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Uso de un acelerómetro de muñeca para medir las diferencias de la mano en el Test de Grooved Pegboard

Use of a hand-worn accelerometer to measure hand differences in Grooved Pegboard Test

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Abstract. Research on laterality, which pertains to the preference for using one hand over the other in daily activities, has recently been a growing topic of investigation. Studies demonstrate that performance differences between the right and left hands arise from distinct strategies in utilizing information for movement execution. To conduct a more comprehensive analysis of these differences, we aimed to investigate various measures using a wrist accelerometer during the execution of a traditional tool to assess manual performance. The proposed hypothesis suggested that tasks performed with the right hand would exhibit shorter movement times due to more efficient real-time information processing. In contrast, tasks performed with the left hand would show shorter reaction times due to movement planning proficiency. Furthermore, we hypothesized that increased task complexity would make these differences more pronounced. The study revealed that, in the less complex task, the right hand outperformed the left hand in execution speed, whereas the left hand demonstrated faster reaction times in the more complex task. The task complexity highlighted the differences, emphasizing the impact of task demands on hand specialization. Using an accelerometer provided valuable insights, indicating potential avenues for refining assessment tools and analyzing manual control.

Keywords: motor control, hemispheric specialization, laterality, hand function, dexterity.

Resumen. La investigación de la lateralidad, que se refiere a la preferencia por usar una mano en las actividades diarias, ha sido un tema de investigación en crecimiento recientemente. Los estudios han demostrado que las diferencias de rendimiento entre la mano derecha e izquierda pueden atribuirse a estrategias distintas en la utilización de información para la ejecución del movimiento. Para realizar un análisis más exhaustivo de estas diferencias, buscamos investigar diferentes medidas con un acelerómetro de muñeca durante la ejecución de una herramienta tradicional para evaluar el rendimiento manual. La hipótesis planteada sugiere que la tarea realizada con la mano derecha mostraría un tiempo de movimiento más corto debido a su procesamiento de información en tiempo real más eficiente, mientras que con la mano izquierda se demostraría un tiempo de reacción más corto debido a su mayor competencia en la planificación del movimiento. Además, se esperaba que estas diferencias se acentuarían con el aumento de la complejidad del GPT. El estudio reveló que, en la tarea menos compleja, la mano derecha superó a la mano izquierda en velocidad de ejecución, mientras que la mano izquierda presentó tiempos de reacción más rápidos en la tarea más compleja. La complejidad de la tarea discriminó las diferencias, enfatizando la influencia de las demandas de la tarea en la especialización de la mano. El uso de un acelerómetro proporcionó valiosos conocimientos, indicando posibles vías para el refinamiento de herramientas de evaluación y análisis del control manual.

Palabras clave: control motor, especialización hemisférica, lateralidade, función de la mano, destreza

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Introduction

Laterality is typically defined as the hand an individual chooses to use in daily activities (Corey et al., 2001). This phenomenon of human behavior has led several investigations in the last decades (Vaquero-Cristóbal, González-Moro & Ros, 2015; Paszulewicz, Wolsk & Gajdek, 2020; Corballis, 2021; Estrada-Marce′n & López-Rubio, 2022), particularly regarding performance differences between hands (Roy, Kalbfleisch & Elliott, 1994; Bryden et al., 2007; Fernandes et al., 2022). In right-handed, studies have revealed that the left hand (LH) exhibits a shorter reaction time (RT) (Todor & Doane, 1978; Fernandes et al., 2018, 2022), while the right hand (RH) shows a shorter movement time (MT) (Boulinguez et al., 2001; Teixeira, 2006). The shorter MT exhibited by the RH results from the involvement of the left hemisphere in adjusting the movement trajectory, whereas the shorter RT exhibited by the LH is due to the involvement of the right hemisphere in the initial stages of movement planning (Flowers, 1975). The differences in performance between the hands are explained by distinct strategies in utilizing available information for movement execution (Sainburg et al., 2014). More specifically, this means that the individual uses real-time visual information to monitor and correct the movement trajectory as it occurs. This contrasts with the preparation and planning of the movement before execution, emphasizing dynamic adaptation based on sensory information received during the actual performance of the movement. The right hand exhibits greater efficiency in processing visual feedback than the left hand. Visual information about the relative positions of the limb and the target is used to make trajectory adjustments necessary for successfully reaching the target (Roy, Kalbfleisch & Elliott, 1994). These adjustments constitute discontinuities in the movement trajectory, involving activities of agonist and antagonist muscles or modulation of the force applied (Elliott et al., 2010). According to the authors, the reduced time spent on making movement corrections due to feedback utilization reflects greater system efficiency in processing feedback (Roy & Kalbfleisch, 1994; Fernandes et al., 2024). From this perspective, there is a relative predominance in utilizing feedback information during movement or online feedback by hand. Additionally, visual feedback's efficiency and processing speed have been associated more with the left hemisphere (Flower, 1975; Roy & Kalbfleisch, 1994).

