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Uncertainty in aiming movements and its association to hand function

Flávia Priscila de Paiva Silva
Sandra Maria Sbeghen Ferreira de Freitas
Emelli da Silva Comenalle
Sandra Regina Alouche
Universidade Cidade de São Paulo, São Paulo, Brazil

Abstract—The purpose of this study was to analyze the influence of the uncertainty of target location on the planning and execution of aiming movements performed towards the ipsilateral and contralateral directions by the right and left upper limbs. In addition, the association between the performance of aiming movements and the performance of functional manual tasks was investigated. Two tasks were proposed: with prior knowledge of the movement direction (simple reaction time) or not (choice reaction time). The grip strength and manual dexterity were measured. The choice option in response (i.e. uncertainty) influenced planning of the aiming movements, but not its execution, while movements performed towards the contralateral direction were worse in execution as compared to the ipsilateral direction. Manual dexterity was significantly correlated with reaction times, while the performance during movement execution was significantly correlated with handgrip/pinch strength.

Keywords: behavior, upper extremity, functional laterality, reaction time

Resumo—"Incerteza de movimentos dirigidos ao alvo e sua associação com a função manual." O objetivo desse estudo foi avaliar a influência da incerteza da localização do alvo no planejamento e execução de movimentos dirigidos ao alvo realizados para as direções ipsilateral e contralateral pelos membros superiores direito e esquerdo. Em adição, a associação entre o desempenho do movimento dirigido ao alvo e o desempenho em tarefas manuais funcionais foi investigada. Duas tarefas foram propostas: com o conhecimento prévio da direção do movimento (tempo de reação simples) ou não (tempo de reação de escolha). Foram avaliadas a força de preensão palmar e a destreza manual. A opção de escolha na resposta (ex. incerteza) influenciou o planejamento do movimento dirigido ao alvo, mas não a sua execução, enquanto os movimentos realizados para a direção contralateral apresentaram pior execução quando comparados à direção ipsilateral. Destreza manual foi significativamente correlacionada com tempos de reação, enquanto o desempenho durante a execução do movimento foi significativamente correlacionado com forças de preensão/pinça.

Palavras-chave: comportamento, membro superior, lateralidade funcional, tempo de reação

Resumen—"La incertidumbre de movimientos dirigidos a la diana y su asociación con la función manual." El propósito de este estudio fue evaluar la influencia de la incertidumbre ubicación de la diana en la planificación y ejecución de movimientos dirigidos a la diana realizado por direcciones ipsilateral y contralateral por los miembros superiores derecho e izquierdo. Además, se investigó la asociación entre el rendimiento de movimiento dirigido a la diana y el rendimiento de la mano para tareas funcionales. Se propusieron dos tareas: con el conocimiento previo de la dirección del movimiento (tiempo de reacción simple) o no (tiempo de reacción del elección). Se evaluó la fuerza de prensión y la destreza manual. La opción de elección en responder (Incertidumbre por ejemplo.) influido en la planificación del movimiento dirigido a la diana, pero no su aplicación, mientras que el movimiento de la dirección contralateral tuvo un peor rendimiento en comparación con la dirección ipsilateral. La destreza manual se correlacionó significativamente con los tiempos de reacción, mientras que el rendimiento durante la realización del movimiento se correlacionó significativamente con la fuerza de prensión / pinzas.

Palabras claves: conducta, miembro superior, la lateralidad funcional, tiempo de reacción

Introduction

The totality of upper limb function is important for the performance of most of daily life activities such as eating, wearing or writing. Three major movements can be described for the

execution of these functions: reach, grip and manipulation (Lima, Nascimento, & Teixeira-Salmela, 2010). The reaching movement, or aiming movement, can be defined as a voluntary movement of the upper limb that depends on its position in space to achieve a target (McCrea & Eng, 2005). The manipulation

of an object involves pinching and gripping movements of the hands, adapted to its shape, size and weight (Khan, Sarteep, Mottram, Lawrence, & Adam, 2011; McCrea & Eng, 2005). The performance of the aiming movement, the main focus of this study, can be divided into three distinct stages: identification of the stimulus (perception), planning (selection and response programming) and execution (action) (Haaland & Harrington, 1989; McCrea & Eng, 2005).

