

Effects of Physical and Observational Practice on Intermanual Transfer

Amin Ghamari, Mehdi Sohrabi, and Alireza Saberi Kakhki

Ferdowsi University of Mashhad, Faculty of Sport Sciences, Mashhad, Razavi Khorasan Province, Iran.

ABSTRACT

Some studies have shown that different coordinate systems in the coding of movement sequences develop during observational and physical practice. According to Newell's (1986) constraints-led approach, such contradictions could possibly depend on task characteristics. Accordingly, in the present study, two experiments were designed using a five-segment sequence timing task, in which the instructions on how to perform the sequence were different. The task in the first experiment comprised an alternating shift of fast and slow segments, whereas the second experiment involved an incremental procedure from slow to fast. In these experiments, the intermanual transfer of absolute and relative timing through observational and physical practice was examined. Transfer conditions were such that they required the same motor commands (mirror transfer) or the same visual-spatial coordinates (non-mirror transfer) as those in the practice conditions. The first experiment showed that the transfer to the non-mirror condition for relative timing in the physical group was better than that to the mirror condition, while the transfer was similar for both conditions in the observational group, indicating a different pattern of transfer for relative timing. The relative timing transfer pattern in the second experiment was the same for both experimental groups, such that the physical and observational practice resulted in a similar transfer to both mirror and non-mirror conditions. In both experiments, observational and physical practice participants exhibited similar intramotor transfer of absolute timing under both transfer conditions. Thus, the task itself as a constraint was revealed to be an effective factor influencing the behavioral results derived from physical and observational practice.

KEYWORDS

observational and physical practice,
movement sequences,
coordinate system,
constraints-led approach,
absolute and relative timing

INTRODUCTION

Theoretical viewpoints in the field of motor control and learning have described two distinct and independent processing mechanisms responsible for organizing and executing movement sequences, which are located at two different levels of the nervous system (Keele, Jennings, Jones, Caulton, Cohen, 1995; Schmidt, 1975; Scully & Newell, 1985; Shea & Wulf, 2005; Verwey, 1999). One higher-level mechanism processes the underlying structures of the sequences, whereas the other is responsible for organizing the elements at lower levels. Nevertheless, by deducing from Newell's (1986) viewpoint on the three factors (in-

dividual, environment, and task) influencing motor task performance, this issue could possibly depend on transfer conditions and task characteristics.

One of the most important underlying structures and known relationships between the movement components in sequential tasks is

Corresponding author: Mehdi Sohrabi, Ferdowsi University of Mashhad, Faculty of Sport Sciences, Azadi Square, Mashhad, Razavi Khorasan Province, Iran.
E-mail: sohrabi@um.ac.ir

relative timing that, as an invariant feature of motor behavior, could remain unchanged while executing with the unpracticed limb at different absolute times (Schmidt, 1975, 2003). The method typically used to examine the transfer of timing information, including relative and absolute timing, has been the *intermanual transfer* from one limb to the other, so that the same visual-spatial coordinates are recruited for the two limbs, but with different patterns of muscle activation and joint angles. However, recent theoretical concepts of motor sequence learning, such as those proposed by Hikosaka et al. (1999, see also Hikosaka, Nakamura, Sakai, & Nakahara, 2002), explain that motor sequence processing in the brain is attributed to spatial (locations of the muscle groups assigned to the target and/or sequential target positions) and motor (sequences of activation patterns of agonist/antagonist muscle-joint angles) coordinate systems. Recent studies using relatively simple (Kovacs, Han, & Shea, 2009; Panzer, Krueger, Muehlbauer, Kovacs, & Shea, 2009; Hayes, Andrew, Elliott, Roberts, & Bennett, 2012) and complex (Kovacs, Han et al., 2009; Kovacs, Mühlbauer, & Shea, 2009; Panzer, Muehlbauer, et al., 2009; Kovacs, Boyle, Grutmatcher, & Shea, 2010; Panzer, Gruetzmacher, Fries, Krueger, & Shea, 2011) spatial-temporal movement sequences have shown different results for the left-to-right (and vice versa) hand transfer of spatial-temporal characteristics in terms of transfer conditions, in which a mirror (requiring the same motor commands as those in practice conditions) or a non-mirror pattern (requiring the same visual-spatial coordinates as those in practice conditions) of practiced task was used.

Physical practice, however, is not the only way to acquire new motor skills, and observing a model could facilitate learning in a wide range of behaviors, generally, and in particular in motor behavior (Bandura, 1986; Blandin, Lhuisset, & Proteau, 1999; Shea, Wright, Wulf, & Whitacre, 2000; Blandin & Proteau, 2000; Mattar & Gribble, 2005). An important theoretical framework regarding the efficacy of observational learning has been proposed by Scully and Newell (1985, see also Scully, 1986, 1987, 1988), which is based on Gibson's ecological approach to visual perception (1979). Specifically, this theoretical framework emphasizes the nature of the perceptual information that observers use to generate movement. The important point here is whether the task, considered as one of the movement constraints to motor performance, as proposed by Newell (1986), could also be effective in this transfer.