Although both hands have the same amount of available time, the left hemisphere requires less environmental information to perform a task (Roy & Kalbfleisch, 1994). This system spends less time detecting errors and making corrections (online control), resulting in a smoother movement for the RH, with less need for gross adjustments in the movement trajectory. The online control efficiency in the performance of the RH has been demonstrated by several studies (Roy, 1983; Roy & Elliott, 1986). According to Roy (1983), these differences are accentuated under conditions of response speed, based on distinct motor control processes.

Traditionally, Grooved Pegboard Test (GPT) has been used to assess manual performance (Albuquerque et al., 2017; Salvador et al., 2017; Bryden et al., 2005; Lage et al., 2008; Fernandes et al., 2018). The GPT can assess a variety of motor skills including fine motor dexterity, motor speed, and eye-hand control (Strauss et al., 2006) through two tasks: place and removing pegs. To perform the place task, the participants must rotate and adjust the pegs to successfully place them into a receptacle, while in the removing task, the participants must remove the pegs from one receptacle and place them into another (Bryden et al., 2005). Thus, the GPT adds a dimension of complexity not found in other motor tasks, such as the Purdue Pegboard Test (Tiffen, 1968), as the place task is more complex than the removing task.

The ability to compare different levels of complexity within the same test has led the GPT to be considered a sensitive tool for detecting general characteristics of manual movement (Fernandes et al., 2018). The increase in task complexity and its precision requirements are variables associated with motor performance, resulting in greater or lesser lateral differences (Vasconcelos & Rodrigues, 2008). Increased complexity has been observed to lead to greater lateral differences (Bryden et al., 2007).

Studies that assess manual performance through the GPT utilize measures such as error rate and total time, obtained through error recordings and manual stopwatches, respectively (Bryden et al., 2007; Albuquerque et al., 2017; Salvador et al., 2017). However, the available measures are limited to measure several characteristics of hand differences. One way to ensure a more detailed observation of movement control is through a manual accelerometer, which allow to identify different temporal aspects of movement, such as planning and execution time, and movement quality (Fernandes et al., 2018).

Among the measures extracted from an accelerometer, it is possible to infer the time required to plan the response, which is related to the stages of identification, selection, and programming of the response, known as reaction time (RT) (Marteniuk, 1976). Furthermore, it is also possible to analyze the time spent on movement execution, known as movement time (MT), and movement efficiency through the variability analysis between cycles of peg removal and placement. According to Elliott et al. (2010), the adjustments made constitute discontinuities in the trajectory of the movement, implying activities of agonist and antagonist muscles or even modulation of the force used. A lower variability between cycles indicates smoother movement and energy economy.

Adopting these measurements, it can be expected that the RH exhibits shorter movement time (MT) and greater movement fluidity associated with more efficient online information processing. Conversely, it is also expected that the LH demonstrates a shorter reaction time (RT) due to its proficiency in movement planning. Moreover, these differences are expected to be accentuated with increased task complexity. Thus, the present study aims to analyze the movement control characteristics of the hands using a manual accelerometer and understand if task complexity impacts the movement control features.

Materials and methods

Participants

The sample was defined using the R package WebPower using data regarding response time from a pilot study. The analysis indicated a sample size of 12 subjects (critical F = 2.92), setting the power of the tests to 95%. We then recruited twelve men aged 18 to 35 (mean 28 ± 3.91) to participate in the study. All participants were university students, right-handed according to the Edinburgh Handedness Inventory (Oldfield, 1971), had normal or corrected-to-normal visual acuity in both eyes, and had no prior experience with the motor task. They were randomly assigned to either the right-hand or left-hand group and remained blinded to the experimental manipulation. The local ethics committee approved all procedures (CAAE 24116513.2.0000.5149), and subjects provided informed consent after receiving a comprehensive explanation about the study.

Apparatus

A standard Grooved Pegboard apparatus (Lafayette Instruments) was used to perform this study. It consists of a 10.1 x 10.1 cm metal surface with a 5 by 5 matrix (25 holes) of keyhole-shaped holes in varying orientations. Each peg was 3 mm in diameter and had a small ridge along its 2.5 cm length. A round receptacle was located at the bottom of the pegboard to place the 25 pegs.

