Association between interlimb transfer and manual asymmetry: analysis of serial reaction time task

Asociación entre la transferencia interlimbica y la asimetría manual: análisis de tarea de tiempo de reacción serial

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Abstract

Introduction: This study investigates the relationship between interlimb transfer and manual asymmetry in a serial reaction time task.
Objective: Our hypothesis was that transfer would primarily occur from the preferred to the non-preferred hand, with the right-hand (RH) practice showing an inverse relationship with asymmetry and the left-hand (LH) practice showing a proportional relationship.
Methodology: Thirty-two right-handed undergraduate students (16 men, 16 women) performed a finger sequence key-pressing task. We did not find significant differences in interlimb transfer or asymmetry indices. However, we did find moderate correlations between transfer and asymmetry: positive for LH and negative for RH.
Discussion: Despite our anticipation of greater transfer from the right hand to the left, no directional transfer was detected. The task's cognitive and motor demands could explain the absence of transfer direction. As expected, the study observed no differences in asymmetry between groups. The correlation between transfer and asymmetry was significant: the RH showed an inverse relationship, suggesting it transferred more task elements to the LH.
Conclusions: These findings have significant implications for our understanding of motor learning and transfer, enlightening us about the complex interplay between hand dominance and task demands.

Keywords

Motor learning; laterality; motor control; performance; handedness.

Resumen

Introducción: Este estudio investiga la relación entre la transferencia interlimbica y la asimetría manual en una tarea de tiempo de reacción en serie.
Objetivo: Nuestra hipótesis era que la transferencia ocurriría principalmente de la mano preferida a la no preferida, con la práctica de la mano derecha (MD) mostrando una relación inversa con la asimetría y la práctica de la mano izquierda (MI) mostrando una relación proporcional.
Método: Treinta y dos estudiantes diestros de pregrado (16 hombres, 16 mujeres) realizaron una tarea de pulsación de teclas en secuencia con los dedos. No encontramos diferencias significativas en la transferencia interlimbica ni en los índices de asimetría. Sin embargo, encontramos correlaciones moderadas entre la transferencia y la asimetría: positiva para la MI y negativa para la MD.
Discusión: A pesar de nuestra expectativa de una mayor transferencia de la mano derecha a la izquierda, no se detectó una dirección de transferencia. Las demandas cognitivas y motoras de la tarea podrían explicar la ausencia de una dirección de transferencia. Como se esperaba, el estudio no observó diferencias en la asimetría entre los grupos. La correlación entre la transferencia y la asimetría fue significativa: la MD mostró una relación inversa, lo que sugiere que transfirió más elementos de la tarea a la MI.
Conclusión: Estos hallazgos tienen implicaciones significativas para nuestra comprensión del aprendizaje y la transferencia motora, arrojando luz sobre la compleja interacción entre la dominancia manual y las demandas de la tarea.

Palabras clave

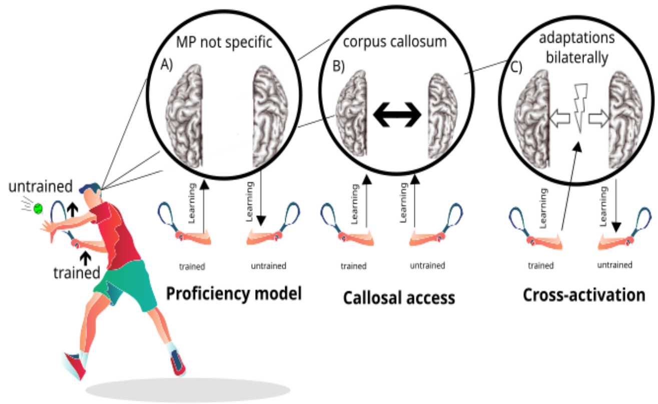
Aprendizaje motor, lateralidad; control motor; rendimiento; dominancia manual.

