presented each observer group with distinct differences in performance error/variability with regard to the target 90° pattern (see Table 1). Visual-interactive routines of the xz trajectories and φ_C time series were used to determine initial arm lead (mirror or non-mirror matching) and rotation strategy (CW or CCW). The visual inspection of hand-lead in combination with the average value of φ_C for the first three cycles was used to determine hand-lead in the 90° relative phase trials. The φ_C measure was set, so that an RH lead produced $\varphi_C > 0^\circ$ and an LH lead produced $\varphi_C < 0^\circ$. For example, if the visual inspection of the xz trajectory suggested an LH lead across

Table 1 Model performance means (std. dev.) for training days on 90° pattern

	Day 1		Day 2		Day 3		
	BW45	RMS	BW45	RMS	BW22	BW45	RMS
Ins	0.62 (0.24)	43° (14°)	0.91 (0.11)	25° (9°)	0.66 (0.21)	0.96 (0.08)	22° (7°)
Dis	0.41 (0.31)	56° (17°)	0.83 (0.22)	29° (15°)	0.76 (0.20)	0.96 (0.06)	19° (7°)
Skl	–	–	–	–	0.79 (0.10)	0.99 (0.02)	17° (4°)

the first three cycles of a trial with $\varphi_C < 0^\circ$ on average, then the LH was labeled the leading hand for the trial. Rotation strategy classification was based on the first three cycles in a trial with four strategies identified for left-hand:right-hand motion: (1) CW: CW; (2) CCW: CCW; (3) CW: CCW; and (4) CCW: CW. The third combination, CW: CCW, was the one modeled for every trial in the instructional and skilled model DVDs. The observers of the discovery model saw trials with directional rotation combinations of CW: CW, CCW: CCW, and CW: CCW. If hand-lead or rotation strategy switched after the first three cycles, then the trial was also classified as containing a switch in strategy.

Results

Pre-observation: hand-lead selection and directional tracing

A binomial proportion test was used to evaluate if observers selected a right-hand lead more often prior to viewing the models train for 2 days. The probability of selecting a right-hand lead (59%) over a left-hand lead (41%) approached significance based on the test ($z = 1.56, p = 0.06$). A 3×2 Chi-square test found no difference between observer groups (Ins, Dis, Skl) in the initial selection of a right- or left-hand lead [$\chi^2(1) = 2.1, p = 0.34$] (Table 2). A switch in hand-lead occurred in 33% of these trials.

A binomial proportion test was used to evaluate if observers selected the other three rotation strategies (> 50%) more often than the CW: CCW rotation strategy before watching a model train. This test was significant indicating no pre-observation bias in selecting the CW: CCW strategy ($z = -3.97, p < 0.0001$): CW: CCW 26.5% of trials, CW: CW 21.7%, CCW: CCW 21.7%, and CCW: CW 30.4%. A 3×2

Chi-square test revealed a difference in observer groups in the selection of the CW: CCW strategy before observation [$\chi^2(6) = 21.4, p = 0.002$]. The observers that would watch the discovery model selected the CW: CCW strategy for 52% of the trials in the pre-test, with the observers of the instructional and skilled models selecting this combination for 8% and 21% of the trials, respectively. A switch in rotation strategy occurred in 31% of the trials across the three observer groups.

Post-observation: hand-lead selection and directional tracing

A binomial proportion test was used to evaluate if after observational training, the observers more often selected a right-hand (non-mirror) over a left-hand (mirror) lead. This test was not significant ($z = 0.42, p = 0.33$) and overall a right-hand non-mirror lead (52%) was selected slightly more often than a left-hand mirror-image lead (48%). As shown in Table 2, observers of the instructional model overwhelmingly selected a right-hand lead, whereas observers of the skilled model overwhelmingly selected a left-hand lead. The observers of the discovery model had a small preference for a right-arm lead. A series of 2×2 Chi-square tests revealed that the number of left-hand and right-hand leads was different between groups (Table 2): skilled versus instructional [$\chi^2(1) = 25.0, p < 0.0001$]; skilled versus discovery [$\chi^2(1) = 15.39, p < 0.0001$]; and instructional versus discovery [$\chi^2(1) = 15.39, p < 0.0001$]. A switch in hand-lead occurred in 17% of the trials across the three observer groups.

