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Mirror Tracing's Bilateral Transfer Patterns: Investigating Transfer Between Hemispheres and the Function of Motor Imagery

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ABSTRACT

The present study was conducted to investigate bilateral transfer (BT) in mirror tracing tasks. The objective of the present study is to describe the phenomenon where motor skill acquisition on one side of the body influences performance on the opposite side. Here, we explore the direction and type of BT, focusing on interhemispheric transfer during mirror tracing. Purposive sampling ensured participants (N=20) with diverse motor skills traced predefined paths with both dominant and non-dominant hands. The study aimed to link BT to the mirror neuron system, suggesting improved non-dominant side performance after dominant side training. Additionally, it positions itself for a future systematic review and meta-analysis to evaluate the overall effectiveness of Motor Imagery Training (MIT) in inducing BT effects. The results revealed a statistically significant effect of the trial on time and error value to complete the task (Wilks' Lambda = 0.531, $F(3, 17) = 5.008$, $p < 0.05$, η^2partial = 0.469) for time and (Wilks' Lambda = 0.607, $F(3, 17) = 3.67$, $p < 0.05$, η^2partial = 0.393) for error value. It can be concluded that a spectrum of individual responses was present, with some participants exhibiting consistent, symmetrical transfer and others demonstrating asymmetrical transfer characterized by fluctuations in improvement. This study emphasizes the need for tailored interventions based on individual BT patterns and calls for further research on refining strategies for skill acquisition between hands.

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Keywords: *Bilateral Transfer (BT), Mirror Tracing, Interhemispheric Transfer, Motor Imagery Training (MIT), Individual Variability*

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INTRODUCTION

In mirror tracing tasks, researchers investigate bilateral transfer (BT), where learning a motor skill with one hand improves performance on the other (Yao, et al., 2023; Nolen, 2019). Also known as cross-education or intermanual transfer, BT involves transferring improved motor skills from a trained limb to the untrained contralateral limb (opposite side). Participants trace shapes while looking at their mirror image, creating a visual-motor inversion that challenges fine motor control. Theories suggest this transfer occurs through similar neural pathways connecting the brain's hemispheres, facilitated by the spinal cord. It has been studied what BT is and how it works, such as whether it transfers from dominant to non-dominant or vice versa (Paparella, et al., 2023; Oosawa, Iwasaki, Suzuki, Tanabe, & Sugawara, 2019) and whether it transfers intrinsic or extrinsic coordinates. This interhemispheric transfer may involve the mirror neuron system and improve sensory integration, leading to better performance on the non-dominant hand after training the dominant hand. Bilateral transfer in mirror tracing highlights how practicing a motor skill with one hand can improve performance with the other.

This phenomenon is related to motor learning, which is theorized to involve two types of coordinates: extrinsic (referring to movement with the environment) and intrinsic (referring to movement based on body landmarks) (Yao, et al., 2023; Galletti, Gamberini, & Fattori, 2022; Torres, 2022). Understanding how the brain communicates and integrates information across hemispheres is crucial for unraveling the neural mechanisms behind motor skill development and transfer. A systematic review and meta-analysis could offer valuable insights into the overall effectiveness of Motor Imagery Training (MIT) in inducing BT effects (Yao et al., 2023). This knowledge would provide robust scientific evidence for practitioners like coaches and physical therapists to design more effective exercise and treatment plans for improving motor performance.

METHODOLOGY

Design

The present study utilized a quantitative method using repeated measured design to quantify the effect of practice and change of peripherals on the amount of BT among participants. This study was part of an experiment conducted during class.

Sampling

The present study employed convenience sampling to recruit 20 participants (N=20), consisting of students who took motor control and learning classes from the Faculty of Sports Science and Recreation, UiTM Seremban. The inclusion criteria ensured that participants were free from any diagnosed neurological or motor impairments. This sampling strategy aimed to achieve a representative range of motor skill proficiency within the chosen population. Participants engaged in mirror tracing tasks, utilizing both their dominant and non-dominant hands to trace predefined paths (e.g., a six-pointed star). This task selection facilitated the investigation of bilateral transfer in motor learning, focusing on the extent to which acquired skills from one hand can be transferred to the other. It is acknowledged that while purposive sampling was appropriate in this context, participant characteristics may influence the generalizability of the findings.

