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Article

Contributions of the Left- and the Right-Hemisphere on the Language-Induced Grip Force Modulation of the Left Hand in Unimanual Task

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Abstract: *Background and objectives:* The language-induced grip force modulation (GFM) can be used to better understand the link between the language and motor functions as an expression of the embodied language. However, the contribution of each brain hemisphere to the language-induced GFM is still unclear. Using six different action verbs as stimuli, this study evaluated the GFM of the left hand in unimanual task to characterize the left- and right-hemisphere contributions. *Materials and Methods:* The left-hand GFM of 20 healthy consistent right-handers subjects was evaluated using the verbs "to write", "to hold", "to pull"(left-lateralized central processing actions), "to draw", "to tie", and "to drive" (bi-hemispheric central processing actions) as linguistic stimuli. The time between the word onset and the first interval of statistical significance regarding the baseline (RT) was also measured. *Results:* The six verbs produced language-induced GFM. The modulation intensity was similar for the six verbs, but the RT was variable. The verbs "to draw", "to tie", and "to drive", whose central processing of the described action is bihemispheric showed a longer Rt compared to the other verbs. *Conclusions:* The possibility that an action is performed by the left-hand does not interfere with the occurrence of GFM when this action verb is employed as linguistic stimulus. Therefore, the language-induced GFM seems mainly rely on the left hemisphere, and the engagement of the right hemisphere seems to slow down the increase in the GFM intensity.

Keywords: grip force modulation; embodied language; left hand; right hemisphere; left hemisphere; unimanual task

1. Introduction

Language is a left-lateralized human function of the brain in right-handed and most left-handed people [1,2]. An in-depth analysis, however, may reveal that lateralization is a more complex issue [3]. Phonological processing seems to be more lateralized in bilinguals than in monolingual people, to whom language processing seems to occur bilaterally [4,5]. Resting state functional connectivity of

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the Wernicke area was found to be right-lateralized [6]. The activation of the left Wernicke area was correlated with the dominant meaning of ambiguous words while the right Wernicke area was correlated with the subordinate meaning [7]. The semantic processing of ambiguous words and idiomatic sentences was found to occur in both hemispheres [8,9].

According to da Silva et al. [10], the gripping force of the left hand during a unimanual task is modulated by the linguistic stimulus provided by the manual action verbs listening. For those authors, this modulation seems to rely on the contribution of both hemispheres.

Manual action verbs usually describe actions unevenly performed for each hand. Oldfield [11] noted “writing” and “drawing” as activities exclusively performed by the right hand of consistent right-handers. In these cases, although “to write” and “to draw” are manual action verbs, they don’t express a manual action performed by the left hand. The cortical activation when writing is left-lateralized and this lateralization is more evident in the frontal cortex [12,13]. Cortical activation is more symmetrical when drawing [12], with a more intense activation of right hemisphere regions related to language comparatively to writing [13]. Besides, there are verbs that express actions carried out with either hand, such as “hold” and “pull,” whose central processing is also left-lateralized [14,15] and verbs that describe coordinated asymmetric bimanual activities such as “tie” and “drive”, whose central processing is non-lateralized and more symmetrical [16-18]. Although all these manual action verbs describe activities performed by the right hand in right-handers, the possibility that they describe an activity performed by the left hand is variable. However, no study has so far evaluated the effect of these verbs on the language-induced grip force modulation (GFM).

The language-induced GFM evaluation of each of these verbs can therefore contribute to elucidating the role of each hemisphere in the language-induced GFM as well as in the linguistic processing. Thus, the objective of this study was to characterize the contributions of the left and right hemisphere on the language-induced GFM by means of six verbs describing actions of variable application to the left hand in a unimanual task.

2. Materials and Methods

2.1. Ethical Statement

The project was approved by the Université du Québec à Montréal, Canada. Ethical approval was obtained from the UNICEUB Research Ethics Committee (CEP-UNICEUB), Brasília, Brazil—Report no. 2.044.460/17.