Introduction

Interlimb transfer of learning is a fascinating and widely studied phenomenon in Neuroscience and Motor Behavior (Aune et al., 2017; Taylor & Heilman, 1980). This phenomenon refers to the ability to transfer skills acquired on one body side to the contralateral side (Uggetti et al., 2016; Sainburg, 2004). Within the same task performed in an identical context, learning can transfer from the trained effector to untrained effectors (Land et al., 2015; Adams, 1987). A pattern learned with one effector system can be transferred to a completely different effector system to perform the same task (Kelso & Zanone, 2002), which has significant implications for rehabilitation, sports training, and the development of motor skills.

Some theories seek to explain the phenomenon of interlimb learning transfer, addressing various aspects of the neural and behavioral mechanisms involved in the process (Shea et al., 2016). Among these theories, researchers most frequently utilize three models. The first model, the 'callosal access' model, proposes that the dominant hemisphere generates motor skill, which is then accessed by the opposite hemisphere through the corpus callosum to enable task execution with the untrained limb (Taylor & Heilman, 1980). This model introduces the notion that both cerebral hemispheres cooperate in the control of movement. The second is the proficiency model, in which movements learned with the dominant arm can be transferred to the non-dominant arm, suggesting the existence of motor programs stored in the opposite hemisphere (Criscimagna-Hemminger et al., 2003), and in this sense, it aligns with Schmidt's schema theory (1975). The third is the cross-activation hypothesis, based on evidence that repetitive unilateral tasks generate contralateral and ipsilateral cortical activity in the trained limb (Parlow & Kinsbourne, 1989). Cross-activation refers to the concept of cortical modulation, as practice induces changes in the activation of brain areas. The primary mechanism for understanding this phenomenon has yet to be entirely clear, and it is likely a combination of 'callosal access,' proficiency model, and cross-activation hypothesis (Uggetti et al., 2016) (Figure 1).

Figure 1. Interlimb learning transfer.



Note: Some theories seek to explain the phenomenon of interlimb learning transfer. A) Proficiency model. B) Callosal access model. C) Cross-activation hypothesis

Regarding the direction of interlimb transfer, it seems to depend on certain factors, such as the movement parameters being examined (e.g., movement time vs. response time) (Sainburg, 2004) and the sequence of limb usage in learning the task (non-dominant arm first vs. dominant arm first) (Taylor & Heilman, 1980; Parlow & Kinsbourne, 1989; Thut et al., 1996; Sim, 2015). In general, the literature has demonstrated that the best transfer direction may occur from the preferred to the non-preferred limb in the Serial Reaction Time Task (SRTT) (Byrd et al., 1986; Wang & Sainburg, 2004; Inui, 2005). However, study results must be more consistent concerning the optimal transfer direction.

Interlimb transfer can be modulated by manual asymmetries, as the dominant hand, being more specialized, tends to transfer skills more effectively to the non-dominant hand. Manual asymmetry, defined as the differences in performance between the hands, can be increased or decreased depending on the hand chosen for motor practice (Estrada-Marce´n & López-Rubio, 2022; Vaquero-Cristóbal et al., 2015; Apolinário-Siouza et al., 2024). For example, the right hand typically exhibits better motor performance in right-handed individuals than the left hand (Fernandes et al., 2024; Aoyama et al., 2018; Schwalbe et al., 2023). The practice with the right hand may amplify the manual asymmetry by increasing the performance of the right hand. Conversely, practice with the left hand could reduce the manual asymmetry. However, if the interlimb transfer occurs from the right hand to the left hand, practicing with the right hand could enhance the performance of both hands more than practicing with the left hand. The enhancement of both hands during practice with the right hand would maintain similar levels of asymmetry compared to practice with the left hand.