One of the factors that can affect the performance of the aiming movement is the uncertainty of the target location when there are multiple options available. This factor can be analyzed through the paradigm of simple and choice reaction times (Ishihara, Imanaka, & Mori, 2002; Khan, Mourton, Buckolz, & Franks, 2008). In simple reaction time, the individual knows which response must be executed prior to receiving the stimulus to start the movement. This is not the case for choice reaction time, in which the stimulus to start the movement indicates the response that must be executed. For aiming movement, smaller latencies to start the movement in simple reaction time tasks are described in relation to choice reaction time tasks independently of the complexity, amplitude and direction of the movement (Ishihara *et al*., 2002; Khan *et al*., 2008).

The direction in which the aiming movement is executed influences its planning and execution independently of the presence or absence of target uncertainty. Movements performed to targets presented in the contralateral space of the moving upper limb are more biomechanically complex than those performed to the ipsilateral space. Such complexity generates increased latency to start the movement (Carey & Liddle, 2013; Ishihara *et al*., 2002). This ipsilateral advantage can be attributed to inertial movement consequences (Carey & Liddle, 2013), as well as the dependence of anticipatory mechanisms of execution controlled by the nervous system, which can generate higher planning demands (Sainburg, Ghez, & Kalakanis, 1999). The direction of the movement also influences its execution. In most movement directions, the intersegmental coordination of the limb creates an interaction torque in the elbow joint due to the active movement of the shoulder (Dounskaia, 2005, 2010; Dounskaia, Goble, & Wang, 2011; Dounskaia, Ketcham, & Stelmach, 2002).This coordination can be seen mostly in contralateral movements, which are slower, less smooth, and less precise than those directed to ipsilateral targets (Coqueiro, de Freitas, Silva, & Alouche, 2014; Ishihara *et al*., 2002; Silva, de Freitas, Silva, Banjai, & Alouche, 2014). For ipsilateral movements, fundamentally in the diagonal direction on the same side as the upper limb performing the movement, the elbow joint is responsible for starting the movement by active torque (Dounskaia, 2005, 2010; Dounskaia *et al*., 2002; Galloway & Koshland, 2002). Ishihara *et al*. (2002) analyzed aiming movements and finger lifting in right-handed individuals, in different directions and associated with both simple and choice reaction-time tasks. Higher latency was observed in the choice reaction-time task and for the contralateral direction in all tasks; slower and less smooth movements were also observed in the contralateral direction. No influence on movement time or accuracy in function of the tasks was observed. Furthermore, interaction between the tasks and directions was not observed.

In all studies, participants performed the tasks only with the right upper limb.

Laterality effects on target-location uncertainty and aiming-movement direction were less explored. Functional laterality is defined as the preferential use and superior functioning of either the left or the right upper limb in function of hemispheric cerebral specialization for motor control, characterizing the upper limbs as dominant or non-dominant (Duff & Sainburg, 2007; Lima, Francisco, & de Freitas, 2012; Mutha, Haaland, & Sainburg, 2013; Ozcan, Tulum, Pinar, & Baskurt, 2004). It has been shown that cerebral hemispheres assume specializations of different aspects of movement control, increasing its efficiency. Studies evaluating the aiming movement in right-handed individuals have shown that the left hemisphere is responsible for anticipatory control of dynamic characteristics of movement, while the right hemisphere optimizes the stability of the upper limb's position during movement (Mutha *et al*. 2013; Duff and Sainburg 2007), especially in tasks with higher spatial demands (Silva *et al*., 2014).

Functional laterality was also described in tasks involving handgrip strength and manual dexterity, which can be defined as the ability to manipulate objects by fine voluntary movements mainly using the fingertips. In those tasks, better performance of the dominant upper limb has been observed (Lima *et al*., 2012; Lima, Santos, & de Freitas, 2011; Ozcan *et al*., 2004). The association between strength and dexterity in aiming movement performance of the right and left sides was not examined in these studies.