A binomial proportion test was used to evaluate if after observational training observers more often selected (> 50%) the CW: CCW rotation strategy compared to the other three strategies combined after watching models train with this

Table 2 Hand-lead as a function of pre- and post-observation and model

	Pre-observation			Post-observation		
	Ins (%)	Dis (%)	Skl (%)	Ins (%)	Dis (%)	Skl (%)
RH lead	50	66	58	81	57	19
LH lead	50	34	42	19	43	81
Switch	38 ^b	29 ^b	33 ^b	9 ^a	25 ^b	16 ^b

^aA single participant

^b2 or more participants

strategy. The test was significant indicating a bias in the observers to select the CW:CCW strategy more often than the other strategies ($z = 7.29$, $p < 0.0001$): CW:CCW 88% of trials, CW:CW 8.7%, and CCW:CW 3.3%. Observers of the instructional and skilled models used this strategy for every trial, while observers of the discovery model used this strategy for 61% of the trials. A 2×3 Chi square revealed a significant difference between observers groups in the selection of rotational strategies, [$\chi^2(2) = 28.5$, $p < 0.0001$].

Coordination performance: time-on-task bandwidths and variability

Before training observers produced the in-phase and anti-phase patterns with very little error while tracing the circles, with a strong attraction when attempting the 90° target pattern to the stable patterns of in-phase and anti-phase. After training, there was no change in the ability of the observers to produce in-phase or anti-phase. The observational training produced an attraction to the 90° pattern with improvements in performance that characterized all three observer groups. The two times on task measures (BW45 and BW22) and root mean square (RMS) measure were analyzed in ANOVAs with model observed (Ins, Dis, Skl) a between factor and test (pre, post) and pattern (0° , 180° , 90°) as within factors. Simple effects tests and post-hoc tests (Tukey) were used to further examine significant main effects and interaction effects.

The analysis of the BW45 data revealed the following significant effects: test, $F(1, 102) = 51.9$, $p < 0.0001$, $np^2 = 0.33$, pattern, $F(2, 102) = 257.6$, $p < 0.0001$, $np^2 = 0.83$, test \times pattern, $F(2, 102) = 47.57$, $p < 0.0001$, $np^2 = 0.48$, test \times model, $F(2, 102) = 4.88$, $p < 0.01$, $np^2 = 0.09$, and test \times model \times pattern, $F(4, 102) = 4.46$, $p < 0.01$, $np^2 = 0.15$ (see Fig. 2). Simple effect tests of the three-way interaction revealed that the time spent on task did not change for in-phase and anti-phase ($ps > 0.9$) (Fig. 2a), yet did change significantly from pre- to post-tests for the target pattern of 90° , $F(5, 102) = 36.3$, $p < 0.0001$, $np^2 = 0.64$ (Fig. 2b). Further post-hoc tests ($p < 0.05$) revealed a significant increase in the BW45 value from pre- to post-tests for each observer group. There were no differences in groups in the pre-test, while in the post-test, the time spent on task was significantly different between all three groups (Fig. 2b).

The analysis of the BW22 data revealed the following significant effects: test, $F(1, 102) = 30.45$, $p < 0.0001$, $np^2 = 0.22$, pattern, $F(2, 102) = 305.44$, $p < 0.0001$, $np^2 = 0.85$, test \times pattern, $F(2, 102) = 11.34$, $p < 0.0001$, $np^2 = 0.18$, and test \times model \times pattern, $F(4, 102) = 2.72$, $p < 0.05$, $np^2 = 0.09$ (see Fig. 2). The model \times pattern interaction approached significance, $F(4, 102) = 2.34$, $p = 0.06$, $np^2 = 0.08$. Simple effect tests of the three-way interaction revealed that the time spent on task did not change for