A possible approach to test this issue is, first, to confirm the direction of the transfer. Specifically, practicing with the right hand should exhibit greater interlimb transfer to the left hand than practicing with the left hand and does transfered to the right hand. Second, both right and left-hand practices should not show differences in manual asymmetry, as interlimb transfer should facilitate improvement in the non-practiced hand while maintaining similar levels of asymmetry. Therefore, the relationship between interlimb transfer and manual asymmetry should vary depending on the practicing hand. In cases where individuals practice with their right hand, the resulting increase in the interlimb transfer leads to decreased asymmetry, as the left hand benefits from this practice. Conversely, when practice occurs with the left hand, the transfer effect may enhance the performance of the right hand, increasing the asymmetry.

We designed our study to investigate the relationship between interlimb transfer and hand asymmetry in a serial reaction time task. We hypothesized the transfer direction from the preferred to the non-preferred hand. Additionally, we hypothesized that practice with the right and left hand would not exhibit differences in manual asymmetry. Additionally, we expect that practicing with the right hand will show an inversely proportional relationship between transfer and asymmetry while practicing with the left hand will show a proportional relationship. By doing so, we aim to significantly contribute to understanding the underlying neurobiological processes, providing evidence that can guide future rehabilitation and motor training practices.

Method

Participants

For this experiment, we carefully selected 32 undergraduate students (16 men and 16 women) with an age range of 18 to 40. To ensure a balanced representation, we counterbalanced the groups, with 16 participants in the RH-group and 16 in the LH-group. The mean age for the RH-group was 24.45 (SD =4.17) and for the LH-group was 24.25 (SD = 3.67). All participants were right-handed university students whose mean laterality quotient on the Edinburgh Handedness Inventory (Oldfield, 1971) was 94.5 in the RH-group, and 95.2 in the LH-group. All participants had normal or corrected-to-normal visual acuity in both eyes. The volunteers had no prior experience with the experimental task. As an exclusion criterion, the participant who did not complete the task or missed a day of practice was excluded.

Procedure

Instrument

For the experimental setup, we placed a computer, color monitor, and alphanumeric keypad on a standard table in the lab room. To ensure precise control over the experimental task, we utilized a custom-made software program (available for free at https://github.com/edftercio/Serial_reaction_time_task) in LabVIEW (National Instruments, Texas, USA). This program allowed us to regulate the participants' actions and monitor their performance. Participants were asked to sit on a chair in front of the computer monitor and to place their fingers (little finger, ring, middle, and index finger, respectively) on positions "a", "s", "d", "f" on the keyboard, with left hand or right-hand fingers (little, ring, middle, and index, respectively) on positions "f" "d", "s", "a". The other keys on the alphanumeric keypad were removed, and their places were covered by a black piece of rubberized paper (Fernandes et al., 2022; Apolinário-Souza et al., 2021).

Task

We adapted and modified a finger sequence keypressing task from Wright and Shea (1991), Lee and Fisher (2018), Apolinário-Souza et al. (2021), and Fernandes et al. (2022). The finger sequence task consisted of sequences of four keystrokes presented on a computer monitor. The participants used their hand to execute the sequential movements accurately and as fast as possible. The sequence on the screen disappeared immediately after the participants made their first keypress. The trial presented a visual warning stimulus ("Ready!") in the screen center. The visual warning stimulus disappeared from the screen at a random interval ranging from 1 to 3 seconds. So, the sequence on the screen was an imperative stimulus, instructing the participants to start and showing them how to proceed. If participants pressed the wrong key during the sequence, a visual signal was displayed ("Wrong!") at the center of the screen for up to 30ms. At the end of each trial, a visual signal ("Finish!") appeared in the center of the screen for 300 ms to indicate that the task was finished. Each trial lasted a maximum of 12 seconds.

Detailed instructions were provided to each participant concerning the information displayed on the computer screen, such as the imperative stimulus (sequence displayed on the screen), information about starting and ending the trial, and warnings about errors made during the sequence. Participants were asked to perform the sequence as quickly and accurately as possible after the imperative stimulus.