The effects of uncertainty of the target location and functional laterality on aiming movements, as well as the influence of the distance to the target, were investigated by Mieschke, Elliott, Helsen, Carson, and Coull (2001) using kinematic analysis. Right-handed individuals either performed right and left aiming movements or lifted their hands upon target illumination. The amount of advance information about the target (distance and/or direction) was manipulated. The authors observed that the uncertainty of the response increased the reaction time; additionally, the participants' previous knowledge of the target's direction was shown to be more important for planning than the targets' distance. For aiming movements toward targets in the left space, the left hand presented a reaction advantage, while the right hand showed higher performance in movements executed primarily toward the right. The authors also observed higher peak velocities when both direction and distance were pre-cued (i.e., simple reaction-time tasks) than when no advance information was provided (i.e., choice reaction-time tasks). Participants responded more quickly and moved more rapidly to targets in ipsilateral space.

Thus, upper-limb aiming movements seem to be influenced by uncertainty of the target direction and functional laterality. The purpose of this study was to verify whether this influence is similar when using a digitizing tablet that simulates daily upper-limb activities and to verify the association between aiming-movements performance' and performance on manual tests such as strength and dexterity. It was expected that individuals would perform better with the

right upper limb in simple reaction-time tasks to the ipsilateral direction, due to lower demands of movement planning and execution. It was also believed that there would be an association between manual dexterity tasks and variables related to aiming-movement planning, since dexterity tasks have more complex components than tasks that demand muscular strength.

Method

Participants

Eleven healthy subjects were included in the study, aged between 18 and 30 years, right-handed as confirmed by the Edinburgh Inventory (Oldfield, 1971), and of both sexes (6 men). Participants were initially characterized in terms of sociodemographic, clinical and functional aspects. Individuals who had some kind of musculoskeletal dysfunction and/ or upper limb pain or any associated neurological symptoms were excluded.

Study design

All the procedures of this cross-sectional study were conducted in accordance with the Declaration of Helsinki and approved by the ethics committee of the Universidade Cidade de São Paulo in 9/17/2012 under the approval number 07764512.9.0000.0064. Each participant signed a term of informed consent before the procedures.

Procedures

After collecting sociodemographic and clinical data, participants were seated on an adjustable-height chair to perform the tests. Initially, the physical-functional tests were applied - the Purdue Pegboard Test (Buddenberg & Davis, 2000) and handgrip strength and pinch (Figueiredo, Sampaio, Mancini, Silva, & Souza, 2007; Mathiowetz *et al.*, 1985). The Purdue Pegboard Test is used to measure manual dexterity (Buddenberg & Davis, 2000). The test consists of pins, washers and collars which are positioned in specific containers on the surface of the test. Before starting the test, participants were familiarized with the assessment tool and the task sequence. Four tasks were proposed. For the two first, participants were instructed to quickly place as many pins as possible in vertical rows in a period of 30 seconds, first with the right hand and then with the left. For the third task, participants placed as many pins as possible into rows using both hands simultaneously for a period of 30 seconds. The last task, called the assembly, consisted of placing in the containers the largest possible number of sets containing two pins, one washer and one collar within a period of 60 seconds. Participants were to grasp the first pin with the right hand, the washer with the left hand, the collar with the right

hand and, to finish, a washer with the left hand. All tasks were quantified by counting the number of objects correctly placed within the time allowed.

Then the dynamometry handgrip (Hydraulic Hand Dynamometer SH5001 Saehan®) and pinch (Hydraulic Pinch Gauge Jamar®, model 7498-05) were performed. For the tests, the participant sat with the shoulder adducted and in neutral rotation, the elbow flexed and the wrist held in a neutral position, with a slight extension of up to 30° for the handle being allowed. The force of the pinch was evaluated between the pulps of the thumb and forefinger, while the interphalangeal joints of the other fingers remained in discrete flexion (Figueiredo *et al.*, 2007; Mathiowetz *et al.*, 1985). Three successive measurements were collected separately for each limb, and the mean value was established for each upper limb.