Some research at the behavioral (Blandin & Proteau, 2000; Bird & Heyes, 2005; Mattar & Gribble, 2005; Rizzolatti, Fogassi, & Gallese, 2001) and neuroimaging (Decety et al., 1997; Grèzes & Decety, 2001) level has shown that approximately similar processing mechanisms and shared neural structures are involved and activated in physical and in observational practice. Recent research, however, indicates that there are different results for physical and observational practice in the transfer of spatio-temporal movement characteristics (Gruetzmacher, Panzer, Blandin, & Shea, 2011; Boutin, Fries, Panzer, Shea, & Blandin, 2010) and the transfer of relative timing (Hayes et al., 2012) from the practiced to the unpracticed hand in terms of mirror (requiring the same pattern of homologous muscle activation as during practice) and non-mirror (requiring the same visual-spatial characteristics of the

sequence as during practice, but non-homologous muscle activation) transfer conditions.

With regard to the above-mentioned issues in relation to movement including control of movement timing, and according to Newell's (1986) perspective about the determining role of movement constraints (individual, environment, and task) affecting the performance of motor tasks, and also the contradictory findings regarding the functional equivalence between physical and observational practice, the current study addressed the question of whether the type of procedure by which the task is performed has an effect on the transfer of the relative and absolute timing from the practiced (or observed) to unpracticed (or unobserved) hand under transfer conditions, in which the visual-spatial coordinates (non-mirror transfer condition) or the motor coordinates (mirror transfer condition) for contralateral unpracticed (or unobserved) limb are the same as those used during the acquisition phase.

EXPERIMENT 1

In this experiment, it was tested the intermanual transfer of timing in a movement sequence that needed sequential segments was alternated with relatively high and low execution times (the task with the manner of intermittent performance).

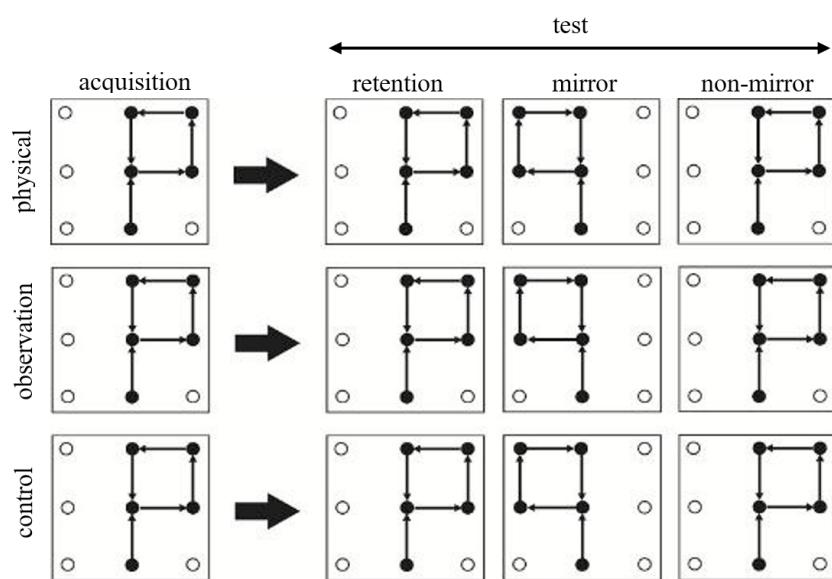
Method

PARTICIPANTS

A total of 36 healthy male volunteers (aged 22–34 years, $M = 27.6 \pm 3.4$), with no prior experience in similar motor skills and unfamiliar with the experimental task, were recruited at the Ferdowsi University of Mashhad (Iran). An equal number of participants was then randomly assigned to one of the three practice groups (physical practice, observational practice, and control), in which they were supposed to learn the task. All participants were right-handed, as assessed by the Edinburgh Handedness Inventory (Oldfield, 1971). The local ethics committee at The Ferdowsi University of Mashhad approved the experimental and consent procedures.

APPARATUS AND TASK

The apparatus designed for the present study, depicted in Figure 1, comprised a wooden square ($20 \text{ cm} \times 20 \text{ cm}$), on which 9 sensors were placed at a distance of 10 cm from each other, such that there was one sensor in the center, and the other eight ones positioned around it. The apparatus was wired in order to record the movement time (MT) for each segment (10 cm intervals) with a millisecond clock. The electronic measuring system worked with a frequency of 12 MHz and a precision of 1 ms. Touching the sensors caused the system to detect the duration between two sensors. The apparatus was connected to a computer, whereby criterion times were displayed on the monitor, then the time data generated by the participant were collected to be used for later statistical computations. The computer also provided feedback about the actual time of each segment and actual overall time, and

**FIGURE 1.**

Schematic illustrating the experimental design and direction of the movement for the task used in the acquisition, retention, and mirror and non-mirror transfer phases for the physical, observation, and control groups. The retention test was conducted immediately following the acquisition phase. Following the retention test, the two transfer tests (mirror and nonmirror) were conducted in a counterbalanced order.

displayed the difference together with the specified goal times. The experimental task required the subjects to execute sequences of these movement trajectories with their index finger. The tasks used in this study were five-segment sequences that differed with respect to the intended paths depending on the practiced hand and the conditions in which acquisition, retention, and transfer were being performed (see Figure 1). The tasks required the participants to meet the specified goal times for each segment and for the whole sequence. They were provided with feedback about their actual times after each trial and were encouraged to approximate these times to specified goal times. The MT goal for each segment was 460, 1150, 260, 700, and 215 ms, respectively, which constituted an alternation between relatively high and low execution times between the segments (the task with the manner of intermittent performance).

