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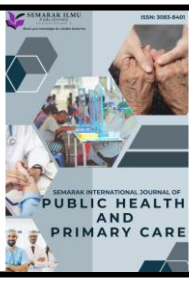


# Asymmetrical Bilateral Transfer of Motor Learning: Evidence from Mirror Tracing Experimental Design

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**ABSTRACT**

The concept of bilateral transfer in motor learning suggests that skill acquisition in one limb can influence performance in the contralateral limb. This phenomenon has practical implications in rehabilitation, skill training, and neuromotor re-education. However, the extent to which such transfer occurs symmetrically or asymmetrically remains a subject of empirical investigation. This study aimed to validate the presence and directionality of transfer of learning using a mirror tracing task, a visuomotor coordination activity known to reflect fine motor adaptation. Fifteen participants completed four phases of tracing tasks: initial non-preferred hand (NP_pre), preferred hand trials (P1 and P2), and final non-preferred hand (NP_post). The scoring method was based on an inverse scale of time and error (divided by 100), whereby higher scores indicate better performance. Descriptive statistics revealed a progressive increase in mean scores across trials (NP_pre = 0.97, P1 = 1.10, P2 = 1.34, NP_post = 1.53), indicating learning and transfer effects. A repeated measures ANOVA showed a statistically significant main effect of trial, $F(3, 42) = 7.15$, $p = 0.0006$, confirming differences in performance across the four conditions. Bonferroni-corrected pairwise comparisons further revealed that performance in NP_post was significantly higher than in NP_pre ($p = 0.0006$), P1 ($p = 0.0046$), and P2 ($p = 0.0028$). However, comparisons between NP_pre and P1 ($p = 0.495$) was not statistically significant after adjustment. These findings indicate that performance improvements with the preferred hand can transfer to the non-preferred hand (asymmetrical transfer), and that practice with one hand can enhance subsequent performance of the same hand after an intermanual phase (symmetrical transfer). This supports bilateral models of motor learning, including cross-activation and bilateral access frameworks. In conclusion, the mirror tracing task successfully captured both forms of bilateral transfer, reinforcing the value of structured intermanual tasks in validating neural plasticity and learning generalization.

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## 1. Introduction

Bilateral transfer is a well-documented phenomenon in motor learning, wherein the acquisition of a skill in one limb enhances performance in the contralateral limb. This intermanual transfer is grounded in the brain's capacity for cross-hemispheric communication, primarily mediated by the corpus callosum, which enables the sharing of sensorimotor representations between hemispheres [5]. The concept of bilateral transfer is particularly significant in fields such as rehabilitation, sports training, and neuromotor development, where improvements in one limb can facilitate gains in the untrained limb.

Two primary models explain this phenomenon: the cross-activation model and the bilateral access model. The cross-activation model posits that unilateral motor practice leads to adaptations in both the contralateral and ipsilateral motor cortices, due to neural activation across hemispheres during motor execution [4]. In contrast, the bilateral access model suggests that a shared neural representation formed during skill acquisition can be accessed by both limbs, regardless of which limb was used during practice [1]. Both models underscore the neural plasticity underpinning interlimb transfer and suggest that such transfer may not be symmetrical in strength or direction.

Recent empirical evidence supports the presence of asymmetrical transfer, with stronger effects from the dominant to the non-dominant hand than vice versa [2]. Additionally, training the preferred limb has been shown to elicit significant performance gains in the non-preferred limb, especially in tasks requiring precision and coordination [3]. However, the extent and symmetry of such transfer remain context- and task-dependent, warranting further empirical investigation using structured tasks like mirror tracing.

Despite extensive theoretical grounding, there remains limited empirical validation of both symmetrical and asymmetrical bilateral transfer in structured visuomotor tasks such as mirror tracing. Understanding whether learning with one hand can enhance performance both on the opposite hand and back on the original hand after intermanual practice is crucial for refining motor learning models and therapeutic interventions.