For analysis of the aiming movement, a 12-inch digitizing tablet (Wacom Intuos 2®) and a stylus, through which tracings were made on the sensitive surface of the tablet, were used. A monitor (15-inch LG Flatron L150S), on which targets were presented for the individuals to perform the movements, was placed in front of the tablet. Both the tablet and monitor were connected to a notebook (14-inch HP, processor 1.58GHz AMD Turion™). The participants sat in front of the table with the collection material, in a chair of adjustable height so as to maintain the initial position: the upper limb near to the trunk with approximately 90º of elbow flexion. A vest was used to restrict trunk-associated movements (Figure 1).
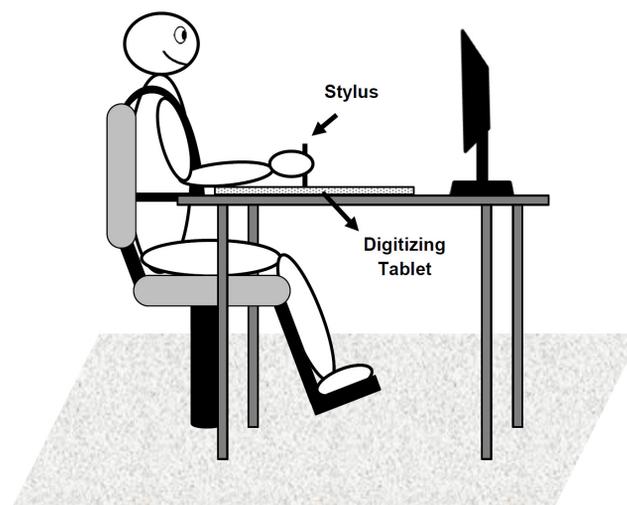

Figure 1. Schematic representation of the experimental apparatus and positioning of the participant to the experiment. Adapted from Silva *et al.*, 2014.

Prior to starting the experimental task, participants were familiarized with the experimental apparatus by moving the cursor toward targets located on the monitor screen in different positions from those analyzed during the experiment to avoid learning effects. Subsequently, the calibration of the targets position was made. For the experimental protocol, participants performed the movements with the stylus from

a fixed point (starting point: lower and centrally located circle) towards targets positioned at 45° above this to the right and left sides of the monitor. The targets were placed 12 cm apart and had 1 cm diameter each. The movements were performed with the right and left upper limbs. Two conditions were evaluated: simple and choice reaction time tasks. Two directions of movement (ipsilateral and contralateral) were an additional factor that was included in both conditions. Regarding simple reaction time tasks, the participants knew the direction of the movement prior to the triggering stimulus response (imperative stimulus); in choice reaction times, the movement direction was indicated by the imperative stimulus, thus not allowing prior knowledge of the direction of the movement to be performed. The directions of movement varied according to the upper limb that performed the task: ipsilateral for those that occurred on the same side of the upper limb in movement and contralateral for those that occurred to the opposite side. On the monitor, targets and starting point were presented as white circles on a black background before the tasks started. In simple reaction time tasks, the target changed color (white to red for 200 ms) to indicate which direction the individual should go (ipsilateral or contralateral) and then reverted to white. After an interval time randomized between 300 and 800 ms, the target changed color (white to green until the end of the trial) characterizing the imperative stimulus for the beginning of the movement. In the choice reaction time tasks, the target changed from white to green, occurring concomitantly with the orientation of the direction of the movement and the imperative stimulus. The participants were instructed to perform the movement as fast as possible, trying to reach the center of the target.

For each upper limb, 48 attempts divided into 2 blocks of 24 attempts randomized per task were performed. The randomization of the directions occurred in each block (12 trials in the ipsilateral direction and 12 in the contralateral). The upper limb that initiated the procedure (right or left) was randomized, totalizing 96 attempts per participant. These values were established based on previous studies of our laboratory with the same equipment and were the same for simple and choice reaction time tasks.

Analysis and processing of data

The events involved in each trial were monitored and the trajectory was recorded at a frequency of 300 Hz using a customized LabView program routine (National Instruments, 2009). The data of the x and y coordinates of the position of the stylus were filtered with a Butterworth second-order low-pass filter at a frequency of 10 Hz. These data were used to calculate the linear velocity resulting from the end of the stylus, and the peak velocity was determined. The peak velocity was defined as the instant of maximum linear velocity. The beginning and end of each movement was defined as the instant in time when the resulting linear velocity reached 5% of the prior maximum value (the start of the acceleration phase) and after (the end of the deceleration phase) peak

velocity. The following temporal variables were analyzed: reaction time, movement time and time to peak velocity. The reaction time (in milliseconds) was defined as the interval time between the start of the imperative stimulus and the beginning of the movement. The movement time (in milliseconds) was calculated as the interval between the beginning and the end of the movement. The time to peak velocity (in milliseconds) refers to the time between the beginning of the movement and the moment of maximum linear velocity, which represents the duration of the acceleration phase. Spatial variables were also analyzed, including smoothness and resulting variable error. The smoothness of the movement was calculated as the number of times the acceleration movement curve changed direction, in movement units (mu). The resulting variable error (in centimeters) was calculated using the square root of the sum of the squared differences between the end and the middle point between the endpoint attempts divided by the number of attempts for the horizontal and vertical directions.