These quantities formed an absolute time goal (ATG) of 2775 milliseconds, which was the time duration to perform the entire movement. Therefore, the relative time goal (RTG) was 16% (450 ms) for Segment 1, 41% (1150 ms) for Segment 2, 9% (260 ms) for Segment 3, 25% (700 ms) for Segment 4, and 8% (215 ms) for Segment 5 (i.e., 450 ms + 1150 ms + 260 ms + 700 ms + 215 ms = 2775 ms). Being similar in time to the original task, the transfer included the mirror and non-mirror performance of the trained sequence during the acquisition phase under conditions in which the untrained left arm was used to conduct them (see Figure 1).

PROCEDURE

Participants were tested individually while sitting on a height-adjustable chair in a quiet, appropriately lit room, facing a computer and the apparatus on a desk at a distance of approximately 60 cm. They were

informed that they would be participating in a study in which basic perceptual-motor processes would be examined. Before entering the testing room, the participants were randomly divided into three equal groups: a physical practice group, an observational practice group, and a control group. Necessary instructions about how to execute the movement tasks were given to the participants by the examiner prior to the beginning of the practice session. All participants then completed a 5-trial pretest with the dominant right arm without feedback. This was followed by the practice phase for the physical practice group, which consisted of six blocks of 10 practice trials, with feedback on the execution time of each segment and the difference of the criterion values given after each trial. To ensure that the participants perceived the post hoc test knowledge of results (KR) correctly, they verbally explained to an experimenter how their performance differed, giving the ms duration the and direction from the ATG and the RTG (+ for *too slow* and – for *too fast*).

To present a learning model, each participant in the observation practice group was randomly paired with a participant in the physical practice group. Therefore, the participant in the observation group observed the execution of the task by the paired physical practice group member during the acquisition phase. The participant in the observation group was asked to sit with their arms at rest on the adjustable chair on the right side of the physical group participant performing the task, and while observing the execution of the task, to pay attention to the KR. In order to standardize the learning environment for the participants in the observation group, they also verbalized the MTs and the differences from the ATG and RTG criteria to the experimenter. In addition, to assess the effect of observation on learning, there was a control group who observed an irrelevant computer task.

STATISTICAL ANALYSIS

Performance on the task was evaluated by calculating the total error (errors in absolute timing) and the root mean square error (RMSE) for each segment (errors in relative timing) in each trial. The RMSE is the sum of the absolute differences between the goal proportions and the actual proportions for each segment in each trial. The total error is the deviation of the actual overall MT from the goal movement time in each trial, determining the bias and the stability of the total MT (Shea & Wulf, 2005). Therefore, the following two formulas were used for calculating the total error and relative timing error:

- (total error) $E_2 = CE_2 + VE_2$, where CE is a measure of response bias, computed as the average of the signed differences between actual total MT and the ATG, and VE is a measure of response variability, computed as the SD of the signed errors.
- Relative timing error = $|R_1 - 0.16| + |R_2 - 0.42| + |R_3 - 0.09| + |R_4 - 0.25| + |R_5 - 0.08|$, where R_1-R_5 are the proportions of total MT utilized in Segments 1–5.

Changes in motor performance during practice were initially computed as the pre-post difference for both total error and RMSE. Then, a one-way analysis of variance (ANOVA) was used to compare the group results. Intermanual transfer in the experimental groups was examined using separate Group (physical practice; observational prac-

tice) \times Phase (retention; mirror; non-mirror) ANOVAs on total error and RMSE, followed by the least significant difference (LSD) post hoc tests for group comparisons and interaction effects when the ANOVAs yielded a significant difference. All statistical analyses were performed at a significance level of .05.

Results

A one-way analysis of variance (ANOVA) was conducted to determine the existence of statistically significant differences between the three groups (physical practice, observational practice, and control) on Δ (post-pre) for the total error and relative error in each condition. The one-way ANOVAs detected main effects for total error, $F(2, 33) = 6.61, p < .01$, and RMSE, $F(2, 33) = 145.6, p < .01$. A post hoc analysis on total error (see Figure 2, Panel A) demonstrated no significant differences between the experimental groups, but the error in both groups was significantly lower than that in the control group ($p < .01$). However, for the RMSE (see Figure 2, Panel B), the post hoc comparisons revealed that the physical practice group significantly outperformed both the observational practice and the control group, while the observational practice group was better than the control group ($p < .01$).

The Group \times Phase ANOVA conducted on total error detected no significant main effects or interactions ($p > .05$), indicating the transfer of absolute timing under both of the transfer conditions

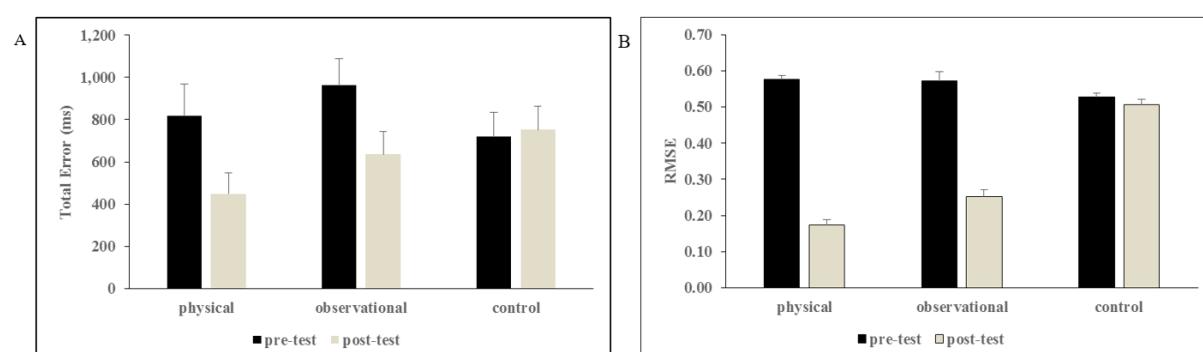


FIGURE 2.

