MODULATION OF MOTOR CORTICES ON MANUAL ASYMMETRIES

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Abstract:

Differences between hands in motor performance are associated with differences in the interaction of inhibitory connections of homologous parts of the cerebral hemispheres. Modulation of these inhibitory connections in the right and left primary motor cortex (M1) may alter manual performance asymmetries. To investigate this assumption, eleven right-handed male university students performed a discrete aiming task in a digitizing tablet under three experimental conditions: dominant M1 inhibition, non-dominant M1 inhibition, and sham. The Transcranial Direct Current Stimulation technique was used to increase or decrease participants' M1 excitability. We used a within-subject design, in which we counterbalanced the order of conditions and the order of the starting hand among participants. The performance-dependent variables were: reaction time, movement time, and radial error, while kinematic variables were: peak velocity, relative time to peak velocity, and number of discontinuities in acceleration in the final homing phase. Results showed changes in asymmetry related to reaction time, movement time, and relative time to peak velocity. The interaction between M1 modulation and hemispheric specialization produced specific changes in these variables. Taken together, these findings revealed that modulation of the dominant and non-dominant M1 affects manual performance asymmetries.

Key words: *handedness, hemispheric specialization, transcranial direct current stimulation (tDCS), aiming task*

Introduction

In right-handed individuals, the corpus callosum connects the dominant primary motor cortex (M1), located in the left cerebral hemisphere, with the non-dominant M1, located in the right cerebral hemisphere (Vines, Nair, & Schlaug, 2008b). Hemispheric dominance is a physiological mechanism, called interhemispheric inhibition that suppresses undesired activity of the opposite hemisphere (Pal, et al., 2005). Interhemispheric inhibition releases movement from the contralateral M1 while preventing the occurrence of a mirror activity in the ipsilateral M1 (Duque, et al., 2007). Interhemispheric inhibition is also related to differences observed in manual performance asymmetries (Takeuchi, Oouchida, & Izumi, 2012).

Manual performance asymmetries are characterized by differences in the control of homologous contralateral body segments (Carson, 1989). The dominant M1 largely controls right-hand movements, while the non-dominant M1 controls left-hand movements. In aiming movements to fixed targets, specific functions are lateralized in both cerebral hemispheres. For instance, there is a reaction time advantage for the left-hand/non-dominant M1 system, and a movement time advantage for the right-hand/dominant M1 system (Mieschke, Elliot, Helsen, Carson, & Coull, 2001). Since the access to resources and capabilities of each hemisphere differ between hands (Lavrysen, et al., 2012), we propose that changes in the M1 inhibitory/excitatory connections can modulate asymmetries in aiming movements.

This assumption is based on the rationale that inhibition of the dominant M1/excitation of the non-dominant M1 (from now on defined as inhibition of the dominant M1) would decrease inhibitory connections, facilitating access of the non-dominant hand to the processing of the dominant M1 (Figure 1A). Consequently, the asymmetry between hands

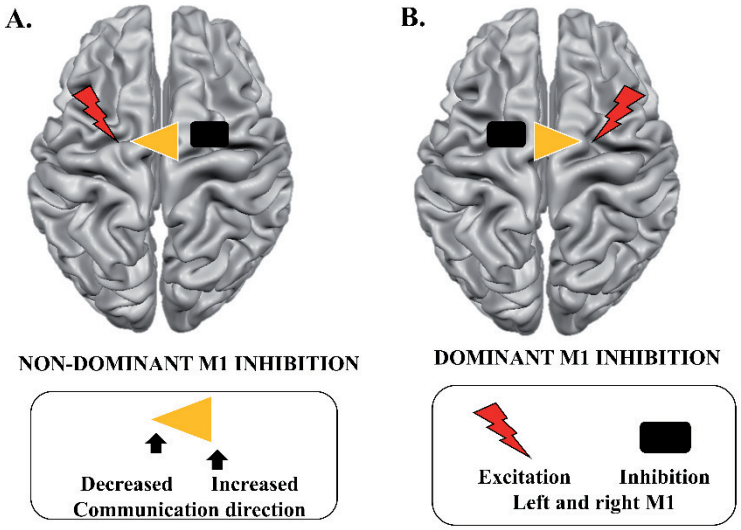

Figure 1. Effects of the M1 modulation in the direction of the communication between hemispheres. A. Non-dominant M1 inhibition. B. Dominant M1 inhibition.

in movement time would be reduced. The same pattern of result is expected to movement accuracy, since right-handed individuals show higher accuracy in movements performed with the right-hand (Carey, et al., 2015; Sainburg, 2014). Moreover, inhibition of the non-dominant M1/excitation of the dominant M1 (from now on defined as inhibition of the non-dominant M1) would decrease inhibitory connections, facilitating access of the dominant hand to the processing of the non-dominant M1 (Figure 1B). Consequently, the asymmetry between hands in reaction time would be diminished.