2.2. Subjects

20 healthy subjects participated in the experiment. Subjects was consistent right-handers according to the Edinburgh Handedness Inventory (EHI >80) [11], with no deficits in cognitive or motor skills, nor neurological or musculoskeletal disorders. They should have at least five years of schooling and be able to read and write. In addition, they should know how to drive a vehicle with a manual gearbox. This last criterion was chosen in function of the verb "to drive", which was chosen in as a verb describing an asymmetric bimanual function. Informed consent for participation in the experiment was obtained from all participants.

2.3. Grip Force Assessment

Participants remained comfortably seated and kept the left forearm supported on the table from the elbow to the distal end of the fifth metacarpal in a neutral position. Using a three-digital pinch, they were told to hold the grip force sensor and kept it beyond the edge of the table, without support. They were asked to stay relaxed and as still as possible. A laptop screen was used to show them the variation of the force exerted on the sensor and they were trained to exert a force between 1.5 N and 2.0 N to prevent the grip force sensor slippage. Participants were asked to maintain a constant level of grip force during the experimentation, with no visual feedback of the generated force since they kept their eyes closed. This protocol has been previously analyzed and described by Nazir et al. [19].

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Experimentation was composed by six tests. In each test the participant listened to a playlist through headphones lasting about two minutes and divided into two blocks. Each block contained 35 nouns unrelated to a manual action, such as “plane” and “frog”, and a variable number of repetitions of one of the six given action verbs: “to write”, “to draw”, “to hold”, “to pull”, “to tie”, and “to drive” in Brazilian Portuguese. There was a total of 18 repetitions of the action verb by playlist. These repetitions were interspersed in the word sequence to prevent a sequential presentation or an identifiable distribution scheme. The interval between two consecutive words was 1000 ms. The six playlists can be found at the supplemental material Table S1: Playlists. The list of words and its equivalents in English is provided at the supplemental material Table S2: Word list. The action verb was presented to the participant as a “keyword” without drawing attention to its grammatical class. Previously the test, the participant was instructed to mentally count the keyword number of repetitions, in order to keep their attention on the current language stimulation. By finishing the first block listening, they opened their eyes, put the grip force sensor on the table and reported the number of repetitions. The procedure was repeated for the second block following a one-minute rest. They had two-minutes of rest by the ending of the test, and a new test was performed with a second keyword. The experimentation’s sequence of keywords was randomly defined. The study dataset can be found at the supplemental material Spreadsheet S1: Dataset.

The force sensor was connected to an amplifier (Honeywell DV10L) that was connected to an acquisition card (Measurement Computing USB-1608GX). The compression force was recorded in mN / ms with 1 kHz data transmission for a laptop. The Dasylab 11.0 software was used to filter the data at 15Hz by mean of a fourth-order Butterworth zero-phase low-pass 50 Hz band-drop filter and to display the force variation. The laptop also sent the playlists to the acquisition card, which were then delivered to the participant by the headphones.

2.4. Data Analysis

The data were segmented from 200 ms before up to 1000 ms following the keyword onset. The 200 ms average signal before the start of the action verb (baseline) was used to normalize the data for that verb, and this procedure was repeated for each occurrence. If the signal variation between 200 ms before and 800 ms following the word onset was greater than or equal to 200 mN the data for that occurrence were rejected. In the same way, the data of an occurrence were rejected if there was a force increasing at a rate greater than 100 mN within 100 ms [19]. If more than 30% of the repetitions of a verb were rejected, data from that participant were rejected. Since the comparison between non-action names and action verbs is currently well documented [20-22], only the action verbs were analyzed in this study.