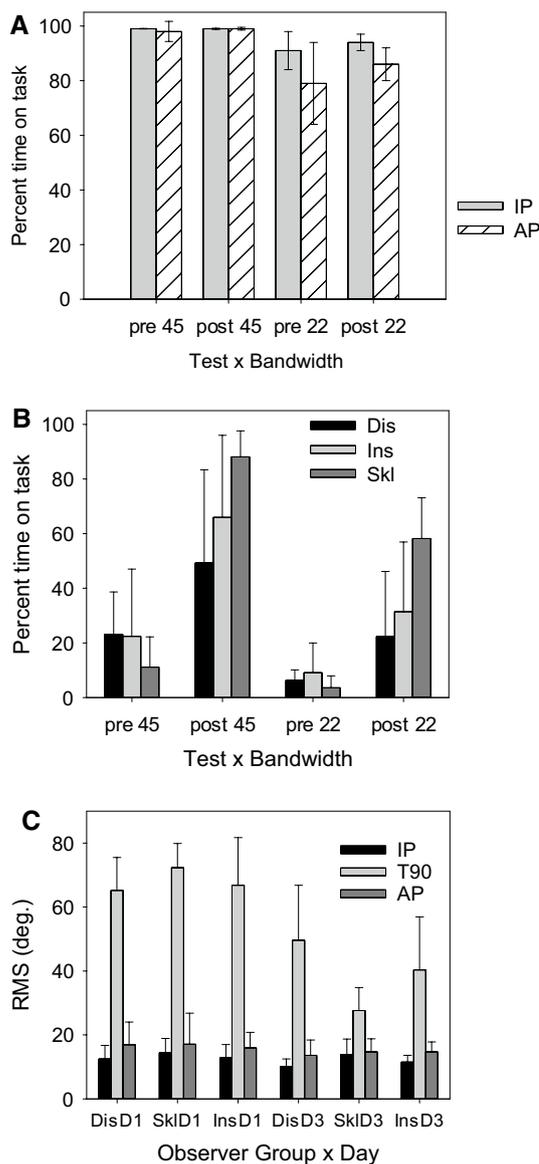


Fig. 2 Performance measures for bimanual task. **a** Percent time on task as a function of test (pre, post) for the in-phase (IP) and anti-phase (AP) patterns for the BW45 and BW22 measures. **b** Percent time on task as a function of test (pre, post) for the target pattern of 90° . **c** RMS for the IP, AP, and 90° pattern (T90) as a function of observer group (Ins, Dis, Skl) for the pre-test (D1) and post-test (D3) trials. The error bars represent standard error

in-phase and anti-phase ($ps > 0.7$) (Fig. 2a), yet did change significantly from pre- to post-observations for the target pattern of 90° , $F(5, 102) = 14.9$, $p < 0.0001$, $np^2 = 0.42$ (Fig. 2b). Further post-hoc tests ($p < 0.05$) revealed a significant increase in the BW22 value from pre- to post-tests for each observation group. There was no difference between groups in the pre-test, while in the post-test, the observers of the skilled model spent significantly

more time within a $\pm 22.5^\circ$ bandwidth than the other two observer groups (Fig. 2b).

The analysis of the RMS data revealed the following significant effects: test, $F(1, 102) = 52.05$, $p < 0.0001$, $\eta^2 = 0.34$, pattern, $F(2, 102) = 307.81$, $p < 0.0001$, $\eta^2 = 0.86$, test \times pattern, $F(2, 102) = 35.66$, $p < 0.0001$, $\eta^2 = 0.41$, and test \times model \times pattern, $F(4, 102) = 3.84$, $p < 0.01$, $\eta^2 = 0.13$ (see Fig. 2c). The test \times model interaction approached significance, $F(2, 102) = 2.98$, $p = 0.055$, $\eta^2 = 0.06$. Simple effect tests of the three-way interaction revealed that RMS did not change for in-phase and anti-phase across days and was not different between observers groups ($ps > 0.9$). RMS did change significantly from pre- to post-observation for the target pattern of 90° , $F(5, 102) = 29.78$, $p < 0.0001$, $\eta^2 = 0.59$. Post-hoc tests ($p < 0.05$) revealed a significant decrease in RMS from pre-test to post-tests for each observer group (Fig. 2c). There was no difference in RMS between groups in the pre-test, while in the post-test, observers of the skilled model had significantly lower RMS values compared to the other two observer groups.