The participants were randomly assigned to one of two practice groups, right group or left group. The experiment consisted of three phases: the pretest, the practice phase or acquisition phase, and the posttest. During the pretest, all participants performed 16 trials of the motor task (sequence "d," "a," "f," "s") with each hand in a counterbalanced manner. Namely, half of the participants started with their right hand, and the other half started with their left hand. Immediately after the pretest, the acquisition phase was started. During this practice (acquisition) phase, all participants performed 96 trials; however, the two groups differed concerning the hand. The right-group practiced with right hand and left-group practice with left hand. The posttest was conducted 24 hours after participants practiced in the acquisition phase. The posttest was equal to pretest.

Data analysis

Our primary measure is the interlimb transfer index, which we obtained from the differences between the hands (see the following equation) in the performance measure of the motor task: the total time. The total time comprised the duration from the stimulus presentation on the screen to the participant's last finger keypress. This enabled us to consider the potential differences in error rate and the speed of the two participant groups (Apolinário-Souza et al., 2021; Fernandes et al., 2022). The interlimb transfer index was the following equations:

$$LHgroup = \frac{RH_{pre} - RH_{pos}}{RH_{pos}}$$
$$RHgroup = \frac{LH_{pre} - LH_{pos}}{LH_{pos}}$$

Where RHpre and LHpre are the values of the total time on right hand and total time in left hand on pretest, respectively. RHpos and LHpos are the values of the total time on right hand and total time in left hand on posttest, respectively.

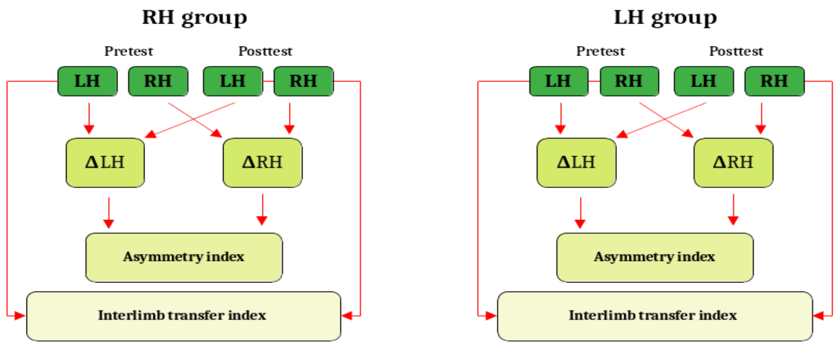
The asymmetry index was obtained through the following equation:

$$\Delta_{LH} = \frac{LH_{pre} - LH_{pos}}{LH_{pos}}, \Delta_{RH} = \frac{RH_{pre} - RH_{pos}}{RH_{pos}}$$
$$assymmetryindex = \frac{\Delta_{RH} - \Delta_{LH}}{\Delta_{RH} + \Delta_{LH}}$$

Where RHpre and LHpre are the values of the total time on right hand and total time in left hand on pretest, respectively. RHpos and LHpos are the values of the total time on right hand and total time in left hand on posttest, respectively. Negative values in the asymmetry index indicate that the left hand demonstrated more change from pretest to posttest than the left hand. Positive values in the asymmetry index indicate that the right hand demonstrated more change from pretest to posttest than the right hand. We adopted this method of obtaining asymmetry to account for the potential shift in hand superiority due to learning processes, especially for the left-hand group.

Figure 2 presents the flowchart and summary of the measures used in the study.

Figure 2. Flowchart and summary of the measures



Note: LH group = left hand practice group. RH group = right hand practice group. LH = left hand. RH = right hand. Δ = delta.

For analysis, we organized the data into mean values over sixteen trials for each participant on the pretest left hand, pretest right hand, posttest left hand, and posttest right hand. We calculated using the previously indicated equations to assess interlimb transfer and asymmetry index. We conducted the Shapiro-Wilk test to assess the normality of the data ($p > 0.05$). We used independent Student's t-tests to analyze normally distributed data and employed the Mann-Whitney test for non-normally distributed data. Finally, we made the correlation between interlimb transfer and asymmetry.