Although previous studies presented evidence of M1 modulation altering manual dexterity (Vines, Nair, & Schlaug, 2006; Vines, Cerruti & Schlaug, 2008a), to our knowledge, no study did specifically investigate the effects of M1 modulation in manual performance asymmetries. Our assumptions are reinforced by results indicating that excitation of the dominant M1 improves the right-hand performance, while inhibition of the dominant M1 improves the left-hand performance (Vines, et al., 2006). Of note, the combined modulation of dominant M1 inhibition with non-dominant M1 excitation produces an additive effect, facilitating the left-hand performance (Vines, et al., 2008a). Finally, dominant M1 excitation affects right- and left-hand performances, while non-dominant M1 excitation only affects the left-hand performance (Vines, et al., 2008b). If these results observed in sequential keystrokes tasks are also observed in aiming tasks, inhibition of the dominant and non-dominant M1 should, as described, change manual performance asymmetries with regards to reaction time, movement time, and movement accuracy.

Movement time can be examined in terms of preprogrammed and feedback-controlled components. Kinematic analysis of aiming movements shows both an initial impulse phase (preprogrammed) that roughly approaches the fixed target (Elliot, et al., 2010), and a final homing phase (feedback-controlled) with adjustments guided by online feedback (Lage, Malloy-Diniz, Neves, Moraes, & Corrêa, 2012). The initial impulse phase shows a higher peak velocity for the right hand (Elliott & Chua, 1996), and an increased time to peak velocity for the left-hand (Bryden, 2002). In the final homing phase, a higher number of corrections guided by visual feedback is exhibited by the left-hand (Carson, Goodman, Chua, & Elliott, 1993). The M1 makes a functional contribution to the production of movement parameters such as length, direction, force, and the time derivative of force (Roland, 1993; Vollmann, et al., 2013). Therefore, M1 inhibition should affect these functions associated with the initial impulse phase. Inhibition of the dominant M1 should decrease asymmetries in peak velocity and time to peak velocity.

Concerning the movement's final homing phase, the role of the posterior parietal cortex in corrections has been emphasized by several studies (Desmurget, et al., 1999; Oliveira, et al., 2019; Tunik, Frey, & Grafton., 2005). The dorsal premotor cortex and the M1 are also brain areas highlighted in cortico-cortical communication involving ongoing corrections (Mutha, et al., 2014). Changes on the original motor plan, demanding changes of hand trajectory, involve neural activity from the premotor cortex, M1 and parietal cortex (Archambault, Caminiti, & Battaglia-Mayer, 2009), but activity of a population of cells remained higher in the parietal than the in the other areas (Archambault, Ferrari-Toniolo, & Battaglia-Mayer, 2011). Therefore, the posterior parietal cortex is more involved in the implementation of online corrections in hand trajectory than the premotor cortex and M1 (Archambault, et al., 2011). This finding suggests that M1 inhibition should not directly affect adjustments implemented in the final

homing phase. Therefore, manual performance asymmetries should not be altered in this movement component.

Therefore, the relative proficiency of each M1 on information processing can be modulated via interhemispheric inhibition/excitation. Thus, the present study aimed to investigate the effects of M1 modulation on manual performance asymmetries. To our knowledge, this is the first study to use two distinct mechanisms to modulate manual asymmetries, aiming to understand which movement control characteristics are associated with these asymmetries. We hypothesized that M1 modulation would modify the asymmetries in movement time, accuracy, peak velocity, and relative time to peak velocity by decreasing asymmetry in dominant M1 inhibition and increasing asymmetry in non-dominant M1 inhibition. Moreover, M1 modulation would modify the asymmetry in reaction time by decreasing asymmetry in non-dominant M1 inhibition and increasing asymmetry in dominant M1 inhibition. Finally, M1 modulation would not modify the asymmetry in the number of corrections in the final homing phase.