Moreover, there is a lack of structured investigations that assess transfer dynamics over multiple sequential trials, particularly using both preferred and non-preferred limbs in repeated mirror tracing activities. This gap limits our understanding of the directional strength and practical application of intermanual transfer in performance-based learning environments. Hence, there is a pressing need to evaluate the nature of bilateral transfer in a systematic and measurable manner that accounts for directionality, task structure, and performance progression.

The present study was designed to address the gap by pursuing the following specific objectives, (i) to determine the presence of bilateral transfer in a mirror tracing task using both non-preferred and preferred hands across four structured trials, (ii) to evaluate the asymmetrical nature of learning transfer, particularly whether skill acquisition with the preferred hand enhances subsequent performance in the non-preferred hand, (iii) to examine symmetrical transfer effects, focusing on performance changes when participants return to using the non-preferred hand after intervening practice with the preferred hand, and (iv) to validate the effectiveness of the mirror tracing task as a tool for observing intermanual transfer and to explore its implications for motor learning applications in sports and education.

The present study offers valuable contributions to both the fields of sports performance and educational motor learning. By empirically confirming the existence of both asymmetrical and symmetrical bilateral transfer through a structured mirror tracing task, the findings have multiple applied implications.

First, in the context of sports training, the study demonstrates that motor skills practiced with the preferred limb can significantly enhance performance in the non-preferred limb. This asymmetrical transfer effect suggests that training programs can be strategically designed to maximize motor efficiency and coordination using unilateral drills, particularly beneficial when time constraints or fatigue limit bilateral practice. Such findings are especially relevant in sports requiring ambidextrous proficiency, including basketball, fencing, or racquet sports, where enhancing non-dominant limb capability can provide competitive advantages.

Second, the outcomes of this study support the integration of bilateral motor learning strategies in educational settings. In physical education and skill-based instructional programs, incorporating tasks that require alternation between limbs—such as mirror tracing or coordinated hand exercises—can foster improved hand-eye coordination, attention, and neuro-motor adaptability among learners. These benefits are pertinent across all educational levels, from early childhood development to tertiary-level motor learning curricula.

Third, the demonstrated evidence of intermanual transfer presents a practical framework for inclusive education and rehabilitation. The ability to improve performance in one limb through training of the contralateral limb is especially beneficial for individuals with unilateral motor limitations, including those recovering from injury or coping with neurological impairments. Educators and rehabilitation specialists can utilize this principle to design adaptive programs that promote recovery and learning through cross-limb facilitation.

In sum, the significance of this study lies in its ability to bridge theoretical models of bilateral transfer with real-world applications, offering a scientifically grounded approach to enhancing motor performance in both athletic and educational environments.

## 2. Methodology

### *2.1 Design*

This study employed a quantitative repeated-measures design to evaluate the effects of practice and hand switching on bilateral transfer during a mirror tracing task. The aim was to determine the direction and type of learning transfer by measuring performance improvements across sequential trials.

### *2.2 Participants*

Fifteen (N = 15) healthy volunteers were recruited through convenience sampling. All participants were free from any diagnosed motor or neurological impairments and had varying levels of motor skill experience. The sample was selected to reflect a range of motor control capabilities and handedness tendencies relevant to the study's focus on bilateral skill transfer, transfer of information from the preferred to non-preferred peripheral or vice versa.

### *2.3 Procedure*

The experiment was conducted in a controlled laboratory environment using the Lafayette Auto Scoring Mirror Tracer (Model 58024E). Participants were individually seated in front of the device, which consists of a horizontal tracing surface and an overhead mirror angled to reflect the tracing path. The design ensures that participants rely solely on mirrored visual feedback, creating a visuomotor inversion that challenges perceptual-motor coordination.

Before beginning the task, each participant was briefed on the procedure and provided with one non-scored familiarization trial using their non-preferred hand to minimize anxiety and ensure understanding of the equipment. They were then instructed to trace a fixed six-pointed star path affixed to the platform using a stylus attached to the instrument. This path was consistent across all trials and participants.

The testing session consisted of four consecutive trials conducted in the following order as shown in Figure 1:

i. Trial 1 (NP_pre) – Participants used their non-preferred (typically non-dominant) hand to trace the star pattern.
ii. Trial 2 (P1) – Participants switched to their preferred (dominant) hand for the first trial.
iii. Trial 3 (P2) – A second tracing was completed with the preferred hand to facilitate within-hand practice and reinforcement.
iv. Trial 4 (NP_post) – Participants returned to the non-preferred hand for a final tracing trial to assess transfer effects.