Statistical analysis

The sociodemographic and clinical data were described using measures of central tendency and dispersion. The mean of the three trials for each hand to analyze the strength of handgrip and pinch tests was considered. The performance in strength and the Purdue Pegboard Test between the right and left sides were compared using the Student t test. The performance of the aiming movement was analyzed after checking the normality of the data using the Shapiro-Wilk test. Then, analysis of variance (ANOVA) for repeated measures (2 x 2 x 2 factors) was performed. We considered the main factors to be the tasks (simple and choice reaction time) and the repeated measures to be the upper limbs that performed the tests (left and right) and the direction of movement (ipsilateral and contralateral). When appropriated, post-hoc tests with Bonferroni's adjustments were used to detect differences between conditions.

The reaction time and movement time performance variables in aiming movements were used to analyze the association between functional testing and aiming movements. Pearson's correlation test was performed for simple and choice reaction time tasks for the ipsi- and contralateral directions with the forces of the handgrip and pinch and the Purdue Pegboard Test. The performance of the participants with the right and left upper limbs was grouped for analysis. SPSS 19.0 software was used for statistical analysis. The criterion for significance was set at 5%.

Results

All participants were able to complete the requested tasks. The sociodemographic data and physical-functional characteristics of the participants are described in Table 1. No difference was observed in the performance of participants when assessing muscle strength and dexterity between the right and left upper limbs.

Table 1. Sociodemographic and physical-functional data of individuals.

Gender	Frequency (%)	p value
Male	6 (55)	
Female	5 (45)	.36
Age (years)	Average (SD)	p value
	24 (4.0)	
Hand grip		
Right	37.7 (11.6)	.59
Left	35 (11.8)	
Pinch (Kg/f)		
Right	3.9 (1.0)	.24
Left	3.4 (0.8)	
Purdue Pegboard Test (score)		
Pin RUL	15 (2.0)	.91
Pin LUL	15 (2.0)	
Bilateral pin	12 (1.0)	
Montage	9 (2.0)	

SD: standard deviation; RUL: right upper limb; LUL: left upper limb.

Regarding the proposed tasks, the participants reaction time was shorter for the simple reaction time task (330 ± 6 ms) than for the choice reaction time task (346 ± 8 ms) [$F_{1, 10} = 7.54$, $p = .021$]. No significant interactions were observed among the other factors analyzed (Figure 2A).
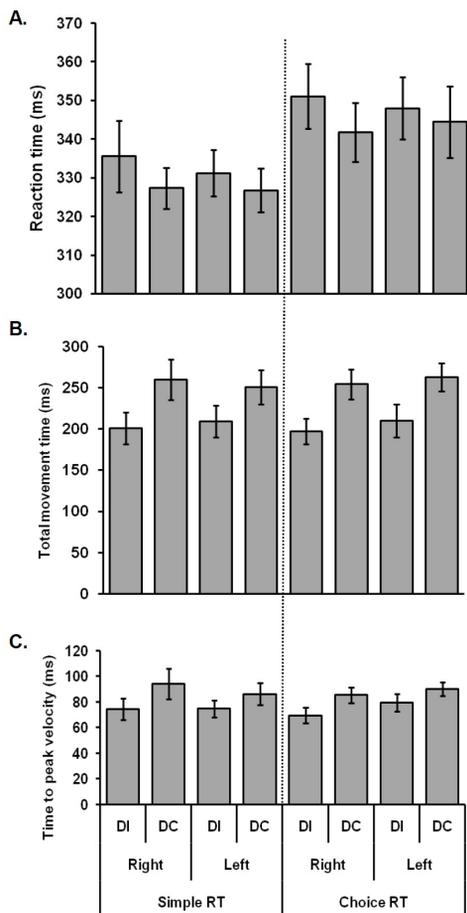

Figure 2. Performance presented by the participants (average and standard error) to the reaction time, movement time and time to peak velocity for the tasks of simple and choice reaction time (RT), performed with right and left upper limbs, toward ipsilateral (DI) and contralateral (DC) directions.