We chose an alpha level of .05 for all inferential statistics. For the Student's t-test, we calculate the effect size using Cohen's d. We determine the effect size using the corresponding rank biserial correlation for the Mann-Whitney test. Pearson's correlation analysis was performed to examine the relationship between interlimb transfer and asymmetry.

Results

Interlimb transfer index

The Interlimb transfer index was to analyze whether the relationship between interlimb transfer and manual asymmetry varies depending on the practicing hand.

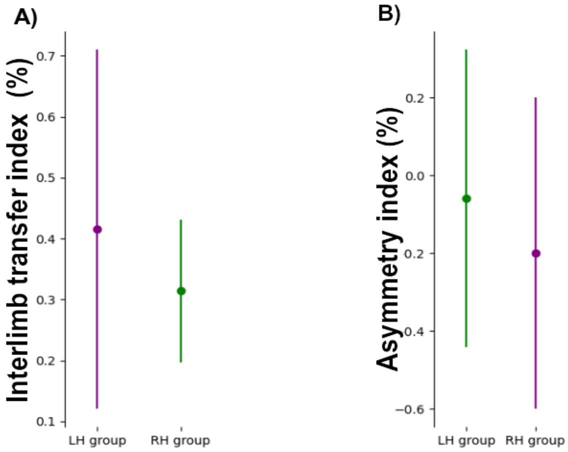
Inferential analyses did not detect hand differences in interlimb transferer index [$U(32) = 115$, $p = 0.63$, $r = -0.10$] (Figure 3 A).

Asymmetry index

The asymmetry Index was assessed to determine whether practice with the right and left hands exhibits differences in manual asymmetry.

Inferential analyses did not detect hand differences Asymmetry index [$U(32) = 115$, $p = 0.21$, $r = 0.26$] (Figure 3B).

Figure 3. Index of Inter-limb Transfer and Asymmetry

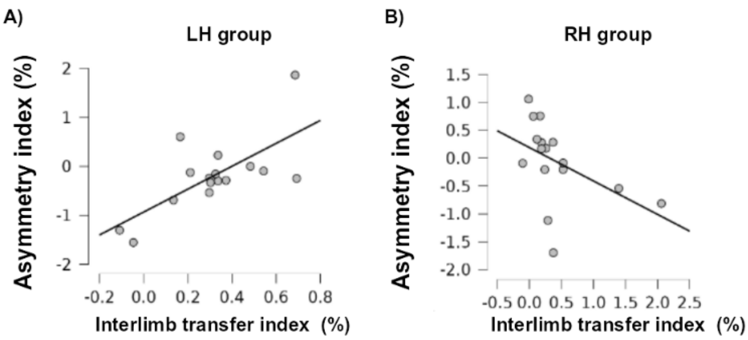


Note: (A) Interlimb transfer index total time (B) Asymmetry index total time. LH: left hand practice

Correlation between interlimb transfer and asymmetry

For LH group the correlation between interlimb transfer and asymmetry was significative, moderate and proportional (r = 0,55, p=0,02) (Figure 4A). These results indicate that the improvement of the right hand due to practice with the left hand that is, interlimb transfer is proportionally associated with differences in asymmetry. In other words, improvement in the right hand increases asymmetry, whereas, conversely, a decline in the left hand reduces asymmetry. For RH group the correlation between interlimb transfer and asymmetry was significative, moderate and inversely proportional (rho = -0,66, p <0,01) (Figure 4B). These results indicate that improvement in the left hand due to practice with the right hand that is, interlimb transfer is inversely proportional to differences in asymmetry. In other words, improvement in the left hand reduces asymmetry, whereas, conversely, a decline in the left hand increases asymmetry.

Figure 4. Correlation between interlimb transfer and asymmetry.



Note: A) left hand practice group (LH group) and (B) right hand practice group (RH group). Total time index for groups.