Procedure

Data was collected using an automatic mirror tracer (Figure 1, Lafayette Instrument Auto Scoring Mirror Tracer, Model 58024E, Sagamore Lafayette) (Auto Scoring Mirror Tracer, 2024). Participants were seated in front of the instrument and positioned such that their direct view of the tracing pathway was obscured. Conversely, a strategically placed mirror allowed them to observe the pathway's reflected image while tracing. This setup ensured reliance on visual feedback from the mirror image for successful task completion. A predefined pathway (Figure 1, six-pointed star) was securely affixed to the instrument to prevent movement during tracing. Participants will trace the pathway in the same direction for all trials where they need to complete four (4) trials in a specific order: non-dominant hand, dominant hand, dominant hand again, and finally, non-dominant hand. Each trial involved tracing the pathway with the designated hand. The time taken to complete the task, as well as any errors made during the tracing process, were recorded automatically by the counter as soon as the participant touched their metal pen to the pathway. Performance improvement was assessed throughout the trials by analyzing changes in both completion time and error rates.

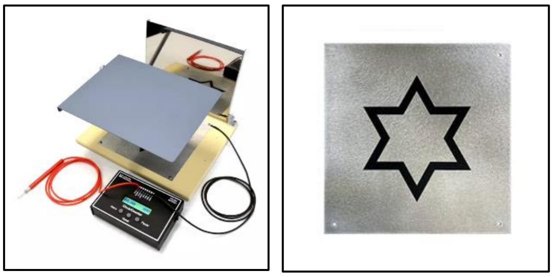

Figure 1: Mirror Tracer with Automatic Counter

Data Analysis

The present study utilized descriptive analysis (Mean ± Standard Deviation) to describe the performance of every participant in terms of time and number of errors for every trial. Further analysis was conducted using One-Way Repeated Measures ANOVA to seek the effect of trials on the performance. A post-hoc test using Bonferroni correction was further conducted to seek specific differences between trials. A significant level of $p<0.05$ was predetermined to show any statistical significance.

RESULTS AND DISCUSSION

Table 1: Mean and standard deviation values for time and error recorded for all participants

Rotation/Values	Time accumulation (Mean ± SD)	Error-values (Mean ± SD)	Total score (Time + Error)
Non-dominant hand (1st trial)	87.1±63.2	9.9±8.4	97
Dominant hand (1st trial)	85.5±60.2	11.1±9.2	96.6
Dominant hand (2nd trial)	64.3±39.4	5.5±4.1	69.8
Non-dominant hand (2nd trial)	53.1±26.5	8.0±8.2	61.1

The dataset comprises results from a mirror tracing task where participants completed four trials using both their dominant and non-dominant hands. Data points include trial time, errors, overall score, and progress percentage for the non-dominant hand. Based on the result, the less time accumulated and the fewer error values recorded showing a much better outcome compared to the other. These metrics are summarized in a table, allowing for a comprehensive comparison of performance across dominant and non-dominant hand trials (Table 1).

Table 2: Wilks' Lambda Value for Time and Error

Condition	Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
Time	0.531	5.008	3.000	17.000	0.011	0.469

Error	0.607	3.670	3.000	17.000	0.033	0.393

To investigate the influence of hand dominance switching on learning transfer, a one-way repeated-measures ANOVA was employed. This analysis compared performance across four trials: the first with the non-dominant hand, the second and third with the dominant hand, and the final trial returning to the non-dominant hand. Table 1 presents the means and standard deviations for both time and error scores. The results revealed a statistically significant effect of the trial on time and error value to complete the task (Wilks' Lambda = 0.531, $F(3, 17) = 5.008$, $p < 0.05$, η^2partial = 0.469) for time and (Wilks' Lambda = 0.607, $F(3, 17) = 3.67$, $p < 0.05$, η^2partial = 0.393) for error value. These findings suggest that switching hand dominance plays a role in learning transfer. The pattern of getting better on each trial and then getting back to the same level of performance when switching back to the non-dominant hand suggests symmetrical transfer rather than asymmetrical transfer.