The baseline was compared to the three phases of the linguistic processing defined by Friederici [23] by means of a one-factor repeated measures ANOVA to evaluate the occurrence of language induced GFM for each verb. According to Friederici, the analysis of the syntactic structure characterizes the Phase 1 (100-300 ms); Phase 2 (300-500 ms) presents a broader analysis that includes lexical-semantic and morphosyntactic processes; and during the Phase 3 (500-800 ms) the information generated in the previous phases is reanalyzed and integrated. The occurrence of language induced GFM was defined as a significant increase in grip force between the baseline and one or more of these phases [10]. Tukey's post hoc test (DSH) was used to identify the phase in which the grip force became significantly different from the baseline. Data from this phase was reordered in 50 ms time intervals and a new one-factor repeated measures ANOVA was performed to identify the reaction time. Data of the selected time interval and its predecessor were reorganized in 10 ms micro-intervals and a new one-factor repeated measures ANOVA was performed to finish the time interval characterization. The time between the word onset and the first micro-interval significantly different from baseline was named Reaction Time (RT). The RT was identified for each of the six verbs.

Lastly, action verbs “to write”, “to hold”, and “to pull” were compared as a group to the verbs “to draw”, to tie”, and “to drive” as a second group. The first group was composed by verbs expressing actions whose central processing is left-lateralized (LHCP) while the central processing in the second group involves a significant participation of the right hemisphere (RHCP).

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2.5. Statistical Analysis

A one-factor repeated measures ANOVA was used to evaluate the occurrence of language-induced GFM and Tukey's post hoc DSH was used to determine the RT. To compare the two action verb groups, three two-factor ANOVA with repeated measures were conducted, one for each linguistic processing phase. The Spearman correlation test was used to evaluate the correlation between sex, age, years of schooling, manuality score, and language induced GFM for each of the six verbs. In this case, the mean and median values of the time intervals for each subject were used to make the comparisons. Spearman's correlation test was chosen based on sample size and non-normal distribution of data when it was indicated by the Shapiro-Wilk test.

3. Results

3.1. Subjects

20 healthy subjects aged 20 to 55 years (7 women, 31.1 ± 8.8 years old and 13 men, 31.1 ± 9.7 years old) participated in this study, but two data subjects were excluded from the analysis for having lost five of the six verbs. They had between 5 and 18 years of schooling (women from 8 to 18 years, mean 12.3 ± 3.7 years, men aged 5 to 15 years, mean 11.7 ± 2.7 years) and scored 80 to 100 according to the Edinburgh Handedness Inventory (EHI) as consistent right-handers (women 85 to 100, mean 88.5 ± 7.2, men 80 to 100, mean 94.3 ± 5.3).

3.2. Language-Induced Grip Force Modulation Occurrence

The six verbs produced language induced GFM. The RTs were found in Phase 1 of the linguistic processing for the verbs “to write” and “to pull” and in Phase 2 for the verbs “to hold”, “to draw”, “to drive” and “to tie”. The verb “to write” presented the lowest RT (250-260 ms) and the verb “to tie” presented the highest (410-420 ms). Table 1 presents the findings related to the LGFM occurrence as well as the RT determination.

Table 1. Statistical notation of the language-induced grip force modulation occurrence and reaction time determination by interval and micro-interval.

VERB		RESULT	NOTATION
	GFM	+	$F_{(1.77,30.089)} = 8.345$, $p = 0.002$
Write	*interval (ms)*	250-300	$q_{(289)} = 5.782$, $p = 0.007$, $d = 1.36$
	RT (ms)	**250-260**	$q_{(153)} = 5.194$, $p = 0.0119$, $d = 1.22$
	GFM	+	$F_{(1.824,31.006)} = 9.101$, $p = 0.001$
Draw	*interval (ms)*	350-400	$q_{(289)} = 5.954$, $p = 0.0044$, $d = 1.4$
	RT (ms)	**350-360**	$q_{(153)} = 4.991$, $p = 0.0191$, $d = 1.18$
	GFM	+	$F_{(1.446,24.578)} = 6.464$, $p = 0.010$
Hold	*interval (ms)*	300-350	$q_{(289)} = 5.413$, $p = 0.0181$, $d = 1.28$
	RT (ms)	**330-340**	$q_{(153)} = 4.668$, $p = 0.0385$, $d = 1.1$
	GFM	+	$F_{(2.022,34.373)} = 15.619$, $p < 0.001$
Pull	*interval (ms)*	250-300	$q_{(289)} = 6.164$, $p = 0.0024$, $d = 1.45$
	RT (ms)	**270-280**	$q_{(153)} = 4.978$, $p = 0.0196$, $d = 1.17$
	GFM	+	$F_{(1.679,28.549)} = 9.222$, $p = 0.001$
Tie	*interval (ms)*	400-450	$q_{(289)} = 5.283$, $p = 0.0249$, $d = 1.25$
	RT (ms)	**410-420**	$q_{(153)} = 4.883$, $p = 0.0243$, $d = 1.15$
Drive	*GFM*	+	$F_{(1.586,26.956)} = 11.155$, $p < 0.001$