Panel A: The mean data in the pre-test and post-test for total error as a function of group. Panel B: The mean data in the pre-test and post-test for the root mean square error (RMSE) as a function of group. Error bars represent the SEM.

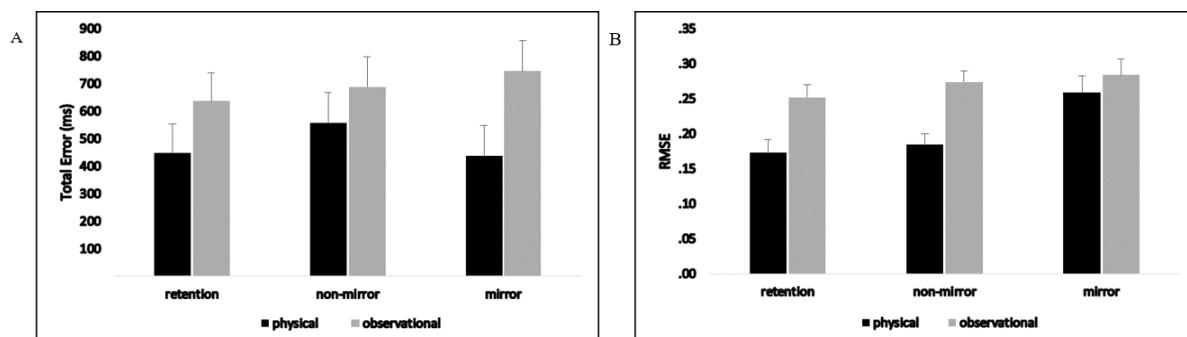


FIGURE 3.

Group mean data for physical practice (black bars) and observational practice (grey bars) for retention to mirror and non-mirror conditions. Panel A: total error. Panel B: root mean square error. Error bars represent the SEM.

(see Figure 3, Panel A). There were also no significant differences between the two groups, $p > .05$. In relation to the RMSE, there were significant main effects of group, $F(1, 22) = 6.76, p < .05$, and phase, $F(2, 44) = 18.79, p < .01$. The group and phase interaction was also significant, $F(2, 44) = 6.18, p < .01$. The physical practice group had lower RMSE than the observational practice group, $p < .05$.

A breakdown of this interaction (see Figure 3, Panel B) revealed that the physical practice group significantly outperformed the observational practice group in the retention and non-mirror phases, $p < .01$. However, there were no significant differences between the two groups in the mirror phase, $p > .05$. In the physical practice group, the RMSE in the retention and non-mirror transfer test was significantly lower compared to the mirror transfer test ($p < .01$), with no differences between each other, $p > .05$. In the observational practice group, there were no significant differences between the three phases, $p > .05$. Interestingly, while the observed difference between the mirror and non-mirror transfer in the physical practice group was significant ($p < .01$), this was not the case for the observational practice group, $p > .05$.

In an analysis of the individual segments in the post-test between the two experimental groups, there was a significant difference for the first segment, $t(22) = 2.62, p < .05$, the third segment, $t(22) = 4.03, p < .01$, the fourth segment, $t(22) = 2.64, p < .05$, and the fifth segment, $t(22) = 2.31, p < .05$. However, no significant differences were found between the second segment in the two experimental groups, $t(22) = 0.48, p > .05$.

Discussion

The purpose of the present experiment was to examine the effect of observational and physical practice on timing transfer of a five-segment motor task to the conditions in which mirror and non-mirror transfer tests were carried out with the unpracticed (contralateral) hand. The results showed superior retention performance in attaining the absolute and relative time goals for the experimental groups than for the control participants, indicating the effectiveness of observational practice in line with the findings and theoretical frameworks (Blandin & Proteau, 2000; Mattar & Gribble, 2005; Hayes et al., 2012; Scully, 1986, 1987, 1988; Scully & Newell, 1985). While there were no significant differences between the experimental groups in performing retention for absolute timing, the relative timing in the physical group was better than in the observational group. This finding, in line with the early views on processing the underlying structures and organizing the movement components forming the sequences, provides evidence for a dissociation between the independent processing mechanisms that are engaged in controlling relative and absolute timing (Keele et al., 1995; Schmidt, 1975; Scully & Newell, 1985; Shea & Wulf, 2005; Verwey, 1999).

A different relationship was observed in the results of the two groups in absolute and relative timing at the transfer stages. Participants in the physical practice and in the observation group did not perform differently in terms of the total error, such that the level of performance achieved at the retention for absolute timing was maintained on the

transfer tests. This shows that the general goal of the movement, like what is seen in the transfer of absolute timing from the practiced hand to the unpracticed hand in mirror and non-mirror transfer conditions, can be extended through observational practice similarly to physical practice. This finding is in accordance with the results of Hayes et al. (2012), which imply that learning absolute time involves a general, goal-related representation.