Material and methods

Participants

A within-subjects design approach involving comparisons between three treatments was applied to eleven adults aged 18-35 years (mean age=25.3, SD=±4.15 years). Participants were male university students, right-handed, had no prior experience with the motor task, and had normal or corrected-to-normal vision. The sample size was defined using Power Analysis package from r (the official release of the package: http://cran.r-project.org/web/packages/pwr/). The analysis indicated a sample size of 11 subjects, considering an effect size of 0.55 and the power of the test as 0.80. Participants included in this study declared no neurological impairment, use of metal implants in the skull, cardiac pacemakers, recurrent epilepsy, or use of medications that were prone to alter brain excitability (Nitsche, et al., 2008). An ethics committee from a local university approved all procedures, and participants signed an informed consent after receiving a full explanation about the study (protocol CAAE 24116513.2.0000.5149).

Instruments and task

We used a digitizing tablet (WACOM Intuos 3, North Carolina, USA) with a sampling rate of 200 Hz and accuracy of 0.01 cm. A microcomputer with MovAlyzer software (Neuroscript, Arizona, USA) was used to control the task. We also used a Transcranial Direct Current Stimulation (tDCS) device (HDC Magstim, North Carolina, USA), to induce an electric current of 1 mA (current density 0.04 mA/cm²; total charge 0.048 C/cm²) for 20 minutes (Apolinário-Souza, et al., 2016; Nitsche, et al., 2008;). The cathodal and anodal electrodes were placed either over the left M1 (C3) or the right M1 (C4), according to the international 10/20 system. The current was increased in a ramp-like fashion for 30 seconds. In sham condition, the same montage was used, but the current was turned off after 30 seconds (Mesquita, Lage, Franchini, Romano-Silva, & Albuquerque, 2019). The Edinburgh Handedness Inventory (Oldfield, 1978) was used to determine the participants' handedness.

A discrete aiming task was performed to analyze manual asymmetries. The discrete aiming tasks are among the most used in the study of manual performance asymmetries (Elliott & Chua, 1996), presenting a short duration and well-defined beginning and end. These tasks are controlled in a hybrid way, that is, sometimes with an open circuit (preprogramming) predominance and sometimes with a closed circuit (online control) predominance. Thus, the analysis of discrete aiming allows accessing the modifications in the use of a more central and/or peripheral movement control. In our study, the task consisted of moving a non-inking pen on a digitizing tablet to move the cursor on the computer screen from the home position to the target (Figure 2). The target had a diameter of 1 cm. The target and the starting point were 19 cm away center-to-center and angled 45º. The index of difficulty (ID) of the target was 5.2 bits (Fitts, 1954).

The MovAlyzer software (Neuroscript, Arizona, USA) provided all performance and kinematic measures used, as well as the data filtering. In addition, we used a low-pass filter at 12 Hz, using the Fast Fourier Transform method.

Procedures

After signing the informed consent form, participants filled the Edinburgh Handedness Inventory (Oldfield, 1978) out to assure their right-hand preference. Next, they were given instructions for the task and were asked to perform it as fast and accurate as possible. Before each trial, the home position and the target appeared on the microcomputer screen, and participants placed the pen on the home position. After 2.5 seconds, the target disappeared. The target reappeared on the screen randomly 2-3 seconds later, indicating that the participant should immediately start the aiming movement. Each trial had a 2-second time limit to be completed before it was terminated. Home position was aligned at the midline of the participant. The target was positioned on the right side for trials performed with the right-hand and positioned on the left side for trials performed with the left-hand (Figure 2). Trials in which participants performed reverse movements or did not stop the pen within the target boundaries were considered error trials.

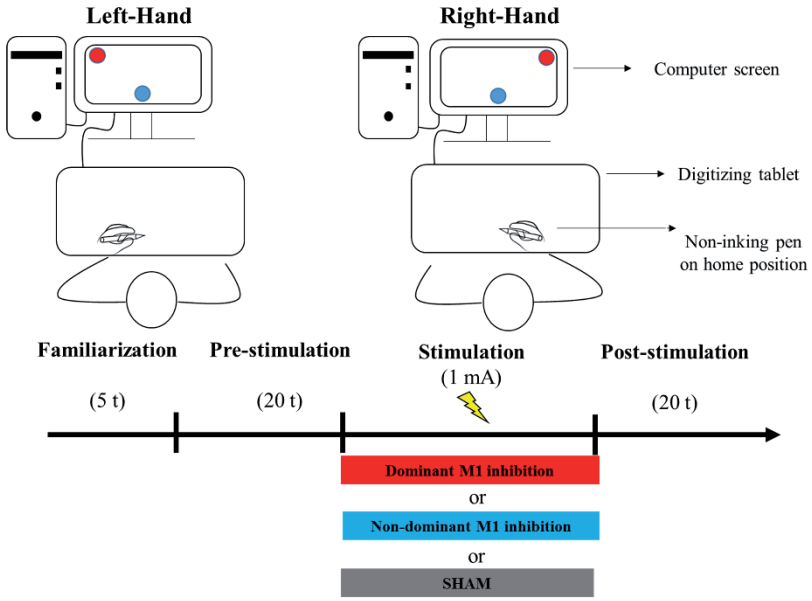

Figure 2. Motor task set-up and experimental conditions.