A custom-made apparatus was used to control the experimental task and to measure the variables of the experiment. This apparatus included an accelerometer sensor (Accelero MMA7361), an open-source electronic prototyping platform (Arduino Uno), and a custom-made software program (Figure 1). The accelerometer sensor was connected to the Arduino board as follows:

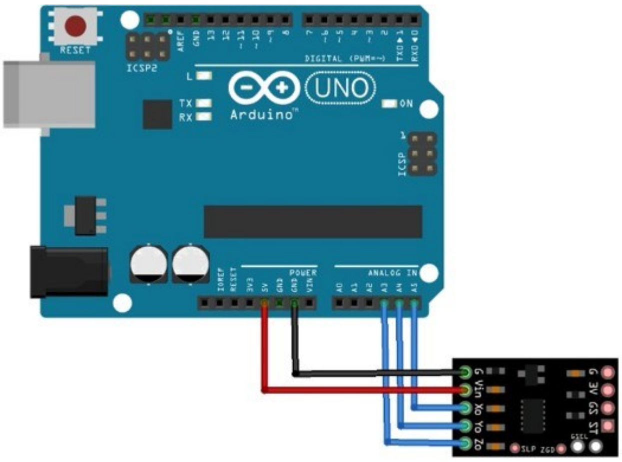

Figure 1. Connection between arduino board and accelerometer sensor. The arduino board was connected to a computer (via USB) and controlled by a custom-made software program made into Labview (free access: https://github.com/edftercio/Leitura-do-Acelerometro).

Task

The GPT involves a motor task where participants must place or remove 25 pegs, one at a time, into the holes as quickly as possible and in a specific order. A superior performance is indicated by faster task completion. Traditionally, the experimenter would provide a verbal signal (e.g., "Go") and manually start a device (e.g., a chronometer) simultaneously. Once the task is completed, the experimenter stops the device and assesses the performance. However, in our experiment, we automated the registration of performance, introducing new variables. To achieve this, we used a custom-made software program that delivered a beep signal (500Hz and 200ms) to initiate the task.

Procedures

Initially, all participants were provided with a detailed overview of the experiment, and subsequently, the Edinburgh Handedness Inventory (Oldfield, 1971) was administered. Posteriorly, participants were instructed to sit comfortably in a chair facing the Grooved Pegboard apparatus and an accelerometer sensor was affixed to the dorsal surface of each participant's hand. The Grooved Pegboard was positioned precisely along the participant's midline, and a standardized hand placement for commencing the task was delineated adjacent to the Grooved Pegboard for both hands (Bryden et al., 2007; Salvador et al., 2017; Fernandes et al., 2024) (Figure 2).

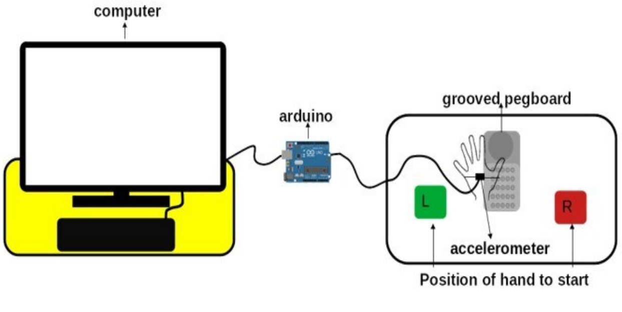

Figure 2. Apparatus used and standardized position of hand

The participants were provided with standardized instructions regarding the Grooved Pegboard test. In the place task, participants were instructed to position pegs one at a time, from left to right on the board when using their RH, and to place the pegs in the opposite order when using their LH. In the remove task, participants were asked to remove the pegs from the holes in the same order in which they were originally positioned. The place task was performed first, followed by the remove task. The starting hand (left or right) was counterbalanced among individuals to avoid any potential effects of the starting hand.

Data analysis

The data collected from the accelerometer sensor was sampled at 200 Hz and filtered using a 3rd-order Butterworth low-pass filter with a cutoff frequency of 12 Hz for attenuation. To determine the initiation and completion of a movement, an algorithm automatically identified a threshold of 5% of the absolute peak acceleration that was maintained for 500 ms.

Four specific measures were analyzed: reaction time, movement time, response time, and variability of cycles. Reaction time was defined as the duration between the onset of the imperative stimulus (a beep sound with a frequency of 500Hz and a duration of 200 ms) and the initiation of the movement. Movement time was calculated as the duration from the start to the end of the movement. Response time was calculated as the sum of reaction time and movement time. We determined the variability of cycles by calculating the mean of the derivative of the total time for each cycle. To achieve this, we followed these steps. First, we obtained the time between each cycle of picking up or removing the peg for each participant. Each cycle represented the time taken to pick up the pegs from the receptacle and place them in the corresponding holes for the place task or vice versa for the remove task (Figure 3). Therefore, we obtained a time series with the total times for each cycle. In the second step, we calculated the difference between these total times along the time series by subtracting the value at point i from the value at point $i+1$. Finally, we calculated the mean of these differences.