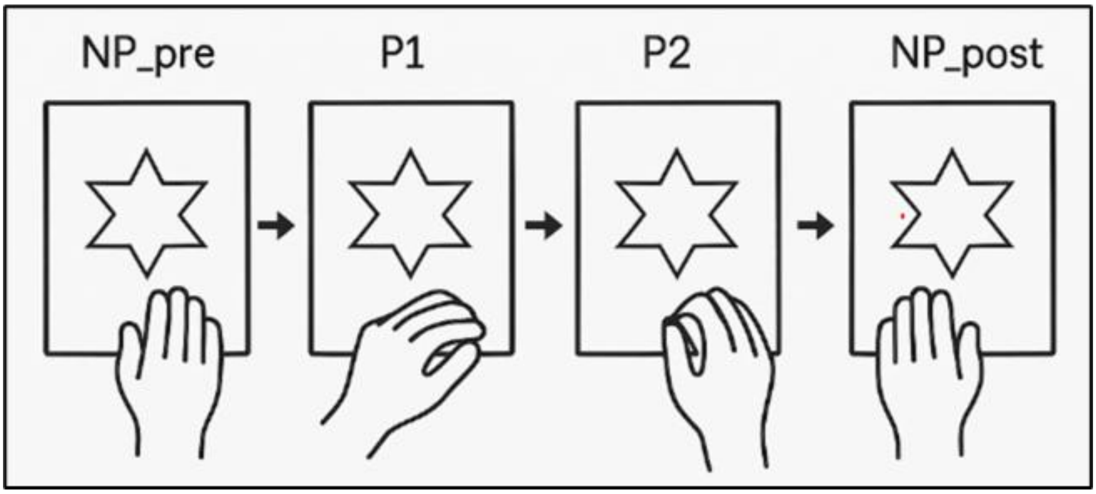


**Fig. 1.** Sequence of mirror tracing trial

Each tracing trial was completed without a time limit, though participants were instructed to trace as accurately and quickly as possible. The device automatically recorded (i) time to complete the tracing (in seconds) and (ii) number of errors, which were counted each time the metal stylus deviated and contacted the star's boundary. To calculate the score for every trial, equation from Figure 2 was utilized:

$$SCORE = \frac{TIME + ERROR}{100}$$

**Fig. 2.** Equation for score computation

Where:

i. Score represents the performance index (higher = better performance),
ii. Time is the duration taken to complete the mirror tracing task,
iii. Error is the number of deviations or mistakes recorded during the task.

Participants were required to complete each tracing in the same direction and starting point, standardized across all trials. Breaks of 30 to 60 seconds were allowed between trials to minimize fatigue but avoid retention interval effects [6].

*2.4 Data Analysis*

Descriptive statistics (Mean ± SD) were calculated for each phase. A One-Way Repeated Measures ANOVA was used to test for performance differences across trials, with Bonferroni-corrected post-hoc tests identifying pairwise significance. A p-value of < .05 was used to indicate statistical significance.

## 3. Results

The mirror tracing task evaluated participants' performance across four stages:

i. NP_pre: Non-Preferred Hand (Initial Trial)
ii. P1: Preferred Hand (First Trial)
iii. P2: Preferred Hand (Second Trial)
iv. NP_post: Non-Preferred Hand (Final Trial)

Higher scores represent better performance (faster and fewer errors). The analysis included 15 participants. The improvement was calculated as the difference between consecutive scores.

A one-way repeated measures ANOVA was conducted to determine whether there were statistically significant differences in performance across the four trial conditions. The analysis yielded a significant main effect of trial, F (3, 42) = 7.15, p = 0.0006, indicating that participants' performance scores differed significantly across at least one pair of trials. Figure 3 depicts the distribution of scores for each trial using a boxplot. The graph illustrates a consistent trend of improvement from NP_pre through P2 to NP_post. This visual representation aligns with the inferential results, showing reduced variability and higher median scores by the final trial.