We used a within-subject design, in which we counterbalanced the order of conditions (dominant M1 inhibition, non-dominant M1 inhibition, and sham) and the order of the starting hand (left-hand or right-hand) among participants, similarly to Vines et al. (2008a). This specific design was chosen to reduce the influence of individual differences, since each participant serves as their own control, increasing the internal validity of the study. Participants performed five trials with each hand to familiarize themselves with the task. Immediately after the familiarization, the pre-stimulation phase was conducted, which consisted of performing 20 trials with each hand. After pre-stimulation, participants were stimulated according to the predetermined inhibition condition (Figure 3).

TDCS was applied to participants after they were comfortably seated on a chair. Under condition 1, we inhibited the dominant M1 by positioning the cathodal electrode over the C3 region, and we excited the non-dominant M1 by placing the anodal electrode over the C4 region (Figure 3). In this condition, we expected a decrease in asymmetry due to improvement of the left-hand via the preprogrammed mechanism. Under condition 2, the non-dominant M1 was inhibited by the positioning of the cathodal electrode over the C4 region, while the dominant M1 was excited by the anodal over the C3 region (Figure 3). In this condition, we expected a decrease in asymmetry via improvement of the right-hand feedback mechanisms. Under condition 3, sham stimulation was applied. Since this was a

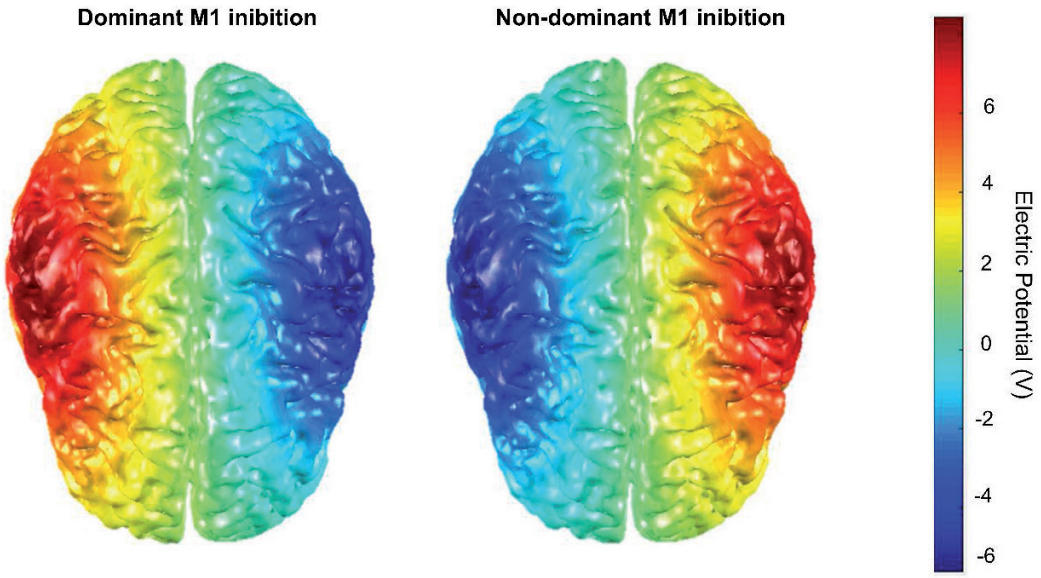

Figure 3. Bihemispheric M1 tDCS simulation. Electric potential distribution over the dominant and non-dominant M1 cortex.

control condition, we expected no change in asymmetry and hand performance.

Immediately after the stimulation, the post-stimulation phase was performed with a configuration identical to the one on the pre-stimulation. The interval between each experimental condition was 48h. We adopted this interval to dissipate any possible remaining effect of the last condition.