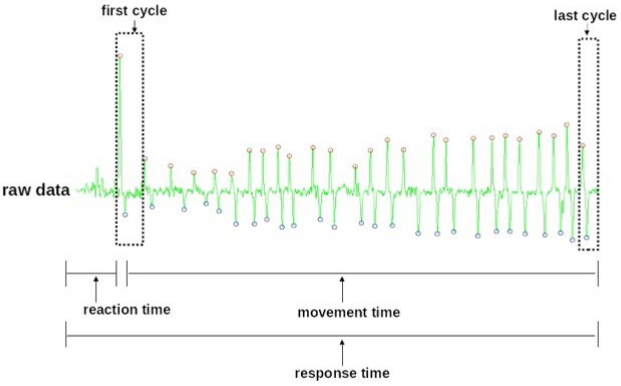

Figure 3. Explanation of variability of cycles in the raw data and indication of reaction time, movement time, and response time

The Shapiro-Wilk test was used to evaluate data normality. The inferential analysis was performed using a two-way ANOVA (2 tasks × 2 hands) with repeated measures on both factors, separately for all variables. All post-hoc analyses were conducted using Tukey's test. An alpha level of 0.05 was chosen for all inferential statistics. The effect sizes were calculated using eta-squared (η^2).

Results

Figure 4 shows the reaction time for the LH and RH in the place and remove tasks. The inferential analysis detected tasks x hands interaction [F(1,11) = 17.04, $p < 0.01$, $\eta^2 = 0.21$], while in the main results, the subsequent post hoc analysis indicated that in the place task, there were no differences between the LH and RH ($p = 0.07$). However, in the remove task, there were differences between the LH and RH ($p < 0.01$), indicating that the LH exhibited a lower reaction time than the RH.

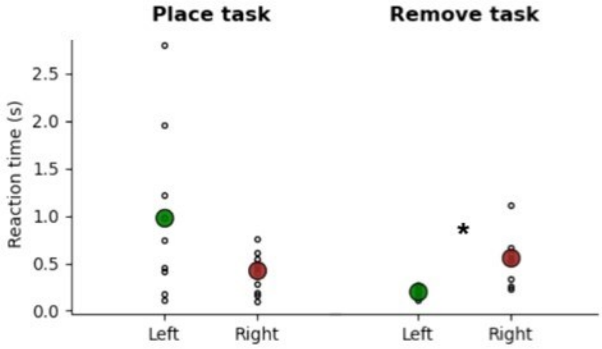

Figure 4. Reaction time analyses of the left hand (in green) and right hand (in red) in place task and remove task. * = $p < 0.05$.

Figure 5 shows the movement time for the LH and RH in the place and remove tasks. The inferential analysis detected tasks x hands interaction [F(1,11) = 12.90, $p < 0.01$, $\eta^2 = 0.00$], while in the main results, the subsequent post hoc analysis indicated that in the place task, there were differences between the LH and RH ($p = 0.02$), with the RH exhibiting a lower movement time than the LH. However, in the remove task, there were no differences between the LH and RH ($p = 0.52$).

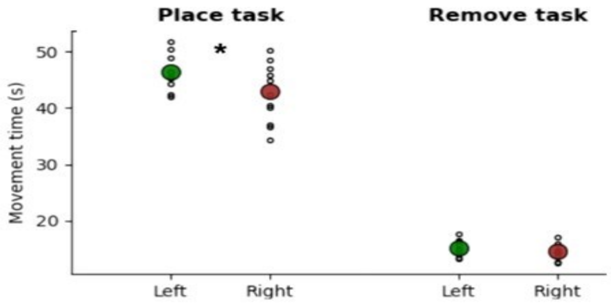

Figure 5. Movement time analyses of the left hand (in green) and right hand (in red) in place task and remove task. * = p < 0.05.

Figure 6 shows the response time for the LH and RH in the place and remove tasks. The inferential analysis detected a tasks x hands interaction [F(1,11) = 17.10, $p < 0.01$, $\eta^2 = 0.00$]. As for the main results, the subsequent post hoc analysis indicated that in the place task, there were differences between the LH and RH ($p = 0.01$), with the RH exhibiting a lower response time than the LH. However, in the remove task, there were no significant differences between the LH and RH ($p = 0.62$).