**Table 1**
Descriptive value for all interactions

| Comparison | Mean Change | Std. Dev. | Min | Max | Interpretation |
|---|---|---|---|---|---|
| NP_pre → P1 | +0.131 | 0.726 | -0.870 | +2.320 | Mixed trend: some worsened (negative score) indicating interference, others improved. |
| P1 → P2 | +0.237 | 0.420 | -0.440 | +1.080 | Majority improved: shows practice effect on preferred hand. |
| P2 → NP_post | +0.186 | 0.199 | -0.140 | +0.570 | Indicates positive bilateral transfer back to non-preferred hand. |
| NP_pre → NP_post | +0.555 | 0.488 | +0.050 | +2.040 | Strong overall improvement on non-preferred hand, suggesting symmetrical bilateral transfer. |

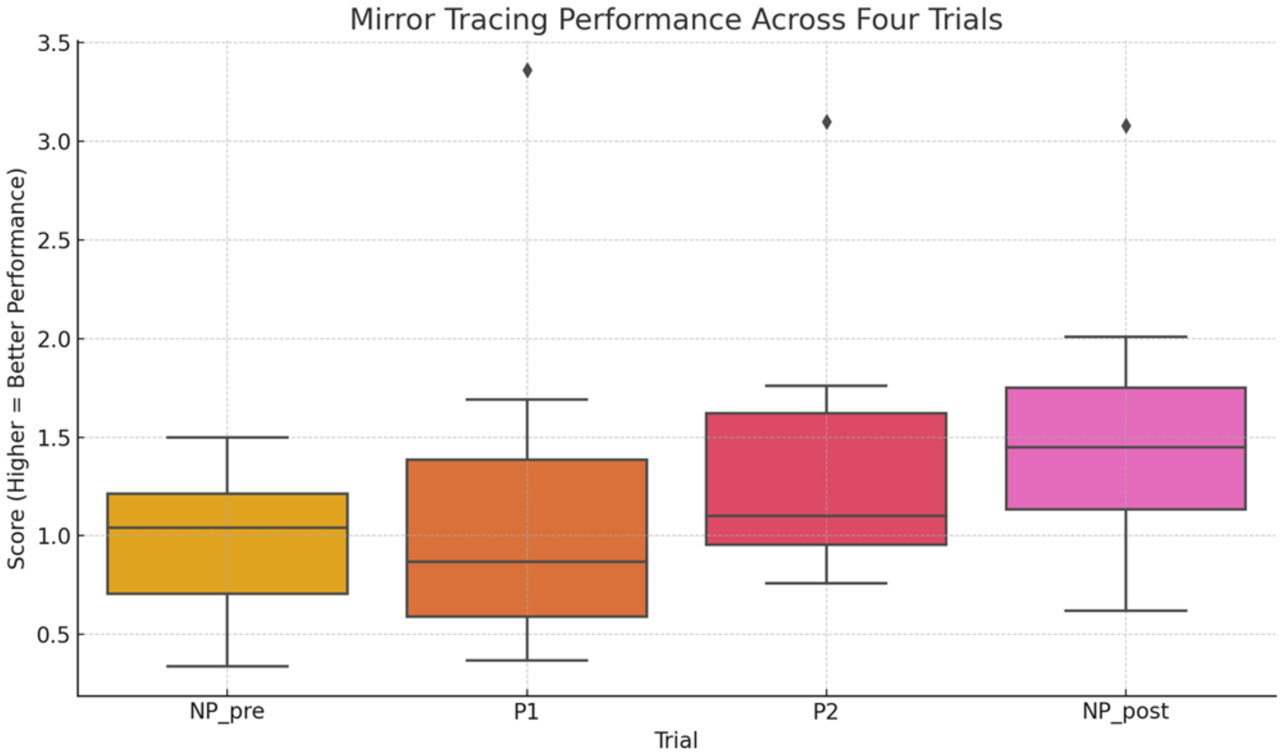


**Fig. 3.** Mirror tracing performance ([Time + Error] / 100)

According to Table 2, the non-significant, NP_pre → P1 transition shows some participants may initially perform worse when switching from non-preferred to preferred hand—possibly due to a lack of familiarity or context shift. The significant improvement from P1 → P2 indicates within-hand learning as performance improved on repeated trials using the preferred hand. The significant gains from P2 → NP_post support asymmetric to symmetric transfer, demonstrating how skills learned with the dominant hand enhance performance of the non-dominant hand upon return. Overall, the significant NP_pre → NP_post comparison confirms robust bilateral transfer, especially as learning appears to generalize from preferred to non-preferred hand over trials.