Data analyses

Dependent variables

The performance-dependent variables used were: (1) reaction time (RT); (2) movement time (MT); and (3) radial error (RE). The reaction time corresponds to the time interval between the stimulus onset and the start of the movement. The movement time corresponds to the time interval between the beginning and the end of the movement. The RE was calculated as the distance between the movement endpoint and the target. The RE was computed as follows:

$$(1)\ \Re = \sqrt{\left(x_f - x_t\right)^2 + \left(y_f - y_t\right)^2}$$

where:

- x_f = endpoint on the x-axis;
- x_t = target position on the x-axis;
- y_f = endpoint on the y-axis;
- y_t = target position on the y-axis.

The kinematic variables used were: (1) peak velocity; (2) relative time to peak velocity; and (3) number of discontinuities in acceleration in the final homing phase. The peak velocity refers to the highest velocity during the movement. This measure allows inferences regarding the limb's force modulation during the initial impulse phase (Lage, et al., 2012). The relative time to peak velocity corresponds to the time interval between the start of the movement and the first zero-crossing on the acceleration profile. We considered the first zero-crossing as the final homing phase start point. Through relative time to peak velocity, it is possible to infer about the predominant mechanism used (Lage, et al., 2014). For example, if the right-hand has a greater relative time to peak velocity than the left-hand, it can be inferred that the movement time observed in the right-hand was more based on the pre-programming mechanism than the left-hand. On the contrary, the movement time observed in the left-hand was more based on corrective mechanisms than the right-hand. The number of discontinuities in acceleration in the final homing phase corresponds to the number of zero-crossings on the acceleration profile during the final homing phase. The number of discontinuities in acceleration can be used to infer about the use of feedback corrections during the last part of the movement (Elliott, Helsen, & Chua, 2001).

Statistical analysis

Participants' data for each of the performance and kinematics variables were organized for each hand into blocks of 20 trials on each phase (pre-stimulation and post-stimulation) in the three experimental conditions: dominant M1 inhibition/non-dominant M1 excitation, non-dominant M1 inhibition/dominant M1 excitation, and sham. The Shapiro-Wilk test was used to evaluate data normality ($p>.05$). After that, the index of change in asymmetry was calculated for each variable in each condition. First, the indexes of asymmetry on both the pre- and post-stimulation phase were obtained by subtracting the dominant hand value from the non-dominant hand value. Next, the index of change in asymmetry was obtained by subtracting the index of asymmetry on the post-stimulation phase by the index on the pre-stimulation phase.

For inferential analysis of the indexes of change in asymmetry, one-way ANOVAs with repeated measures were used to compare the effect of experimental conditions on the changes in asymmetries. We used Tukey's *post-hoc* test for all the variables. The significance level considered was $\alpha=.05$. Effect sizes were calculated using partial eta-squared (ηp^2). Effect sizes values were interpreted according to the following reference values: 0.01-0.05 were considered small; 0.06-0.13 were considered medium; and values above 0.13 were considered large effects (Open Science Collaboration, 2015).

Results

Performance variables

Reaction time

The inferential analysis for reaction time detected a significant difference between the conditions [$F_{2,20}=5.36$, $p=.01$, $\eta p^2=.37$] (Figure 4A). The *post-hoc* analysis indicated that the dominant M1 inhibition and the non-dominant M1 inhibition conditions were different from each other ($p<.01$), with the dominant M1 inhibition condition increasing asymmetry and the non-dominant M1 inhibition condition reducing asymmetry. No other significant difference was found ($p>.05$).

Movement time

The inferential analysis for movement time detected a significant effect of the conditions [$F_{2,20}=4.75$, $p=.05$, $\eta p^2=.32$,] (Figure 4B). The p*ost hoc* analysis indicated that the dominant M1 inhibition and the non-dominant M1 inhibition conditions were different from each other ($p<.05$), with the dominant M1 inhibition condition reducing asymmetry and the non-dominant M1 inhibition condition increasing asymmetry. No other significant difference was found ($p>.05$).

Radial error

The inferential analysis for radial error detected no significant effect for the conditions [$F_{2,20}$=.44, p=.36, ηp^2=.04] (Figure 4C).

Kinematic variables

Peak velocity

The inferential analysis for peak velocity detected no significant effect for the conditions [$F_{2,20}$=.35, p=.70, ηp^2=.05] (Figure 5A).