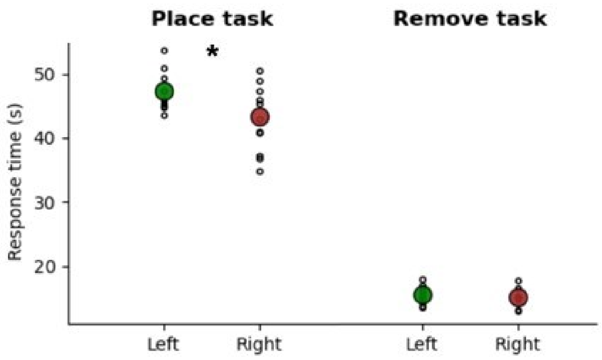

Figure 6. Response time analyses of the left hand (in green) and right hand (in red) in place task and remove task. * = $p < 0.05$.

Figure 7 shows the variability of cycles for the LH and RH in the place and remove tasks. The inferential analysis detected an effect of the task [F(1,20) = 1926.67, $p < 0.01$, $\eta^2 = 0.96$]. Subsequent post hoc analysis indicated that the variability of cycles was significantly greater in the place task than in the remove task ($p < 0.01$). Furthermore, the inferential analysis detected an effect of the hands [F(1,20) = 7.78, $p = 0.01$, $\eta^2 < 0.01$]. The post hoc analysis indicated that the variability of cycles was greater in the LH than in the RH ($p = 0.01$).

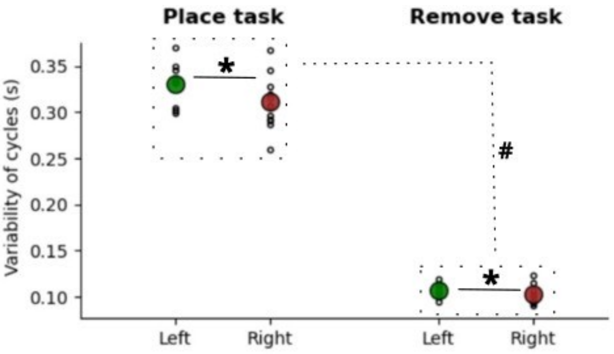

Figure 7. Variability of cycles analyses of the left hand (in green) and right hand (in red) in place task and remove task. # = Effect of the task. * = Effect of the hands.

Discussion

The present study aimed to analyze the movement control characteristics of the hands using a manual accelerometer and to understand whether task complexity impacts these features. It was hypothesized that the RH would demonstrate shorter movement time (TM) and greater movement fluidity, reflecting more efficient online information processing. Conversely, the LH, known for its expertise in movement planning, was expected to exhibit a shorter reaction time (TR). Furthermore, it was anticipated that these differences would become more pronounced as task complexity increased. However, the results revealed that our hypotheses were only partially supported.

Overall, the study observed distinct characteristics in hand movement control, particularly in the more complex task of placing the pegs. The first hypothesis of the study was confirmed as the RH demonstrated faster execution times in movement (movement time and response time) compared to the LH. This advantage can be attributed to the left hemisphere's superior ability to process perceptual and motor information during movement (Boulinguez; Velay & Nougier, 2001; Carson et al., 1995; Fernandes et al., 2022). Another noteworthy finding, although unrelated to task complexity in this instance, was the lower variability between cycles in the movement of the RH. This indicates that the RH executed the movement more swiftly and efficiently, with fewer changes in the movement trajectory.

The observed lower variability may be attributed to the efficiency of visual information acquisition during movement execution. According to Elliott et al. (2010), visual information regarding limb and target positions is utilized to make trajectory adjustments necessary for successfully reaching the target. These adjustments introduce discontinuities in the movement trajectory, involving activities of agonist and antagonist muscles or the modulation of force used. Todor and Doane (1978) and Sainburg et al. (2014) associated the observed differences between hands with the strategies employed in utilizing information to perform the movement. According to the authors, the right hand (RH) can more effectively manage feedback information during movement execution, or online feedback. In this sense, Fernandes et al. (2024) observed that the hands exhibited different proficiencies; the right hand utilizes the visual feedback phase more efficiently, whereas the left hand demonstrated better performance in aspects related to movement preparation. The task used in the present study is characterized by the prominent use of online feedback, specifically visual online feedback, to perform the peg displacements and insertions (Fernandes et al., 2018). Therefore, despite both hands having access to the same visual information, the left hemisphere/RH utilized the online feedback more efficiently for executing the peg displacements and insertions.