**Table 2**
Inferential statistics

| Comparison | T-statistic | P-value | Interpretation |
|---|---|---|---|
| NP_pre vs P1 | 0.70 | 0.495 | No significant improvement, possibly initial interference due to hand switching. |
| P1 vs P2 | 2.19 | 0.046 | Indicates learning effect on preferred hand through practice. |
| P2 vs NP_post | 3.61 | 0.003 | Significant bilateral transfer from preferred to non-preferred hand. |
| NP_pre vs NP_post | 4.40 | 0.001 | Strong evidence of symmetrical bilateral transfer (long-term benefit on NP hand). |

This phenomenon aligns with contemporary theories of bilateral transfer of learning such as the cross-activation model and the bilateral access model [1,7], which suggest that neural pathways engaged during practice on one side may support performance improvements on the opposite side.

## 4. Discussions

The present study provides strong evidence for the presence of bilateral transfer (BT) in motor learning through a structured mirror tracing task. Participants exhibited statistically significant improvement between the second preferred-hand trial (P2) and the final non-preferred-hand trial (NP_post) ($p = .003$), reflecting robust asymmetrical transfer—a process whereby skills acquired using the preferred limb positively influenced the performance of the contralateral, non-preferred limb. This observation aligns with the cross-education theory, where unilateral practice induces neural adaptations benefiting the untrained side [3,5]. The finding is consistent with the study by Azhari *et al.,* [6], which similarly found varied patterns of asymmetrical transfer in mirror tracing performance, emphasizing how dominant limb training could enhance performance on the non-dominant side.

Moreover, this study revealed strong evidence of symmetrical transfer, as indicated by the significant improvement from the initial (NP_pre) to the final non-preferred hand trial (NP_post) ($p < .001$). This suggests that motor performance can not only improve between limbs but also within the same limb after an intermanual training phase. The bilateral access model provides a neurophysiological explanation for this, proposing that shared motor representations are accessible by both hemispheres and reinforce performance upon reactivation [4,7]. Azhari *et al.,* [6] also highlighted symmetrical transfer in their study, noting that many participants regained or exceeded initial performance levels when returning to the non-dominant hand, further confirming that intermanual practice supports within-limb improvement through cortical integration.

From an applied perspective, the implications of these findings are highly relevant to both sports training and educational practice. In sports, bilateral transfer can be strategically employed to enhance skill acquisition and limb symmetry, allowing coaches to reduce fatigue or injury risk by alternating limb use during training while still achieving performance gains [2,8]. In educational contexts, particularly in physical education and rehabilitation programs, incorporating mirror tracing or similar bilateral coordination tasks can promote neuroplasticity and functional motor recovery. As emphasized by Azhari *et al.,* [6], such interventions may be tailored to account for individual variability in BT responsiveness, making them valuable tools for inclusive and personalized motor skill instruction.

## 5. Conclusions

This study confirmed the presence of both asymmetrical and symmetrical bilateral transfer through a structured mirror tracing task. The findings demonstrated that motor learning acquired through the preferred hand significantly improved performance in the non-preferred hand (asymmetrical transfer) and enhanced performance in the same non-preferred hand after an intermanual phase (symmetrical transfer). These outcomes highlight the brain's adaptability and the value of cross-limb training strategies. In the context of sports, these findings suggest that training one limb can benefit the untrained limb, optimizing practice efficiency and recovery protocols. Similarly, in education and motor skill development, especially among novices or in rehabilitation settings, incorporating bilateral tasks can accelerate learning and reinforce neural pathways critical for coordination and functional independence.

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