Relative time to peak velocity

The inferential analysis detected a significant effect of the conditions for relative time to peak velocity [$F_{2,20}$=8.59, p=.01, ηp^2=.46,] (Figure 5B). The *post-hoc* analysis indicated that the dominant M1 inhibition condition and SHAM were different from each other (p<.05), with the dominant M1 inhibition condition reducing asymmetry and the SHAM condition increasing asymmetry. No other significant difference was found (p>.05).

Number of discontinuities

The inferential analysis of the number of discontinuities detected no significant effect for the conditions [$F_{2,20}$=.41, p=.32, ηp^2>.01] (Figure 5C).

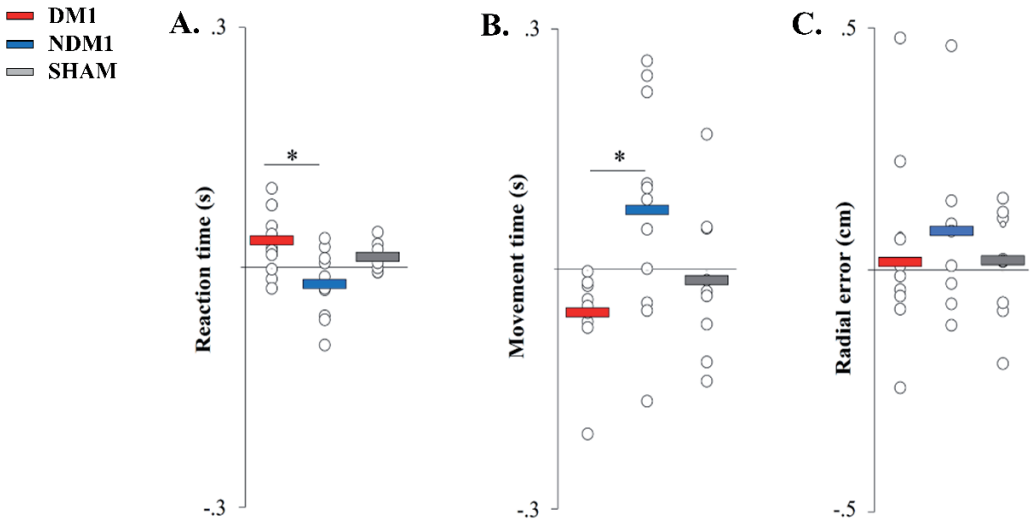

*Figure 4. Asymmetries. **A.** Group and individual means for reaction time. The DM1 condition increased the asymmetry while the NDM1 condition reduced the asymmetry. **B.** Group and individual means for movement time. The NDM1 condition increased the asymmetry, while the DM1 condition reduced the asymmetry. **C.** Group and individual means for radial error. No differences were reported between the conditions. DM1 = dominant M1 inhibition; NDM1 = non-dominant M1 inhibition; SHAM = sham stimulation. The asterisk (*) indicates significant differences (p<.05).*

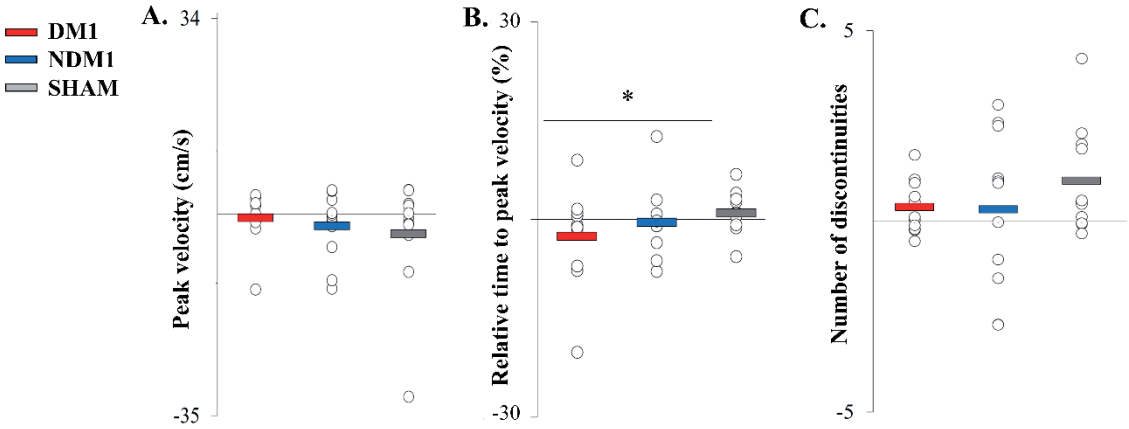

*Figure 5. Index of change in asymmetries. **A.** Group and individual means for peak velocity. No differences were reported between the conditions. **B.** Group and individual means for relative time to peak velocity. The dominant DM1H inhibition condition reduced the asymmetry, while SHAM condition increased the asymmetry. **C.** Group and individual means for number of discontinuities variable. No differences were reported between the conditions. DM1 = dominant M1 inhibition; NDM1 = non-dominant M1 inhibition; SHAM = sham stimulation. The asterisk (*) indicates significant differences (p<.05).*