Discussion

This study evaluated the relationship between interlimb transfer and hand asymmetry in a serial reaction time task. We proposed that practice with the right hand would result in improved learning transfer compared to practice with the left hand. Our results partially confirm our hypotheses. The hypothesis that the transfer would be greater from the right hand to the left was not confirmed. Therefore, we can-not identify the direction of interlimb transfer in this study. On the other hand, to confirm our hypotheses, no differences in asymmetry were observed between the groups, and both groups showed distinct relationships between transfer and manual asymmetries.

Practicing with the right hand may result in greater transfer between limbs as it is the dominant hand. However, the symmetry seen in the current results contrasts with the asymmetric directionality of the transfer of right hand to left hand (Byrd et al., 1986; Wang & Sainburg, 2004; Schwalbe et al., 2023) and transfer of left hand to right hand (Taylor & Heilman, 1980; Kumar & Mandal, 2005) seen across several studies. Nonetheless, Yadav and Mutha (2020) did not find a direction for the transfer, calling it symmetric. The inconsistency among results is likely related to different factors, such as participant laterality, various task demands, distinct methods of analysis, and possible interactions of these variables with the neural mechanisms underlying this phenomenon. Additionally, the quantity and intensity of practice, on the one hand, can influence transfer; on the other hand, intensive and prolonged practices tend to result in a more robust transfer. Intrinsic motivation may also positively influence learning transfer (Magill, 2012). The absence of directionality in asymmetry leads us to reflect that, in addition to considering the aforementioned factors, it is important to understand the mechanisms underlying this transfer phenomenon. In this case, the models of callosal access and the cross-activation hypothesis appear to be more closely related to the absence of directionality in transfer. However, further studies are needed to strengthen this understanding.

The absence of a transfer direction may be related to the task demand. The task used in this study is considered a discrete motor task, characterized by specific motor demands related to speed and accuracy and significant cognitive demands, including inhibitory control and motor planning. We can understand the nature of motor tasks as a predominance of motor or cognitive demands. Rather than a dichotomy of movements, this relationship should be interpreted in an integrated manner (Tani, 1992). To understand learning transfer from the perspective of elements that can be accessed by the contralateral hemisphere (Taylor & Heilman, 1980) or to understand learning transfer through the transfer of motor programs (Criscimagna-Hemminger et al., 2003), it is essential to consider that cognitive demands, in addition to motor demands, must also be transferred, which may depend on cerebral hemisphere specialization (Gazzaniga, 2000). Thus, it is reasonable to think that demands related to cognitive aspects can be transferred without a direction that provides an advantage, while demands related to motor aspects may be more linked to an advantageous direction, from the right hand to the left. If our reasoning is correct, the difference between the transfer of different demands (motor and cognitive) may impact this study's result.

These two types of demands do not operate independently. On the contrary, many motor tasks—including the keypress sequence task used in the present study—require both physical precision and mental processes to encode, retain, and apply motor information. The integration between cognition and motor control enables the brain to form internal representations of the task, which can be accessed by both cerebral hemispheres, thereby facilitating learning transfer.

However, cognitive demands tend not to exhibit a clear directional pattern in interlimb transfer, unlike what is often observed with motor demands. This may be related to the fact that cognitive processes are typically supported by more distributed and less lateralized neural networks, whereas motor processes often display hemispheric specialization (e.g., left-hemisphere dominance for motor control in right-handed individuals). Therefore, while tasks with higher motor demands tend to show a preferential transfer from the dominant to the non-dominant limb—due to the specialization and proficiency of the dominant hemisphere—tasks with greater cognitive load may be more symmetrically represented in the brain, allowing the information to be accessed by both hemispheres equally. As a result, learning transfer may occur in a more symmetric and limb-independent manner.

Furthermore, our study showed that practice with the right hand did not change the asymmetries compared to practice with the left hand. When analyzing the asymmetry between the groups, it was expected that the practice with both the right and left hands might not exhibit differences in manual asymmetry because, in both cases, interlimb transfer ensures the improvement of the non-practiced hand, maintaining similar levels of asymmetry. As for the relationship between interlimb transfer and asymmetry, our hypothesis was confirmed. The practice with the right hand shows an inversely proportional correlation; that is, as for the greater transfer, lower asymmetry. This means the right hand seems to transfer more elements about the task to another limb, the left hand.