In relation to performance of relative timing from the retention to the transfer stages, the results were different for the two groups. In general, the physical practice group had a higher performance level than the observational group. This finding, in agreement with past research (Blandin et al., 1999; Shea et al., 2000), suggests that observational practice seems to cause the observer to employ some, but not all, of the cognitive processing involved in physical practice. Given the positive effect of observational practice on learning and transfer of the motor task in the current study, the findings are generally in line with the theoretical framework proposed by Scully and Newell (1985, see also Scully, 1986, 1987, 1988).

The results on the transfer tests are also noteworthy. In the physical practice group, the non-mirror transfer test, having no significant differences from the retention test, was performed better than the mirror transfer test. This confirmed and extended the findings of previous research (Kovacs et al., 2010; Kovacs, Han et al., 2009; Kovacs, Mühlbauer et al., 2009; Panzer, Mühlbauer et al., 2009; Panzer et al., 2011). Nevertheless, unlike the results of the physical practice group, no differences were found between the mirror and non-mirror transfer, contrary to past research findings (Gruetzmacher et al., 2011; Boutin et al., 2010). Yet, this supports the results of Hayes et al. (2012).

EXPERIMENT 2

The second experiment was designed around the assumption that the manner of performing a movement sequence inducing motor dynamics and perceptual requirements different from those of the first experiment affects the intermanual transfer of timing information in the sequence trained through physical and observational practice. In this experiment, a task similar to the one used in the first experiment (the same number of movement elements and the same overall execution time) was administered, except that the execution time was decreased as the sequence segments were performed. Accordingly, the first segment had the longest time (i.e., was the slowest), while the last segment had the shortest time (i.e., was the fastest).

Method

PARTICIPANTS

Thirty-six male students from the Ferdowsi University of Mashhad ranging in age from 21 to 32 years old ($M = 26.9 \pm 3.5$), with no prior experience with similar experimental tasks, voluntarily participated in this experiment. There was no overlap between the subjects of Experiments 1 and 2. They were all right-handed, as assessed by the Edinburgh Handedness Inventory (Oldfield, 1971). All participants

gave informed consent and the study was approved by the local ethics committee of The Ferdowsi University of Mashhad.

APPARATUS, TASK, AND PROCEDURE

The apparatus, tasks, procedures, and statistical analyses were the same as in Experiment 1, with the exception that execution durations of each of the five segments in the timing task were different, performed as decreasing in duration. The criterion of overall time, similar to the task in Experiment 1, had a duration of 2775 ms, and the segment criterion movement times were 1150, 700, 450, 260, and 215 ms, which were the same durations as the previous task, except in different order. The relative-time ratios were obtained by dividing the movement component durations by the total MT, including 41, 25, 16, 9, and 8%. Before entering the testing room, the participants were randomly divided into three equal groups: the physical practice group, the observational practice group, and the control group.

Results

A one-way ANOVA was conducted to determine the existence of statistically significant differences between the three groups on Δ scores ($\Delta = \text{post-pre}$) for the total error and relative error in both conditions. The one-way ANOVA detected main effects of total error, $F(2, 33) = 6.71, p < .01$, and RMSE, $F(2, 33) = 35, p < .01$. A post hoc

analysis on total error (see Figure 4, Panel A) demonstrated no significant differences between the experimental groups, but the error in both these groups was significantly lower than in the control group, $p < .01$. For the RMSE, (see Figure 4, Panel B), however, the post hoc comparisons revealed that the physical practice group significantly outperformed both the observational practice group and the control group, and that the observational practice group was better than the control group, $p < 0.01$.

The Group \times Phase ANOVA conducted on total errors detected no significant main effects or interactions ($p > .05$), indicating the transfer of absolute timing under both transfer conditions (see Figure 5, Panel A). Also, there were no significant differences between the two groups, $p > .05$. In relation to the RMSE, there were significant main effects for group, $F(1, 22) = 16, p < .01$, and phase, $F(2, 44) = 7.2, p < 0.01$, indicating that the physical practice group had lower RMSE than the observational practice group, $p < .01$. The interaction between group and phase was not significant, $F(2, 44) = 1.04, p > .05$, indicating that the change in performance across the three phases was similar for both training groups (see Figure 5, Panel B). More interestingly, a significant difference was not found for the mirror and non-mirror transfer in both the physical and observational practice groups, $p > .05$, indicating similar performance patterns in the transfer tests under both training conditions.

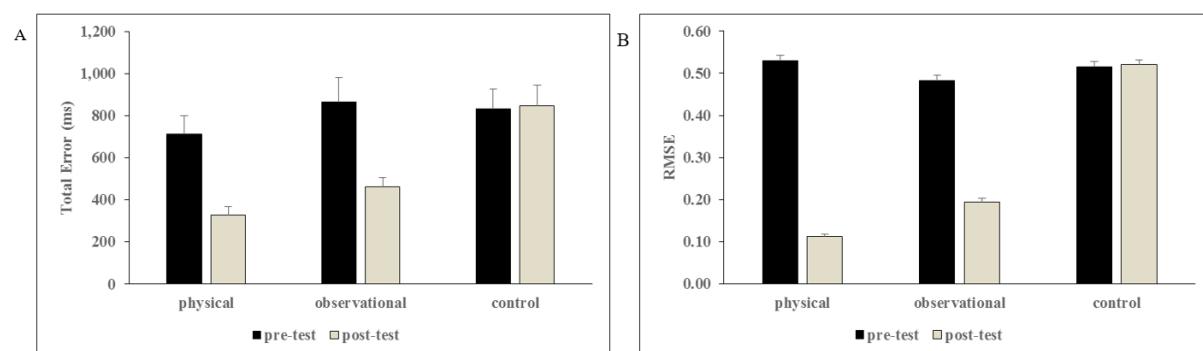


FIGURE 4.