Discussion and conclusions

This study aimed to investigate the effects of cortical modulation on manual performance asymmetries. We hypothesized that: (a) M1 modulation would modify asymmetries in movement time, accuracy, peak velocity, and relative time to peak velocity by decreasing asymmetry in the dominant M1 inhibition and increasing asymmetry in the non-dominant M1 inhibition; (b) M1 modulation would modify asymmetry in reaction time by decreasing asymmetry in the non-dominant M1 inhibition and increasing asymmetry in the dominant M1 inhibition; and (c) M1 modulation would not modify asymmetry in the number of corrections in the final homing phase. Our hypotheses regarding M1 modulation were partially confirmed, since changes in asymmetries were observed in reaction time, movement time, and relative time to peak velocity measures. We did not find changes in asymmetries in radial error and peak velocity measures. Finally, the hypothesis of no modulation effect on asymmetry related to feedback-based corrections was confirmed.

Overall, the results confirm our initial assumption that changes in the M1 inhibitory/excitatory connections can modulate asymmetries in aiming movements. Previous studies show effects of the modulation of excitability in M1 communication. For instance, decreased excitability of the dominant M1 with transcranial magnetic stimulation resulted in decreased interhemispheric asymmetry between the non-dominant and the dominant M1 (Pal, et al., 2005). This effect has also been observed in studies using transcranial direct current stimulation (tDCS). Tazoe, Endoh, Kitamura, and Ogata (2014) investigated the tDCS effects on interhemispheric inhibition between the dominant M1 and the non-dominant M1. Regardless of the electrode montages, tDCS increased interhemispheric inhibition from the anodal site to the cathodal site and reduced interhemispheric inhibition in the opposite direction. In addition, M1 modulation produced behavioral changes in the performance of the hands (Vines, et al., 2006, 2008a, 2008b).

Despite the possibility of modulating the M1 and, consequently, behavior, the study of M1 modulation on manual performance asymmetries has been neglected. Our results indicate that manual asymmetries can be augmented or reduced by an interaction between (a) the left and right M1 modulation and (b) hemispheric specialization. Changes in communication between the dominant and non-dominant M1 modulate asymmetries in some variables, while no effects are found in others. These results not only confirm the possibility of modulating manual asymmetry via M1 modulation but also reinforce the role of hemispheric specialization in aiming movements to fixed targets. Previous findings that are not related to changes in manual asymmetries show changes in the performance of the hands via M1 modulation (Vines, et al., 2006, 2008a, 2008b), but not the interaction between M1 modulation and hemispheric specialization observed in the present study. We believe this is due to the tasks and dependent variables used in these studies (e.g. number of correct sequential keystrokes), which did not allow conclusions to be drawn in this regard.

In aiming movements to fixed targets, there is a reaction time asymmetry in favor of the non-dominant M1 system, and a movement time asymmetry in favor of the dominant M1 system (Mieschke, et al., 2001). Our results indicated that the interaction between M1 modulation and hemispheric specialization produced specific changes in these two response components. Beyond the inferential analysis indicating differences in the index of change in the reaction time asymmetry, descriptive analysis of the direction of the change in asymmetry shows that the dominant M1 inhibition increases asymmetry and the non-dominant M1 inhibition decreases it. Conversely, for movement time, descriptive analysis of the direction of the change in asymmetry shows that the dominant M1 inhibition decreases asymmetry and the non-dominant M1 inhibition increases it. Altogether, the direction of changes in each response component was specific to the type of inhibition/excitation setup and the specialization of each M1.