On the other hand, the LH exhibited an advantage related to movement preparation, demonstrating a shorter reaction time, observed only in the less complex task. This finding has been observed across multiple tasks (Carson et al., 1995; Fernandes et al., 2018; Roy & Elliott, 1986; Fernandes et al., 2022), and it can be elucidated through two distinct explanations: (*i*) The first explanation is based on the pivotal role that the right hemisphere assumes in the allocation of attentional resources (Heilman & Van Den Abell, 1980). In general, attentional mechanisms processed in the right hemisphere allow for more immediate orientation and activation of the LH system after the stimulus presentation. On the other hand, the task used in the present study does not require a high degree of attention to perform the task, as there is only one possible response to the presented stimulus. When there is only one response to a stimulus, the system does not need to overly direct attention to the processes involved in movement preparation (Rosenbaum, 1980). Nevertheless, we need to consider that the less complex task is performed faster due to reduced spatial demands, eliminating the need for fine adjustments to remove and place the peg in the receptacle. Therefore, attention is crucial for guiding movements with precision at high speed, although it is imperative to emphasize that the relationship between attention demands and enhanced planning for the LH necessitates comprehensive elucidation and thorough investigation. (*ii*) An alternative explanation for this result is that the right hemisphere is involved in the initial stages of movement through three-dimensional target specification in space (Carson et al., 1995). From this perspective, it has been observed that the superiority of the LH increases as the uncertainty of three-dimensional target specification in space intensifies (Carson et al., 1995). Nevertheless, in the present study, the three-dimensional target specification in space is highly predictable, given that the equipment for positioning the pegs remains visible throughout the movement preparation.

The anticipatory processes in our study can be inferred through reaction time, while online correction processes can be inferred by evaluating cycle variability. Thus, a possible explanation for this result is that although the LH is specialized in open-loop impedance control (Sainburg, 2016), and movement preparation (Carson et al., 1995), this specialization is compromised when there is an increase in precision demand and force modulation (Bryden et al., 2007). This outcome could be attributed to the fact that more processing time may be required to program the LH in situations that involve higher spatial demands. Alternatively, assuming that the left hemisphere programs the sequential movements of both hands (Kimura, 1993), this time difference may reflect the accumulated interhemispheric transfer time between the left hemisphere's programming centers and the right hemisphere's motor centers that govern LH control (Hicks, Gualtieri & Schroeder, 1983). According to Marteniuk et al. (1987), movement control is influenced by the goal of the movement. Therefore, left-hand specialization can be viewed as advantageous under reduced task demands. The more complex task involves a greater number of elements to plan, and the system may employ a strategy of reduced engagement in planning. Likewise, in a lower complexity condition, the system may adopt an opposite strategy. Regarding task complexity, our hypothesis was partially confirmed. The differences between the hands were accentuated based on the requirements of place and withdrawing the pegs but were not necessarily related to increased task complexity. In the more complex task, differences in movement time, reaction time, and cycle variability were revealed, suggesting that the differences in the components of the movement are more pronounced when task demands are heightened. These findings corroborate with previous studies (Bryden et al., 2007; Roy, 1983; Roy & Elliott, 1986, 1989; Roy & Kalbfleish, 1994; Salvador et al., 2017; Fernandes et al., 2018). According to Bryden et al. (2007), the more complex condition requires greater precision and force modulation, leading to more substantial disparities when these parameters are under higher demand. The study conducted by Vasconcelos and Rodrigues (2008) demonstrated that task complexity is associated with motor performance, yielding greater or lesser lateral differences.

On the other hand, the impact of complexity on LH performance differed, as the advantages of LH in movement preparation became apparent in the lower complexity condition. It is possible that task complexity, as initially conceived, is primarily related to the characteristics of movement execution rather than movement planning. In other words, the complexity factor lies in the adjustments required during execution rather than in the planning itself.

Conclusion

In summary, the implementation of an accelerometer has made a significant contribution to advancing the understanding of hand performance differences. The Grooved Pegboard Test comprises an accessible and user-friendly tool that exhibits sensitivity in analyzing different movement features. However, to optimize its application, additional technological resources are endorsed. Researchers can explore the integration of other technologies to augment the utility of the equipment, thereby validating the obtained measurements. Future studies could be conducted with a specific focus on the spatial aspects of the task, thereby complementing the measures employed in the current investigation.

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Declarations of conflicts of interest

None.

References

Albuquerque, M., Diniz, L., Silva, M., Paula, J., Neves, M., & Lage, G. (2017). Can eye fixation during the grooved pegboard test distinguish between planning and online correction? *Perceptual and Motor Skills*, *124*(2), 380–392.

Batista, L. N., Apolinário-Souza, T., Amaral-Medeiros, D., & Fernandes, L. A. (2024). Influência do sexo e nível cognitivo na destreza manual em pessoas idosas. *Corpoconsciência*, *28*, e16012.