Panel A: mean data in pre-test and post-test for total error as a function of group. Panel B: mean data in pre-test and post-test for root mean square error as a function of group. Error bars represent the SEM.

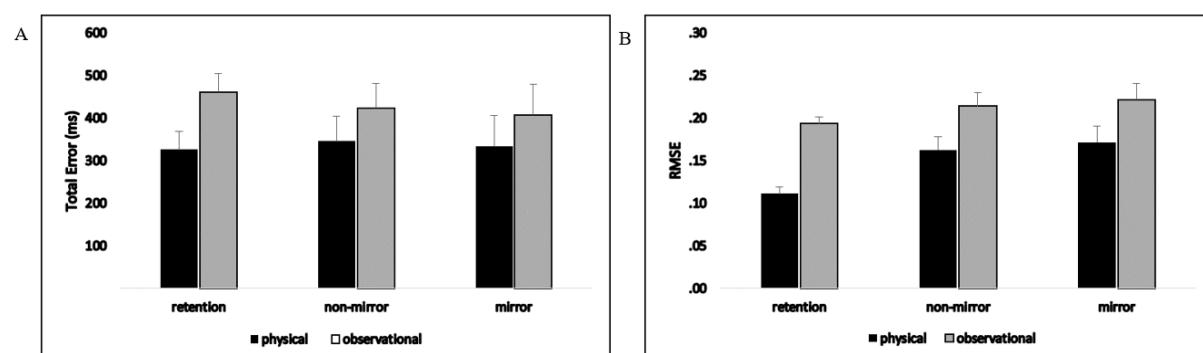


FIGURE 5.

Group mean data for physical practice (black bars) and observational practice (grey bars) for retention to mirror and non-mirror conditions. Panel A: total error. Panel B: root mean square error. Error bars represent the SEM.

In an analysis of the individual segments in the post-test between the two experimental groups, there were no significant differences for the first segment, $t(22) = 1.91, p = .069$, the second segment, $t(22) = 0.15, p = .881$, the third segment, $t(22) = 1.8, p = .086$, and the fourth segment, $t(22) = .77, p = .448$. However, a significant difference was found between the fifth segment in the two experimental groups, $t(22) = 2.62, p = .016$.

Discussion

The performance superiority in experimental groups compared with the control group for the examined variables, having a similar pattern of results to that obtained in Experiment 1, showed that individuals are able to perceive and acquire the timing characteristics of the movement by observation without overt practice, which confirms previous findings and early theories of observational learning (Blandin & Proteau, 2000; Mattar & Gribble, 2005; Hayes et al., 2012; Scully, 1986, 1987, 1988; Scully & Newell, 1985). On the other hand, the physical group performance on the relative timing was more influential than for the observation group, whereas this superiority was not found in the absolute timing. Therefore, consistent with the results of Experiment 1, this dichotomy between the relative and absolute timing results supported the idea that there are independent mechanisms for the processing of different movement characteristics (Keele et al., 1995; Schmidt, 1975; Scully & Newell, 1985; Shea & Wulf, 2005; Verwey, 1999). This also held true for the transfer of time information from the retention to the transfer tests.

The discrepancy in performance between the retention and transfer tests concerning relative timing, however, was related to the physical practice group. Participants performed the retention test with the same limb as during practice, whereas in the mirror and non-mirror conditions of the practice task, the contralateral limb was used for transfer tests. The participants in this study were all right-handed. The descending trend of the performance time for sequential segments has probably led the learners to have longer processing times in the first segments, which were slower than the last ones. This could have caused a better understanding of the movement-related information, and thus, in this type of task and with this amount of practice, there emerged an opportunity to exploit and develop muscle-specific characteristics in an attempt to refine the movement pattern. Consequently, despite the positive transfer of information to the opposite, unpracticed limb, the more preferable control and efficiency of the practiced limb probably resulted in the difference between the retention and transfer tests. This finding points to the fact that the asymmetry in inter-limb transfer depends on whether the dominant or the non-dominant arm is used during practice (Sainburg, 2002; Sainburg & Wang, 2002).

Of particular interest in the current study, however, were the results regarding the relative timing transfer between the experimental groups. This pattern, contrary to that achieved in Experiment 1, was similar in the groups allocated to physical or observational practice, meaning the performance of relative timing did not differ significantly between the transfer tests. This was true in each experimental group.

GENERAL DISCUSSION

This study aimed to investigate the effects of physical and observational practice on the intermanual transfer of absolute and relative timing in a sequential timing task. Since it was assumed that the task procedure affects learning transfer, two experiments were designed so that the time order of the segments was first an alternation formed from relatively fast and slow segments, and second - an incremental procedure from slow to fast.