Discussion

This experiment was designed to determine if model skill level interacted with a third-person viewpoint and influenced the selection of mirror or non-mirror responses in novice observers. It was predicted that the novice models (Ins, Dis) would support the use of a non-mirror right-hand lead in observers. This prediction was supported overall and was strongest in the observers of the instructional model (81%) and less so with the discovery model (57%). It was also predicted that the skilled model could support the use of a greater percentage of mirror-image left-hand leads in observers (81%) and this prediction was supported. The previous work using the same task did not reveal such distinct differences in observers hand selection preferences that watched the same instructional, skilled, and discovery models from a first-person perspective (Buchanan and Dean 2014). Why did the change in viewing perspective alter the pattern of hand selection processes?

An answer to the above question may reside in the type of information provided by a model type. In the introduction, it was noted that novice and skilled models afford observers a different look at certain task features, error detection/correction from a novice model, and strategy identification from an expert model (Rohbanfard and Proteau 2011b; Andrieux and Proteau 2014). Observers of the instructional model saw improvement across practice in the model's ability to produce the 90° pattern. Significant reduction in error and variability occurred as the model learned to lead with the right hand while using the CW:CCW strategy. If the development

of the right-hand lead is a component of the error correction/detection processes, then this may have focused attention onto that feature and resulted in the observers of this model mapping the model's right hand to their right hand. The observers of the discovery model, however, were exposed to trials with left-hand and right-hand leads in combination with different rotation strategies. This greater variation may have detracted from the observers' ability to make hand-lead a component of the error detection/correction process, resulting in less non-mirror right-arm leads. The skilled model demonstrated a consistent right-hand lead with the CW:CCW rotation strategy, and relative phase error and variability were minimal across trials. Observers of this model may have easily identified the right-hand lead and, therefore, directed more attention to trying to extract the produced relative phase between the hands. If less effort is directed at identifying hand-lead, then the selection of hand would most probably default to the mirror-image mode and thereby a left-hand lead emerged most often in this group. Future research needs to utilize dual task studies to clarify the proposed role for attention allocation with regard to strategy selection and performance outcome when viewing perspective is a component of an observational training context. Dual tasks may reveal more about, where an observer places their attention as a function of model skill level, regardless of strategy or hand selection.

The interaction between model type and attention processes outlined above may also find support in neural imaging work that has revealed that the anterior superior parietal lobule (aSPL) in both hemispheres is characterized by different levels of activation as a function of first-person and third-person viewpoints (Shmuelof and Zohary 2008; Koehler et al. 2012). A study by Shmuelof and Zohary (2008) used a visual half-field technique to show observers clips of a model's left or right hand performing an action and measured brain activation patterns with fMRI. The visual half-field technique presents a specific image (in this case the hand) to either the left or right visual field, thereby resulting in the image being projected almost exclusively to the contralateral visual cortex. The divided visual field technique capitalizes on the lateralization of the visual system in an attempt to isolate functional advantages associated with a given hemisphere. Participants in the Shmuelof and Zohary's (2008) study saw images of the left and right hands separately, yet saw each hand in both the left and right visual fields from a first- and third-person perspective. A first-person view of the left or right hand was associated with greater activity in the contralateral hemisphere for the observer. In other words, a viewed right-hand action was associated with more activity in the left-hemisphere aSPL of the observer than the right-hemisphere, with the opposite occurring for a viewed left-hand action. When viewing the model's hand action from the third-person perspective, this mapping was reversed. That is,

viewing a right-hand action from a third-person perspective produced more activity in the aSPL in an observer's right hemisphere compared to left hemisphere, with the opposite occurring when viewing a left-hand action. Shmuelof and Zohary (2008) concluded that this mirror-like mapping is evidence for an automatic simulation system that operates without an imitative response.