Changes in asymmetries were better observed in the central components of the movement than in the peripheral ones. The best examples are the changes in reaction time and relative time to peak velocity, which are associated with the initial impulse phase (Elliott, et al., 2001; Lage, et al., 2014). The functional role of the M1 during movement preparation in parameters such as length, direction, force, and the time derivative of force is well-known (Roland, 1993; Vollmann, et al., 2013). The M1 plays a more direct and earlier role in providing precise control of hand kinematics than the dorsal premotor cortex and posterior parietal cortex (Archambault, et al., 2011). Considering this, when the M1 is modulated, changes in manual asymmetries are better observed in central aspects, related to the movement initial impulse phase. The movement time analysis also contributes to this assumption. Movement time has both the central (initial impulse phase) and peripheral (feedback-controlled phase) components (Elliot, et al., 2010). Changes in manual asymmetries were observed in relative time to peak velocity, a preprogrammed aspect of the movement, but not in the number of online corrections, an aspect related to the final homing phase.

This lack of change in asymmetry related to online corrections was expected. Online changes of the ongoing motor plan, required for the implementation of corrections, involve neural activity

from a corticocortical network (Archambault, et al., 2009), but an increased activity of a population of cells is observed in the parietal cortex more than in other areas of this network (Archambault, et al., 2011). Therefore, the M1 modulation did not significantly influence changes in manual asymmetries related to the adjustments implemented in the final homing phase.

Surprisingly, we expected significant changes in manual asymmetries related to movement accuracy, but this hypothesis was not confirmed. Accuracy efficiency is better observed in right-hand (Carey, et al., 2015; Sainburg, 2014). Nonetheless, considering the lack of change in online corrections, it is possible to associate both findings. The M1 modulation did not change manual asymmetry regarding online corrections, and the final adjustments were essential to guarantee accuracy. Consequently, the M1 modulation did not affect manual asymmetry related to movement accuracy. Further studies could investigate this possible relation.

Finally, our hypothesis regarding changes in peak velocity manual asymmetry was not confirmed. Peak velocity was the single central component of the movement that did not change its level of asymmetry by the M1 modulation. The M1 is functionally involved in the programming of force parameters (Blefari, Sulzer, Hepp-Reymond, Kollias, & Gassert, 2015), and peak velocity has the same behavioral meaning as peak force, if one assumes that frictional forces are negligible in this type of task (Lage, et al., 2012). So, why the M1 modulation did not change the asymmetry in peak velocity? This finding challenges our rationale. A possible explanation is that the index of difficulty of the task constrained the maximal peak velocity that could be produced, creating a ceiling effect. The non-dominant M1 might not have exploited the advantages of the dominant M1 specialization in producing higher peaks of velocity since the task does not afford high peak velocities. Changes in peak velocity covariate reciprocally with the index of difficulty (Winstein, Grafton, & Pohl, 1997). Likely, tasks with a lower index of difficulty than the one used in our study (5.2 bits) would result in the expected change in asymmetry. Further studies are warranted to investigate this hypothesis. Of note, the effects of tDCS on the M1 modulation were not actually tested (using TMS or some other measure) in the present study. Thus, any effects of the tDCS are only assumed to result from this modulation.

The results of this study contribute to the production of basic knowledge about the biological characteristics of movement control. These results supply discussions about the importance of hemispheric dominance in determining lateralized behavior and provides subsidies for future exploration of the laterality enigmas. Thus, by verifying that cortical modulation is able to change manual asymmetries and that this change is associated with different characteristics of the cerebral hemispheres, we corroborate the notion that these differences support the biological characteristics of laterality, which are amenable to modification, even if temporarily, by cortical modulation techniques. Together, these results can support the understanding of the characteristics of laterality and the predominance of performance for certain tasks. Furthermore, they can help in motor rehabilitation and sports training settings, based on the understanding of the different results obtained in different tDCS configurations.

Even though the tDCS is a widely used technique, it has limited focality, which is a limiting aspect of this study. Because of this limitation, other areas besides the target area can be inhibited and stimulated, which could imply changes in the results (Lattari, et al., 2018). As a perspective for future studies that investigate changes in inter-hemispheric communication resulting from the use of cortical modulation, we suggest the use of specific tools that allow inferences about the reduction or increase of inter-hemispheric communication. As an example, the adoption of coherence measures that are obtained by electroencephalography could allow advances in this research topic.

In the present study, the M1 modulation changed asymmetries in reaction time, movement time, and relative time to peak velocity. The interaction between the M1 modulation and hemispheric specialization produced specific changes in these variables. The dominant M1 inhibition increases asymmetry in reaction time, and the non-dominant M1 inhibition decreases it. Conversely, the dominant M1 inhibition decreases asymmetry in movement time, and the non-dominant M1 inhibition increases it. Overall, these findings confirm our initial assumption that changes in the M1 inhibitory/excitatory connections modulate asymmetries in aiming movements.

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