The results revealed that regardless of the way the task was executed, observing without overt practice had a positive effect on learning and transferring the overall timing characteristics of the movement. This effect was as efficient as actual physical practice, which is a result compatible with past research (Blandin & Proteau, 2000; Hayes et al., 2012). However, it was contrary to predictions proposed by Scully and Newell (1985). In fact, in the tasks considered by Scully and Newell (1985; see also Scully, 1986, 1987, 1988) for the observational learning effectiveness, emphasis was placed on intra-and inter-limb coordination as well as on the relationship between body parts and the environment. The overall duration of the movement has not been a very substantial agent. But in tasks used in the present study, where a single limb was involved in performing the movement, the absolute movement time was taken into account as an important feature.

The relative timing transfer data are also notable. While in Experiment 1, the transfer pattern to the mirror and non-mirror conditions between observational and physical practice groups was different, contrary to the idea of functional equivalence between action production and action perception, the results of Experiment 2 showed that physical and observational practice led to the same transfer pattern, consistent with previous findings reflecting the shared processing mechanisms between physical and observational learning (Blandin & Proteau, 2000; Bird & Heyes, 2005; Mattar & Gribble, 2005; Rizzolatti et al., 2001; Decety et al., 1997; Grèzes & Decety, 2001).

According to the constraints-led approach (Newell, 1986), a movement is the result of a dynamic interaction between the individual, the task, and the environment, and due to a change in one of these constraints, movement performance is affected. A decreasing performance procedure, compared to an alternating one, creates different movement dynamics, which seem to give rise to different perceptual, cognitive, and motor requirements. These changes appear to have produced a new form of interaction between the task and the other constraints, which were held constant in both experiments. Eventually, this new interaction has possibly contributed to a person training physically or observationally being able to perform the learned sequence while using the untrained contralateral limb under both the mirror and non-mirror transfer conditions. Therefore, the representation of movement sequences in the form of motor or visual-spatial coordinates and the equivalent coding of observed and executed actions depends on movement constraints, particularly task-specific constraints, according to the present study.

Taken together, these findings lead to developing the theoretical perspectives on human movement behavior and to increasing our

understanding of sequence representation and production. Many skills and tasks in daily life and in sport involve a sequence of continuous movements. The inference of similarities and differences between the processes and factors influencing physical and observational learning creates a more comprehensive insight into what is necessary for people to learn those tasks well. These findings suggest that when researchers examine different variables to understand the processes involved in motor learning, the nature and manner of performing the task should be taken into account.

The findings, however, should be interpreted with caution, because measurements in this study were restricted to the execution time from the beginning to the end of each segment, due to apparatus limitations in the research, whereas the amount of variations along the path and when shifting from one segment to another is a determinative factor. In addition, velocity and force have not been controlled along the paths, which could provide very important information about movement representation.

ACKNOWLEDGEMENTS

This article is based on data from an unpublished dissertation by Amin Ghamari.