Post-hoc analyses using Bonferroni correction revealed significant reductions in time to complete the task between specific trials. Specifically, a mean difference of 34.05 seconds was observed between trial 1 (non-dominant hand) and trial 4 (non-dominant hand), and a mean difference of 32.45 seconds was observed between trial 2 (dominant hand) and trial 4 (non-dominant hand). As for the error value, a reduction of 5.5 times the error can be observed between trial 2 (dominant) and trial 3 (non-dominant). These findings buttress the notion of symmetrical transfer, as performance with the non-dominant hand improved following practice with the dominant hand, and this improvement was maintained when returning to the non-dominant hand. Notably, no significant improvements were observed in the opposite direction (dominant to non-dominant transfer).

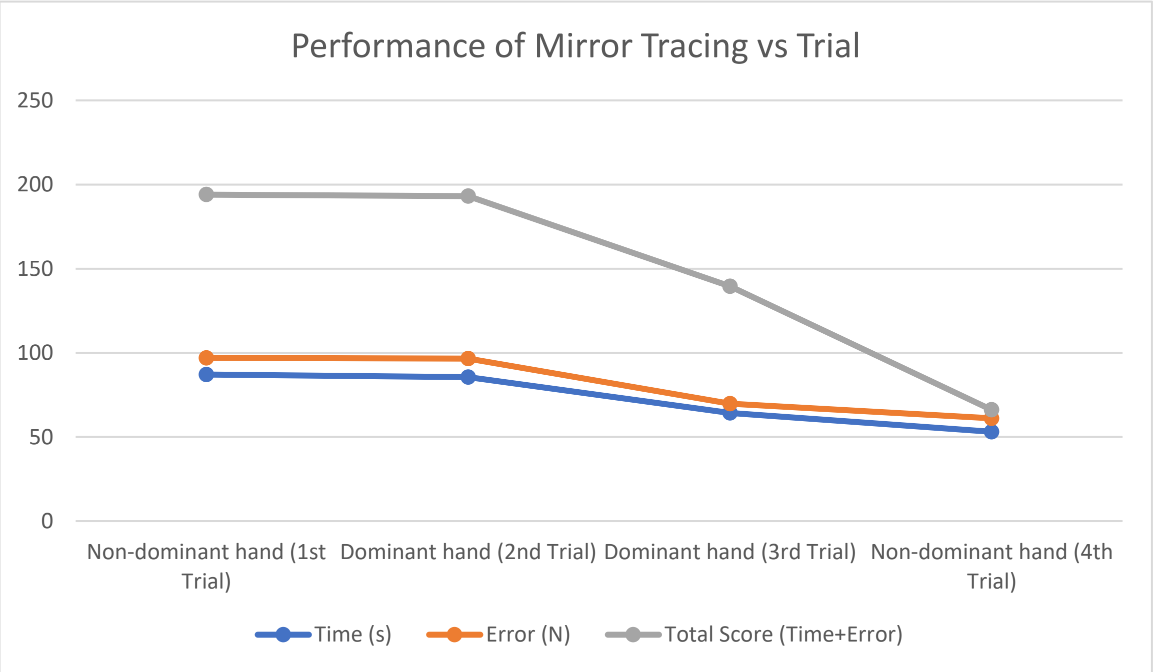

Figure 2: Graph depicting the overall changes in performance

The graph (Figure 2) depicts trends in performance scores across the four trials. The final score is the combination of the time and error value recorded. For the non-dominant hand, scores exhibit a notable decrease from the first trial (97) to the fourth trial (61.1), suggesting a decline in overall performance. However, further inspection reveals a deviation from a strictly monotonic pattern. As for the dominant hand, it also depicted a decline pattern as shown by the second trial (96.6) and the third trial (69.8). A decrease in scores is an indication of improved performance. This observed variability across trials underscores the necessity for a more in-depth analysis of each trial's characteristics and participant responses. Delving into these trends can provide valuable insights for developing improved strategies in future laboratory experiments.