Benda, R., Cavalcante, A., Lage, G., Santos, I., & Ugrinowitsch, H. (2006). Análise da assimetria nos padrões fundamentais arremessar e chutar em crianças. *Revista Portuguesa de Ciências do Desporto*, *6*(2), 188–193.

Borod, J. C., Caron, H. S., & Kolff, E. (1984). Left-handers and right-handers compared on performance and preference measures of lateral dominance. *British Journal of Psychology*, *75*, 177–186.

Boulinguez, P., Velay, J. L., & Nougier, V. (2001). Manual asymmetries in reaching movement control: Study of left-handers. *Cortex*, *37*, 123–138.

Bryden, P. J., & Roy, E. A. (2005). A new method of administering the Grooved Pegboard Test: Performance as a function of handedness and sex. *Brain and Cognition*, *58*(3), 258–268.

Bryden, P. J., Roy, E. A., Rohr, L. E., & Egilo, S. (2007). Task demands affect manual asymmetries in pegboard performance. *Laterality*, *12*(4), 364–377.

Carson, R. G., Chua, R., Goodman, D., Byblow, W. D., & Elliott, D. (1995). The preparation of aiming movements. *Brain and Cognition*, *28*(2), 133–154.

Collins, R. L. (1975). When left-handed mice live in right-handed worlds. *Science*, *187*, 181–184.

Corballis, M. C. (2021). How many lateralities? *Laterality*, *26*(3), 307–309.

Corey, D., Hurley, M., & Foundas, A. L. (2001). Identifying handedness groups via manual performance asymmetries: A multivariate approach. *Neuropsychiatry, Neuropsychology, and Behavioral Neurology, 14*(3), 144-152.

Elliott, D., Helsen, W. F., & Chua, R. (2010). Goal-directed aiming: Two components but multiple processes. *Psychological Bulletin*, *136*(6), 1023–1044.

Estrada-Marce´n, N., López-Rubio, A., & Casterad-Seral, J. (2022). La lateralidad en el Karate: Estudio centrado en la praxis de los entrenadores y entrenadoras. *Retos*, *44*, 806–815.

Fernandes, L. A., Apolinário-Souza, T., Castellano, G., Fortuna, B. C., & Lage, G. M. (2024). Hand differences in aiming task: A complementary spatial approach and analysis of dynamic brain networks with EEG. *Behavioural Brain Research*, *469*, 114973.

Fernandes, L. A., Romano-Silva, M. A., Figueiredo, L. S., Otoni Parma, J., Apolinário-Souza, T., & Menezes Lage, G. (2022). Modulation of motor cortices on manual asymmetries. *Kinesiology*, *54*(1), 15-24.

Fernandes, L. A., Souza, B. G. C. S., Sales, I. S., & Apolinário-Souza, T. (2018). Análise da complexidade da tarefa na assimetria manual no grooved pegboard test. Brazilian journal of motor behavior,12(1), 1-11.

Flowers, K. (1975). Handedness and controlled movement. *British Journal of Psychology*, *66*(1), 39-52.

Heath, M. (2005). Role of limb and target vision in the online control of memory-guided reaches. *Motor Control*, *9*, 281–311.

Heilman, K. M., & Abell, T. V. D. (1980). Right hemisphere dominance for attention: the mechanism underlying hemispheric asymmetries of inattention (neglect). *Neurology*, *30*(3), 327-327.

Hicks, R. E., Gualtieri, C. T., & Schroeder, S. R. (1983). Cognitive and motor components of bilateral transfer. *American Journal of Psychology*, *96*, 223–228.

Kimura, D. (1993). *Neuromotor mechanisms in human communication*. oxford university Press.

Lage, G. M., Gallo, L. G., Miranda, M. G., Vieira, D. R., Schickler, D. J., Coelho, R. R., & Benda, R. (2008). Assimetrias manuais e complexidade da tarefa em habilidades de apontamento. *Revista Portuguesa de Ciências do Desporto*, *8*(1), 47–57.

Lelis-Torres, N., Ugrinowitsch, H., Albuquerque, M. R., Apolinário-Souza, T., & Lage, G. M. (2017). The level of mental workload related to the index of difficulty of the motor task and handedness. *Brazilian Journal of Motor Behavior Research*, *11*, 1–10.

Levy, L. A. (1976). Review of evidence for genetic component in the determination of handedness. *Behavioral Genetics*, *6*(4), 429–453.

Marteniuk, R. G. (1976). Cognitive information processes in motor short-term memory and movement production. In *Motor control* (pp. 175-186). Academic Press.

Marteniuk, R. G., Mackenzie, C. L., Jeannerod, M., Athenes, S., & Dugas, C. (1987). Constraints on human arm movement trajectories. Canadian Journal of Psychology/Revue canadienne de psychologie, 41(3), 365.