REFERENCES

- Bandura, A. (1986). *Social foundations of thought and action: A social cognitive theory*. Englewood Cliffs, NJ: Prentice Hall.
- Bird, G., & Heyes, C. (2005). Effector-dependent learning by observation of a finger movement sequence. *Journal of Experimental Psychology: Human Perception and Performance*, 31, 262–275. doi:10.1037/0096-1523.31.2.262
- Blandin, Y., & Proteau, L. (2000). On the cognitive basis of observational learning: development of mechanisms for the detection and correction of errors. *Quarterly Journal of Experimental Psychology*, 53, 846–867. doi:10.1080/713755917
- Blandin, Y., Lhuisset, L., & Proteau, L. (1999). Cognitive processes underlying observational learning of motor skills. *Quarterly Journal of Experimental Psychology*, 52, 957–979. doi: 10.1080/713755856
- Boutin, A., Fries, U., Panzer, S., Shea, C. H., & Blandin, Y. (2010). Role of action observation and action in sequence learning and coding. *Acta Psychologica*, 135, 240–251. doi:10.1016/j.actpsy.2010.07.005
- Decety, J., Grèzes, J., Costes, N., Perani, D., Jeannerod, M., Procyk, E., ... & Fazio, F. (1997). Brain activity during observation of actions. Influence of action content and subject's strategy. *Brain*, 120, 1763–1777. doi:10.1093/brain/120.10.1763
- Gibson, J. J. (1979). *The Ecological approach to visual perception*. Boston, MA: Houghton Mifflin.
- Grèzes, J., & Decety, J. (2001). Functional anatomy of execution, mental simulation, observation, and verb generation of actions: A meta-analysis. *Human Brain Mapping*, 12, 1–19. doi: 10.1002/1097-0193(200101)12:1<1::AID-HBM10>3.0.CO;2-V
- Gruetzmacher, N., Panzer, S., Blandin, Y., & Shea, C. H. (2011). Observation and physical practice: Coding of simple motor sequences. *The Quarterly Journal of Experimental Psychology*, 64, 1111–1123. doi:10.1080/17470218.2010.543286
- Hayes, S. J., Andrew, M., Elliott, D., Roberts, J. W., & Bennett, S. J. (2012). Dissociable contributions of motor-execution and action-observation to intermanual transfer. *Neuroscience Letters*, 506, 346–350. doi: 10.1016/j.neulet.2011.11.045
- Hikosaka, O., Nakahara, H., Rand, M. K., Sakai, K., Lu, X., Nakamura, K., ... & Doya, K. (1999). Parallel neural networks for learning sequential procedures. *Trends in Neurosciences*, 22, 464–471. doi:10.1016/S0166-2236(99)01439-3
- Hikosaka, O., Nakamura, K., Sakai, K., & Nakahara, H. (2002). Central mechanisms of motor skill learning. *Current Opinion in Neurobiology*, 12, 217–222. doi:10.1016/S0959-4388(02)00307-0
- Keele, S. W., Jennings, P., Jones, S., Caulton, D., & Cohen, A. (1995). On the modularity of sequence representation. *Journal of Motor Behavior*, 27, 17–30. doi: 10.1080/00222895.1995.9941696
- Kovacs, A. J., Boyle, J., Grutmatcher, N., & Shea, C. H. (2010). Coding of on-line and pre-planned movement sequences. *Acta Psychologica*, 133, 119–126. doi:10.1016/j.actpsy.2009.10.007
- Kovacs, A. J., Han, D. W., & Shea, C. H. (2009). Representation of movement sequences is related to task characteristics. *Acta Psychologica*, 132, 54–61. doi:10.1016/j.actpsy.2009.06.007
- Kovacs, A. J., Mühlbauer, T., & Shea, C. H. (2009). The coding and effector transfer of movement sequences. *Journal of Experimental Psychology: Human Perception and Performance*, 35, 390–407. doi:10.1037/a0012733
- Lai, Q., & Shea, C. H., Bruechert, L., & Little, M. (2002). Auditory model enhances relative-timing learning. *Journal of Motor Behavior*, 34, 299–307. doi:10.1080/00222890209601948
- Mattar, A. A. G., & Gribble, P. L. (2005). Motor learning by observing. *Neuron*, 46, 153–160. doi:10.1016/j.neuron.2005.02.009
- Newell, K. M. (1986). Constraints on the development of coordination. In M. G. Wade & H. T. A. Whiting (Eds.), *Motor development in children: Aspects of coordination and control* (pp. 341–360). Boston, MA: Martinus Nijhoff.
- Oldfield, R. C. (1971). The assessment and analysis of handedness: the Edinburgh inventory. *Neuropsychologia*, 9, 97–113. doi: 10.1016/0028-3932(71)90067-4
- Panzer, S., Gruetzmacher, N., Fries, U., Krueger, M., & Shea, C. H. (2011). Age-related effects in interlimb practice on coding complex movement sequences. *Human Movement Science*, 30, 459–474. doi:10.1016/j.humov.2010.11.003
- Panzer, S., Krueger, M., Muehlbauer, T., Kovacs, A. J., & Shea, C. H. (2009). Inter-manual transfer and practice: Coding of simple motor sequences. *Acta Psychologica*, 131, 99–109. doi: 10.1016/j.actpsy.2009.03.004
- Panzer, S., Muehlbauer, T., Krueger, M., Buesch, D., Naundorf, F., & Shea, C. H. (2009). Effects of interlimb practice on coding and learning of movement sequences. *The Quarterly Journal of Experimental Psychology*, 62, 1265–1276. doi:10.1080/17470210802671370

- Rizzolatti, G., Fogassi, L., & Gallese, V. (2001). Neurophysiological mechanisms underlying the understanding and imitation of action. *Nature Reviews Neuroscience*, 2, 661–670. doi: 10.1038/35090060
- Schmidt, R. A. (1975). A schema theory of discrete motor skill learning. *Psychological Review*, 82, 225–260.
- Schmidt, R. A. (2003). Motor schema theory after 27 years: Reflections and implications for a new theory. *Research Quarterly for Exercise and Sport*, 74, 366–375. doi: 10.1080/02701367.2003.10609106
- Scully, D. M. (1986). Visual perception of technical execution and aesthetic quality in biological motion. *Human Movement Science*, 5, 185–206. doi:10.1016/0167-9457(86)90024-2
- Scully, D. M. (1987). *Visual perception of biological motion* [Unpublished doctoral dissertation]. University of Illinois at Urbana-Champaign.
- Scully, D. M. (1988). Visual perception of human movement: The use of demonstrations in teaching motor skills. *British Journal of Physical Education, Research Supplement*, 4, 12–14.
- Scully, D. M., & Newell, K. M. (1985). Observational learning and the acquisition of motor skills: Toward a visual perception perspective. *Journal of Human Movement Studies*, 11, 169–186.
- Shea, C. H., & Wulf, G. (2005). Schema theory: A critical appraisal and reevaluation. *Journal of Motor Behavior*, 37, 85–102. doi: 10.3200/JMBR.37.2.85-102
- Shea, C. H., Wright, D. L., Wulf, G., & Whitacre, C. (2000). Physical and observational practice afford unique learning opportunities. *Journal of Motor Behavior*, 32, 27–36. doi: 10.1080/00222890009601357
- Verwey, W. B. (1999). Evidence for a multistage model of practice in a sequential movement task. *Journal of Experimental Psychology: Human Perception and Performance*, 25, 1693–1708. doi:10.1037/0096-1523.25.6.1693
- Sainburg, R. L. (2002). Evidence for a dynamic-dominance hypothesis of handedness. *Experimental Brain Research*, 142, 241–258. doi: 10.1007/s00221-001-0913-8
- Sainburg, R. L., & Wang, J. (2002). Interlimb transfer of visuomotor rotations: independence of direction and final position information. *Experimental Brain Research*, 145, 437–447. doi: 10.1007/s00221-002-1140-7

RECEIVED 22.04.2018 | ACCEPTED 27.12.2018