Discussions

The Bilateral Transfer Mirror Tracing Test results unveil intriguing performance patterns, illuminating the complexities of bilateral transfer effects and skill acquisition. Observed variations in performance metrics, particularly the improvement percentage in the non-dominant hand, suggest a spectrum of individual adaptability and skill growth. Some of the participants exemplified symmetrical bilateral transfer by exhibiting a consistent ability to transfer skills between hands (Yao, et al., 2023; Neva, Ma, Orsholits, Boisgontier, & Boyd, 2019; Krishnan, Raganathan, & Tetarbe, 2017). This finding aligns partially with research on ballerinas, which suggests some transfer from the non-dominant to the dominant limb (Yadav & Mutha, 2020). However, the cited research emphasizes the overall benefit of bilateral practice, rather than directionality. It highlights that individuals who can effectively utilize both body sides often demonstrate superior performance (Yao, et al., 2023; Yadav & Mutha, 2020). This aligns with the concept of cross-education, where practice in one limb can improve function in the contralateral limb, potentially aiding recovery from injury or disability (Voskuil, Andrushko, Huudleston, Farthing, & Carr, 2023; Yadav & Mutha, 2020).

On the other hand, just a few of them displayed asymmetrical bilateral transfer, exhibiting notable fluctuations in the improvement percentage between hands across trials (Doustan, Namazizadeh, Sheikh, & Naghdi, 2019; Krishnan et al., 2017). This asymmetry underscores the diverse ways individuals adapt and transfer skills during mirror tracing activities. The direction of transfer itself remains inconclusive across studies. Some report greater transfer after initial dominant hand practice (Doustan et al., 2019), while others show the opposite (Yao, et al., 2023). Observations of performance variations, particularly in the non-dominant hand's improvement percentage, suggest individual adaptability and skill development. Analyzing mean scores provides an overall picture of participant proficiency. Further examination of individual trial results might reveal patterns influencing performance based on hand dominance. This data serves as a foundation for evaluating both individual and group performance, facilitating informed judgments, and identifying areas for improvement or further investigation. Scrutiny of the Bilateral Transfer Mirror Tracing Test data reveals significant patterns in bilateral transfer effects. Some participants exhibit consistent symmetrical bilateral transfer, demonstrating a constant improvement rate for their non-preferred hand across trials. Others display asymmetrical bilateral transfer, with marked changes in the non-dominant hand's improvement percentage compared to the dominant hand. This diversity highlights the various ways individuals adapt during mirror tracing tasks, offering insights into individual reactions to bilateral transfer and the complexities of interannual skill acquisition during cognitive tasks.

CONCLUSION

The present investigation into Bilateral Transfer in Mirror Tracing Tasks sheds light on the multifaceted nature of intermanual skill acquisition. Results show a range of responses from individuals, with some showing consistent, symmetrical transfer and others showing asymmetrical transfer, which is marked by changes in how well they did. This variability underscores the intricate interplay between individual factors and the learning process during mirror tracing tasks. These results challenge the notion of a "one-size-fits-all" approach to bilateral transfer. Instead, they suggest a need for tailored interventions that consider individual adaptability and transfer patterns. This insight holds practical value for rehabilitation specialists and coaches who can leverage personalized training programs to optimize skill acquisition across dominant and non-dominant hands. Further research is warranted to delve deeper into the specific factors influencing the direction and magnitude of bilateral transfer effects. Exploring the role of factors such as prior motor experience, handedness dominance, and cognitive processing styles could offer valuable insights for refining training strategies and promoting optimal intermanual skill acquisition. Unveiling these underlying mechanisms will not only contribute to a more comprehensive understanding of bilateral transfer but also pave the way for the development of evidence-based practices to enhance motor learning and rehabilitation across diverse populations.

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CONFLICT OF INTEREST

The author has no conflict of interest to declare. This study was conducted as part of an experiment done by students during class. No financial resources were available to support this study as all needed instruments were ready in the faculty as part of teaching and learning instruments.

AUTHORS' CONTRIBUTION

The authors contributed equally to the design, conception, and research strategy of this article. Muhamad Noor Mohamed led the writing process as the corresponding author, with Prof. Dr Yusuf Hidayat providing coordination and assistance in drafting the manuscript. Alit Rahmat guided the project, while Mohamad Nizam Shah Azhari, Muhammad Nur Ariff Abd Rahim, and Nurul Ain Shafikah Roslan were responsible for conducting the experiment and data collection. All authors have reviewed and approved the final manuscript.

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