No difference was observed between aiming movements performed with the left and right upper limbs for the variables analyzed. No significant interactions were observed between conditions ($p > .05$).

Analyzing the directions of the movement, the reaction time was lower for the contralateral direction (335 ± 6 ms) than for the ipsilateral one (342 ± 7 ms) [$F_{1, 10} = 11.24$, $p = .007$] (Figure 2A). In addition, the movements in the contralateral direction showed longer duration (257 ± 17 ms) than those performed in the ipsilateral direction (205 ± 16 ms) [$F_{1, 10} = 54.53$, $p \leq .0001$] (Figure 2 B). A longer time to reach peak velocity was observed when movements were performed in the contralateral direction (89 ± 7 ms) than in the ipsilateral direction (75 ± 7 ms) [$F_{1, 10} = 34.29$; $p \leq .0001$] (Figure 2C). In addition, in the contralateral direction movements were less smooth [ipsilateral: 1.16 ± 0.04 mu; contralateral: 1.29 ± 0.05 mu, $F_{1, 10} = 10.14$, $p = .010$] (Figure 3A), although, in contralateral direction (0.40 ± 0.03) movements were more precise [$F_{1, 10} = 49.22$, $p \leq .0001$] than in the ipsilateral direction (0.53 ± 0.04) (Figure 3 B). No significant interactions were observed between factors.
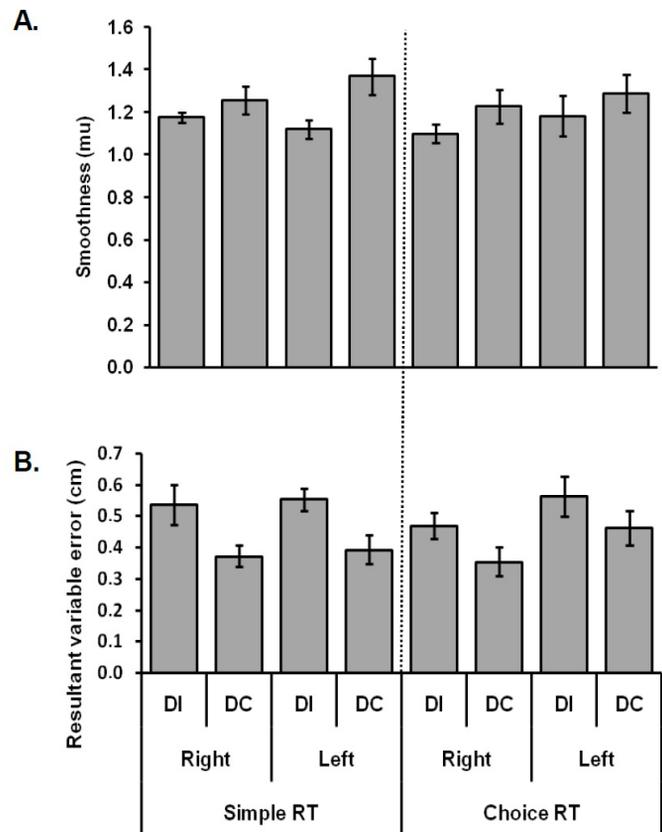

Figure 3. Performance presented by the participants (average and standard error) to the smoothness and resultant variable error for the tasks of simple and choice reaction time (RT), performed with right and left upper limbs, toward ipsilateral (DI) and contralateral (DC) directions.

Regarding the correlations between reaction time and movement time and the physical- functional tests, for reaction

time, a significant negative correlation was observed between the performance on choice reaction time tasks and the Purdue Pegboard Test in the ipsilateral direction ($r = -.448$, $p < .05$). In other words, the higher the reaction time, the worst was the performance of the participants in this functional test. No correlation was observed between reaction time and other physical-functional variables (handgrip and pinch). Regarding movement time, a significant negative correlation was observed between performance on simple reaction time tasks in the ipsilateral direction, handgrip strength ($r = -.454$, $p < .05$) and pinch ($r = -.469$, $p < .05$). In addition, a negative correlation was observed between movement time in choice reaction time tasks in the ipsilateral direction and the muscle strength developed by participants ($r = -.441$, $p < .05$).