McGonigle, B. O., & Flook, J. (1978). The learning of hand preferences by squirrel monkey. *Psychological Research*, *40*, 93–98.

Oldfield, R. C. (1971). The assessment and analysis of handedness: The Edinburgh Inventory. *Neuropsychologia*, *9*, 97–113.

Paszulewicz, J., Wolski, P., & Gajdek, M. (2020). Is laterality adaptive? Pitfalls in disentangling the laterality-performance relationship. *Cortex*, *125*, 175–189.

Provins, K. A., Milner, A. D., & Kerr, P. (1982). Asymmetry of manual preference and performance. *Perceptual and Motor Skills*, *54*, 179–194.

Regaiolli, B., Spiezio, C., & Vallortigara, G. (2016). Manual lateralization in macaques: Handedness, target laterality, and task complexity. *Laterality*, *21*(2), 100–117.

Rodrigues, P. C., & Vasconcelos, O. (2010). Desenvolvimento da assimetria manual. *Revista Portuguesa de Ciências do Desporto*, *10*(1), Porto.

Rosenbaum, D. A. (1980). Human movement initiation: specification of arm, direction, and extent. *Journal of Experimental Psychology: General*, *109*(4), 444.

Roy, E. A. (1983). Manual performance asymmetries and motor control processes: Subject-generated changes in response parameters. *Human Movement Science*, *2*(4), 271-277.

Roy, E. A., & Elliott, D. (1986). Manual asymmetries in visually directed aiming. *Canadian Journal of Psychology/Revue canadienne de psychologie*, *40*(2), 109.

Roy, L. E., & Kalbfleisch, D. (1994). Kinematic analyses of manual asymmetries in visual aiming movements. *Brain and Cognition*, *24*(3), 289–295.

Sainburg, R. L. (2014). Convergent models of handedness and brain lateralization. *Frontiers in psychology*, *5*, 1092.

Sainburg, R. L. (2016). Laterality of basic motor control mechanisms: Different roles of the right and left brain hemispheres. In Laterality in sports (pp. 155-177). Academic Press.

Salvador, M., Ugrinowitch, H., Silva, M. A. R., Miranda, D. M., Souza, T. A., & Lage, G. (2017). Estimulação transcraniana por corrente contínua (ETCC) e assimetrias manuais: O efeito da estimulação na destreza manual. *Journal of Physical Education*, *28*, e2837.

Santos, I., Lage, G., Cavalcante, A., Ugrinowitch, H., & Benda, R. (2006). Análise da assimetria nos padrões fundamentais arremessar e chutar em crianças. *Revista Portuguesa de Ciências do Desporto*, *6*(2), 188–193.

Strauss, E., Sherman, E. M. S., & Spreen, O. (2006). *A compendium of neuropsychological tests: Administration, norms, and commentary* (3rd ed.). Oxford University Press.

Teixeira, L. A. (2000). Assimetrias laterais em ações motoras: Preferência versus desempenho. *Motriz*, *6*(1), 1–8.

Teixeira, L. A. (2006). *Controle motor*. São Paulo: Manole.

Tiffin, J. (1968). *Purdue Pegboard examiner's manual*. London House.

Todor, J. I., & Doane, T. (1978). Handedness and hemispheric asymmetry in the control of movements. *Journal of Motor Behavior*, *10*(4), 295-300.

Todor, J. I., Kyprie, P. M., & Price, H. L. (1982). Lateral asymmetries in arm, wrist and finger movements. *Cortex*, *18*, 515–523.

Vaquero-Cristóbal, R., Martínez González-Moro, I., Alacid, F., & Ros, E. (2015). Efectos de la lateralidad sobre la flexibilidad, la fuerza-resistencia y el equilibrio en mujeres mayores activas. *Retos*, *27*, 127–130.

Vasconcelos, M. O. F. (1993). Assessment of manual asymmetry: Are proficiency and preference measure indicators of a common underlying factor? In S. Serpa, J. Alves, V. Ferreira, & A. Paula Brito (Eds.), *Proceedings of the 8th World Congress of Sport Psychology* (pp. 504–507). Lisboa: Edições FMH.

Vasconcelos, O. (1993). Asymmetries of manual motor response in relation to age, sex, handedness, and occupational activities. *Perceptual and Motor Skills*, 77(2), 691–700.

Vasconcelos, O., & Rodrigues, P. (2008). Métodos de avaliação dos comportamentos de assimetria lateral: Medidas de preferência e medidas de performance. In D. Catela & J. Barreiros (Eds.), *Desenvolvimento motor da criança* (pp. 105–114). Lisboa: Edições FMH.

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