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interval (ms)	350-400	$q_{(289)} = 6.586$, $p = 0.0007$, $d = 1.55$
RT (ms)	**350-360**	$q_{(153)} = 5.415$, $p = 0.007$, $d = 1.28$

*GFM: grip force modulation; RT: reaction time; ms: milliseconds.

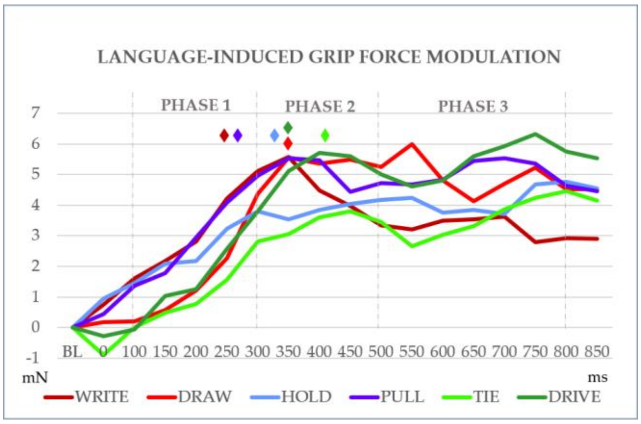

Figure 1. Language-induced grip force modulation by action verb. Phase 1, 2, and 3 are the phases of the linguistic processing described by Friederici [23]. mN: grip force modulation in millinewtons. ms: time-interval in milliseconds. ♦: RT; color indicates the action verb

According to a two-way ANOVA with repeated measures performed with the six action verbs, the language induced GFM was similar among them ($F_{(102;5)} = 0.438$; $p = 0.8209$). Figure 1 presents the curves and the RT of each action verb along the linguistic processing phases. Language induced GFM was significantly more intense ($F_{(1;4168)} = 5.700$; $p = 0.0187$) for LHCP than RHCP during Phase 1 of the linguistic processing. There was no statistical difference along the other phases (Phase 2: $F_{(1;8180)} = 0.002$; $p = 0.9641$); Phase 3: $F_{(1;23431)} = 0.144$; $p = 0.7049$).

3.3. Correlation Analysis

The correlation analysis between the language induced GFM and sex, age, and years of schooling did not find significant relationship (p >0.05). The values of *r* and *p* for these correlations are presented in Table 2.

Table 2. Spearman's correlation—grip force modulation and sample characteristics.

	Write		**Pull**		**Hold**		**Draw**		**Tie**		**Drive**	
	r	*p*	*r*	*p*	*r*	*p*	*r*	*p*	*r*	*p*	*r*	*p*
Sex	0.26	*0.312*	-0.47	*0.115*	-0.29	*0.115*	-0.29	*0.115*	0.16	*0.762*	-0.31	*0.232*
Age	-0.02	*0.958*	0.33	*0.197*	-0.04	*0.598*	-0.04	*0.598*	-0.17	*0.810*	0.41	*0.233*
Schooling	0.03	*0.716*	0.44	*0.280*	0.22	*0.362*	0.22	*0.362*	0.04	*0.673*	0.05	*0.570*
Consistence	-0.19	*0.443*	0.40	*0.169*	0.12	*0.492*	0.12	*0.492*	-0.40	*0.113*	0.38	*0.112*

[1] Consistence refers to handedness consistence according to Oldfield [11].