Discussion

The purpose of this study was to analyze the influence of the uncertainty of target location on the planning and execution of aiming movement on movements performed on ipsilateral and contralateral directions by the right and left upper limbs. Additionally, it was investigated whether the performance of manual dexterity and handgrip/pinch strength tests are associated with reaction times and movement execution parameters of the aiming movements. Our results showed that the presence of choice option in the response influenced the planning of the aiming movement, but not its execution. On the other hand, the execution of the movement is influenced by the direction in which the movement is executed.

In relation to the uncertainty of the target location, we observed that the latency from the beginning of the aiming movement was lower for the simple reaction time tasks than for those of choice reaction time. The presence of response options created a planning demand after the occurrence of the imperative stimulus, increasing latency from the beginning. This result corroborates with those described in studies evaluating the aiming movement in healthy individuals (Ishihara *et al.*, 2002; Khan *et al.*, 2008; Mieschke *et al.*, 2001) and attributes the planning demand delay to starting the movement. There was no loss in the execution of the movement depending on the tasks proposed, as the subjects had similar performance regarding duration, smoothness and precision of movement. Different from our study, Mieschke *et al.* (2001) observed an influence of the uncertainty of the target location in aiming movement execution. They observed higher peak velocities in the movement in simple reaction time tasks than in choice reaction time tasks that involved precues or not associated with the direction and amplitude of the movement. In their study, the aiming movement was performed in a three-dimensional movement analysis system, which differed from the movement performed in the horizontal plane of our study.

For the functional laterality, no difference in the behavior of aiming movement between the left (non-dominant) and right upper limb (dominant) was observed. Similar results were obtained by Poston, Van Gemmert, Barduson, and Stelmach (2009) who evaluated the aiming movement in young and older

people on a digitizing tablet. The authors attributed the lack of difference in behavior to the characteristics of the proposed task, which were similar to our experimental apparatus. The differences between their study and ours were the number of targets (three target positions were at angles of 5, 45, and 85° to the left or to the right of the individual's midline) and the size of the targets (0.6 cm diameter). In addition, all targets were located 13.4 cm from the start position. According to the authors, a low-demand programming for the trajectory of movement due to minimum disturbance created during its execution occurred, with low demand for the regulation of muscle torques produced and proprioceptive feedback, as well as the presence of visual information of the trajectory movement. These results were distinct from other studies that evaluated the aiming movement in right-handed individuals and that had a higher demand for these components and torque feedback, in which a difference in the behavior of the upper limb that performed the movements was observed (Duff & Sainburg, 2007; Mutha *et al.*, 2013). In these studies, it is described that the dominant upper limb movements are dependent on predictive mechanisms that anticipate the dynamic characteristics of the movement, such as the direction and pattern of movement trajectory, while the non-dominant limb is characterized by optimizing the stability of the position of the upper limb during movement, with greater accuracy and precision to achieve the target (Duff & Sainburg, 2007; Mutha *et al.*, 2013). Another explanation for the absence of difference could be the tasks proposed: in all tasks the participants were instructed to make movements as fast as possible and with accuracy to reach the center of the target. van Doorn (2008) developed an study with aiming movement toward a central target on a digitizing tablet and observed differences in the behavior of the right and left upper limbs similar to those described above. In van Doorn (2008) study the instructions for velocity and accuracy in the trials were distributed between conditions. In our study the proposed movement could have been more complex, thereby increasing variability of the results.

A third factor that could have contributed to this lack of inter-lateral asymmetries could be the uncertainty of target presented in our study and not the upper limb performing the movement. Bestelmeyer and Carey (2004) conducted a study with valid and invalid cues for which the upper limb was to execute the aiming movement. They observed that, when indicated by an invalid cue that the movement should be performed with the right upper limb, but the movement requested was with the left upper limb, there was a longer duration in the movement. This did not occur when the right upper limb performed the movement. In addition, no difference between muscle strength and manual dexterity variables for the dominant and non-dominant upper limbs was observed. These results differ from those described in the literature, which has shown that the dominant member is able to develop higher levels of muscle strength and has a better performance on tasks that require manual dexterity in relation to the non-dominant member (Lima *et al.*, 2012; Lima *et al.*, 2011; Ozcan *et al.*, 2004).