The results of Shmuelof and Zohary (2008) indicate that a component of the AON automatically accounts for viewpoint when developing an internal model representation for an observer. Caution is required in assuming that the lateralized functions identified with the visual half-field protocol in the Shmuelof and Zohary (2008) study will map directly to a bimanual task when the two hands are visible in both visual fields simultaneously. However, the lateralized differences between first- and third-person viewpoints identified do allow for specific explanations, that are testable, to be proposed for a bimanual task context. With that being said: the following explanation is proposed with regard to the current study: if the automatic mapping when viewing two hands is similar to the mapping when the hands are viewed individually, then when an observer views a model's hands from a third-person viewpoint, the activity in an observer's right-hemisphere aSPL may be linked more to left-hand motion, while activity in the observer's left-hemisphere aSPL may be linked more to right-hand motion. If the mappings were to hold up, and if little attention is given to strategy identification by an observer in this circumstance, then the automatic action-simulation system proposed by Shmuelof and Zohary (2008) might well support a mirror-image hand mapping in the current learning context and account for the predominant left-hand lead in the observer group that viewed the skilled model. On the other hand, if strategy must be identified as part of the learning process and significant attention is directed at this feature, then the automatic action-simulation system may be overridden and allow for a non-mirror mapping to emerge, as seen in the observers of the instructional model and to some extent in the observers of the discovery model. The current findings reveal a flexible AON network that supports motor skill learning within a variety of observational training contexts.

The possibility that more attentional effort was directed at strategy identification in observers of the two novice models may also account for the differences in performance outcomes between the groups. The current findings are consistent with the previous research showing that both skilled and learning models can equally support observational learning of motor skills (Martens et al. 1976; Blandin et al. 1999; Rohbanfard and Proteau 2011b; Andrieux and Proteau 2013; Harris et al. 2017). Overall, the observers of the skilled model were more accurate in their performance and more stable, a novel finding in itself compared to a lot of the previous research. If, as proposed, the observers of the skilled

model easily identified the right-hand lead and defaulted to a mirror-image response based on the idea of an automatic action-imitation system, then this should have freed up more attentional effort to be directed at identifying the relative phase pattern. Combining more attentional effort with the visual analysis of more stable performance may well account for the performance differences between groups. The component of the action that probably required the least amount of attentional effort to identify by the observers of the skilled and instructional models, hand rotation strategy, was a component that produced some variation in the observers of the discovery model. The observers of this model were characterized by the least amount of performance improvement following observational training. This suggests that the observers of the discovery model may have used more effort to identify hand-lead and rotation strategy compared to the other groups, and this lessened attentional resources that could be devoted to analyzing the relative phase pattern and thereby reducing error and variability.

An issue that emerges from this study is how generalizable are the findings with regard to using models trained with a different rotation strategy, such as CW:CCW. Studies have shown that the CW:CCW rotation strategy with a 0° phase lag between the hands (labeled symmetric) is more stable than a CW:CW (or CCW:CCW) rotation strategy with a 180° phase lag between the hands (labeled asymmetric) (Summers et al. 1995; Carson et al. 1997; Buchanan and Ryu 2005). Training models with a CW:CCW strategy with a phase lead of 90° may result in a more variable 90° pattern with larger error than what was found in the current study. If model skill level is the main factor in directing attention as proposed, the use of a different rotation strategy should not alter the findings with regard to mirror and non-mirror-hand selection if a right-hand lead is established, especially when placed within the context of the role that an automatic action-simulation system as proposed by Shmuelof and Zohary (2008) may play in mapping hand selection in the AON based on viewing perspective. The factor that may be more influenced is the extent of performance error and variability found in the three observer groups used in this study. If the modeled 90° pattern is performed with more variability and larger error when a CW:CCW (or CCW:CCW) rotation strategy is used, then the post-hoc performance of all three types of observer groups may have larger error and more variability, even with improvement. If observing a different direction strategy does not change the hand mapping observed in the current task, then such a finding would suggest the AON plays a prominent role encoding the spatial characteristics of the bimanual task. This does not mean that it plays no role in encoding the temporal characteristics. Extensive work has shown that temporal, anatomical, and spatial constraints influence the production of bimanual patterns in very specific ways (Kelso et al. 1986; Byblow et al.

1994; Swinnen 2002; Carson and Kelso 2004; Salesse et al. 2005; Temprado et al. 2007). However, with different rotation strategies, other constraints on bimanual coordination may play a more prominent role in determining performance outcomes than the encoding characteristics of the AON.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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