Despite no differences in the asymmetry between groups, the advantage of the right hand in transfer could be speculated. This result suggests that the learning transfer to the contralateral limb by practicing with the preferred hand is sufficient to reduce performance differences between hands. In contrast, practice with the non-preferred limb does not significantly reduce differences between limbs. The superior performance of the right hand is observed in several studies (e.g., Fernandes et al., 2024; Aoyama et al., 2018; Schwalbe et al., 2023). The observed differences in hand performance have been attributed to the specialization of the contralateral hemisphere for the organization and control of voluntary movement (Elliott & Roy, 1996). According to Todor and Smiley (1985), researchers typically attribute asymmetries between hands in performing various motor tasks to the relative proficiency of one cerebral hemisphere in certain types of perceptuomotor processing. The right hand appears to have some advantages. The study by Fernandes et al. (2024) analyzed participants' brain activity performing a manual pointing task with both hands. The results showed that we observed the greatest connectivity regardless of the analyzed areas and bands when the right hand performed the movement. Considering this result, we can infer that greater connectivity resulting from practice with the right hand provides greater benefits for most tasks performed. However, considering the complexity of the relationships between cerebral hemispheres, such as hemispheric specialization and neural plasticity, it is evident that much more needs to be understood than what is currently available in literature.

Continuous research in Neuroscience and Motor Behavior is essential to uncover the precise details of how these theories interact and influence the transfer of learning between limbs. Understanding the mechanisms related to bilateral learning transfer has immense potential benefits. It can provide valuable insights for clinical interventions aimed at individuals with brain injuries or motor impairments and optimize training programs for athletes and professionals who rely on refined motor skills. This study adds important nuances to the understanding of interlimb transfer by demonstrating that the direction of transfer is not necessarily fixed or unidimensional. While previous literature often indicates a preferential transfer from the dominant to the non-dominant limb, our findings suggest that this directional pattern may not clearly emerge in tasks with high cognitive demands, such as the sequential key-pressing task used in this experiment.

Furthermore, our analysis of the relationship between interlimb transfer and manual asymmetry reveals distinct patterns depending on the practicing limb, suggesting that training can modulate asymmetry differently depending on the direction of practice. Specifically, practice with the dominant hand showed an inverse correlation between transfer and asymmetry, while practice with the non-dominant hand revealed a proportional correlation. These findings indicate that interlimb transfer is not solely dependent on laterality or hemispheric dominance but is also shaped by the interaction between training characteristics and task demands—both motor and cognitive.

Therefore, the study expands the current understanding of interlimb transfer by showing that it can occur symmetrically and that manual asymmetry can be differentially modulated depending on the trained hand. These results underscore the need to consider multiple factors—such as task type, cognitive complexity, and practice design—when investigating and applying interlimb transfer, particularly in contexts such as motor rehabilitation and sports training.

Limitations and Directions for Further Research

A potential limitation of this study lies in the absence of delayed tests to assess learning transfer. That is, to verify the effects of learning transfer chronically, after weeks or months. Conducting these tests could help understand the effects of offline transfer. Additionally, future studies could evaluate the direction of learning transfer in tasks with different motor and cognitive demands to track possible impacts of cognitive demands on bilateral learning transfer and studies with left-handed individuals may help to understand the mechanisms underlying learning transfer.

Conclusions

This study contributes to understanding interlimb transfer and its relationship with manual asymmetry, particularly in serial reaction time tasks. Our results demonstrate that the transfer of motor skills from the preferred hand to the non-preferred hand did not manifest as clearly as hypothesized, reflecting the complexity of this phenomenon. While the literature suggests a more efficient transfer from the dominant hand to the non-dominant hand, our investigation indicates that laterality may influence this relationship.

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