The direction of the movement influenced the planning and execution of the movement in our study. A lower latency for initiating the movement and a longer time to reach peak

velocity in the contralateral direction than in the ipsilateral one was observed, which suggests a higher planning demand for contralateral movements. Mieschke *et al.* (2001) observed that the previous knowledge of participants regarding the direction of the target was an important aspect for the planning of a movement. The higher biomechanical complexity for contralateral movements (Dounskaia, 2005, 2010; Dounskaia *et al.*, 2011; Galloway & Koshland, 2002) can explain these results, which corroborate with the slower and less smooth execution observed in both the right upper limb and the left. Although individuals showed greater precision in this direction (contralateral), this was observed with a lower resulting variable error, which was not observed in the ipsilateral direction. As described previously, the coordination involved in aiming movements between the shoulder and elbow is different for ipsilateral and contralateral movements, with a higher demand for intersegmental coordination in the contralateral direction (Dounskaia, 2005, 2010; Dounskaia *et al.*, 2011; Galloway & Koshland, 2002).

We did not control and record the pen pressure used by participants during the tasks, which is a limitation of this study, but we calibrated the sensitivity of the digitizing tablet to ensure that participants kept the pen constantly in contact to the tablet. Participants were instructed to look to the monitor. The visual feedback could not be used by the participants during the task for corrections because of the velocity requested, but this information certainly influenced the subsequent trial.

Finally, when analyzing the association between the physical-functional variables and the variables related to aiming movement, it was observed that for the choice reaction time task in the ipsilateral direction, the higher the reaction time of the individuals was, the worse their performance on the Purdue Pegboard Test. This test is a complex task, done in stages that require the movement of fingertips with tweezers and the manipulation of objects. The need to order this sequence of movements with an objective accuracy of the tasks requires greater demand planning, as does the choice reaction time task in aiming movement. Therefore, despite the different nature of the tasks, the test for manual dexterity and the choice reaction time task both generate greater demand planning. Thus, the use of one of these two tasks to evaluate the performance of this aspect can be selected according to the local facility in its implementation.

Yet for the ipsilateral direction, a significant negative correlation was observed between the movement time, the reaction time tasks and the handgrip and pinch forces. Those associations showed that when the duration of the aiming movement was higher, the handgrip and pinch forces were lower. The movement in the ipsilateral direction, which presents reduced demand for intersegmental coordination (Dounskaia, 2005, 2010; Dounskaia *et al.*, 2011; Galloway & Koshland, 2002), is more ballistic, allowing more direct association with the force generation. In the contralateral direction, as the demand for intersegmental coordination is higher (Dounskaia, 2005, 2010; Dounskaia *et al.*, 2011; Galloway & Koshland, 2002), there is a need for a greater modulation of force, thereby masking the above association.

These results suggest that uncertainty in response influences the planning of the aiming movement and is associated with performance in manual dexterity tests. Ballistic movements (for example, ipsilateral movements) show greater relationship with muscular strength. We can conclude that there is an association between aiming movements' and manual tests' performance which should be considered on motor control studies and on the development of training protocols.

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Authors' note

Flávia Priscila de Paiva Silva is affiliated with the master's and doctoral programs in physical therapy at Universidade Cidade de São Paulo (UNICID), São Paulo, SP, Brazil, and with the School of Physical Therapy, Universidade do Vale do Sapucaí (UNIVÁS), Pouso Alegre, MG, Brazil.

Sandra Maria Sbeghen Ferreira de Freitas and Sandra Regina Alouche are affiliated with the master's and doctoral programs in physical therapy, Universidade Cidade de São Paulo (UNICID), São Paulo, SP, Brazil.

Emelli da Silva Comenalle is affiliated with the School of Physical Therapy, Universidade Cidade de São Paulo (UNICID), São Paulo, SP, Brazil.

Corresponding author

Sandra Regina Alouche
Programa de Mestrado e Doutorado em Fisioterapia, Universidade Cidade de São Paulo, Rua Cesário Galeno, 448/475 - Tatuapé - São Paulo - SP - CEP 03071-000
Telephone: +55 11 2178-1565
E-mail: sandra.alouche@unicid.edu.br

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