4. Discussion

In this study, six verbs were chosen as linguistic stimuli to evaluate the language induced grip force modulation of the left hand in a unimanual task. These verbs have been grouped into three categories related to the use of the left hand by consistent right-handers: non-applicable action verbs, optional action verbs, and shared action verbs.

The six action verbs were able to modulate grip strength. Thus, the fact that it was a non-applicable, optional or shared action verb did not prevent any of the verbs from modulating the grip force. In addition, there was no difference among the modulation curves, so that the nature of the action

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described by the verb did not influence the intensity of the modulation. The modulation of the grip force, therefore, seems to be independent of the possibility that the action is performed by the left hand as well as that the left hand is performing alone or asymmetrically accompanied by the right hand.

These results corroborate the notion that the understanding of the action described by the verb is related to the activation of the motor centers responsible for the action processing in general, independently of the potentiality of immediate execution or the choice of the member that will act. Thus, the evaluation of the language-induced grip force is an effective way to evaluate the connection between language processing and motor control. In addition, the evaluation of the non-dominant hand can provide valuable information even by means a non-applicable action verb. Since motor control and primary linguistic processing are left-lateralized, we believe that the production of the language-induced grip force modulation by the left-hand in unimanual activity is also mostly done by the left hemisphere, as is the case with the right hand [24,25].

The analysis of the reaction time of the six verbs, however, found differences between them. The verbs “to write” and “to pull” presented the lowest RT, being the only ones to have their RT in the first phase of the linguistic processing. The shared action verbs “to tie” and “to draw” showed the highest reaction times. Since they describe a bimanual action, although asymmetric, it is expected that the right hemisphere is more activated compared to the right hemisphere activation for writing [16,17,26,27]. Furthermore, drawing showed the same RT as “to drive”, and the literature describes greater activation of the right hemisphere to carry out this task. Thus, the RT analysis seem to indicate that the greater involvement of the right hemisphere in accomplishing the task described by these action verbs has negatively contributed to growing modulation throughout the first phase of the linguistic processing. On the contrary, the verb “to write”, whose activation is described as essentially left-lateralized [28], exhibited the lowest reaction time. In our study, two verbs showed lower RT than that observed for the left hand unimanual condition by da Silva et al. [10], one verb had a similar RT and three others presented higher RT. The six verbs average RT of 326.7 ms falls exactly in the range described in that article, that is 320-330 ms. The RT of the language-induced GFM of the left hand in unimanual activity is therefore a direct function of the chosen action verb in according to the participation of the right hemisphere on its linguistic processing.

The optional action verbs showed modulation curves very similar to the curve of the verb "to write" throughout the first phase of the linguistic processing (100-300 ms). In fact, the ANOVA performed with the verbs divided into two blocks—left-lateralized central processing action verbs versus non-lateralized central processing action verbs—detected a significant difference between them. This difference disappears in the second phase of language processing, when all verbs reach their RT. Although there is no study investigating the zones activated by “to hold” and “to pull”, these verbs are optional verbs as “to grip” and “to grasp”, and these actions are described as components of gripping and grasping actions [15, 29]. Therefore, holding and pulling should rely on the gripping circuit, which is widely described as left-lateralized [30-32].

5. Conclusions

in short, the relevance of the action described by the verb to the member under evaluation does not seem to influence either the production of the language-induced GFM or the intensity of the modulation. A greater involvement of the right hemisphere in the central processing of the action seems to imply in a longer time for the modulation to become significant in comparison to the actions with left-lateralized central processing. Thus, it is concluded that both the left hemisphere and the right hemisphere contribute to the production of the language induced grip force modulation of the left hand in a unimanual task.

Supplementary Materials: The following are available online at www.mdpi.com/xxx/s1, Table S1: Playlists, Table S2: Word List, Spreadsheet S1: Dataset.

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