

1 Article

# 2 Contributions of the Left- and the Right-Hemisphere 3 on the Language-Induced Grip Force Modulation of 4 the Left Hand in Unimanual Task

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

39 **Keywords:** grip force modulation; embodied language; left hand; right hemisphere; left hemisphere;  
40 unimanual task  
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## 42 1. Introduction

43 Language is a left-lateralized human function of the brain in right-handed and most left-handed  
44 people [1,2]. An in-depth analysis, however, may reveal that lateralization is a more complex issue  
45 [3]. Phonological processing seems to be more lateralized in bilinguals than in monolingual people,  
46 to whom language processing seems to occur bilaterally [4,5]. Resting state functional connectivity of

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

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

54 Manual action verbs usually describe actions unevenly performed for each hand. Oldfield [11]  
55 noted "writing" and "drawing" as activities exclusively performed by the right hand of consistent  
56 right-handers. In these cases, although "to write" and "to draw" are manual action verbs, they don't  
57 express a manual action performed by the left hand. The cortical activation when writing is left-  
58 lateralized and this lateralization is more evident in the frontal cortex [12,13]. Cortical activation is  
59 more symmetrical when drawing [12], with a more intense activation of right hemisphere regions  
60 related to language comparatively to writing [13]. Besides, there are verbs that express actions carried  
61 out with either hand, such as "hold" and "pull," whose central processing is also left-lateralized  
62 [14,15] and verbs that describe coordinated asymmetric bimanual activities such as "tie" and "drive",  
63 whose central processing is non-lateralized and more symmetrical [16-18]. Although all these manual  
64 action verbs describe activities performed by the right hand in right-handers, the possibility that they  
65 describe an activity performed by the left hand is variable. However, no study has so far evaluated  
66 the effect of these verbs on the language-induced grip force modulation (GFM).

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

## 72 2. Materials and Methods

### 73 2.1. Ethical Statement

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

### 77 2.2. Subjects

78 20 healthy subjects participated in the experiment. Subjects was consistent right-handers  
79 according to the Edinburgh Handedness Inventory (EHI >80) [11], with no deficits in cognitive or  
80 motor skills, nor neurological or musculoskeletal disorders. They should have at least five years of  
81 schooling and be able to read and write. In addition, they should know how to drive a vehicle with a  
82 manual gearbox. This last criterion was chosen in function of the verb "to drive", which was chosen  
83 in as a verb describing an asymmetric bimanual function. Informed consent for participation in the  
84 experiment was obtained from all participants.

### 85 2.3. Grip Force Assessment

86 Participants remained comfortably seated and kept the left forearm supported on the table from  
87 the elbow to the distal end of the fifth metacarpal in a neutral position. Using a three-digital pinch,  
88 they were told to hold the grip force sensor and kept it beyond the edge of the table, without support.  
89 They were asked to stay relaxed and as still as possible. A laptop screen was used to show them the  
90 variation of the force exerted on the sensor and they were trained to exert a force between 1.5 N and  
91 2.0 N to prevent the grip force sensor slippage. Participants were asked to maintain a constant level  
92 of grip force during the experimentation, with no visual feedback of the generated force since they  
93 kept their eyes closed. This protocol has been previously analyzed and described by Nazir et al. [19].

94 Experimentation was composed by six tests. In each test the participant listened to a playlist  
95 through headphones lasting about two minutes and divided into two blocks. Each block contained  
96 35 nouns unrelated to a manual action, such as “plane” and “frog”, and a variable number of  
97 repetitions of one of the six given action verbs: “to write”, “to draw”, “to hold”, “to pull”, “to tie”,  
98 and “to drive” in Brazilian Portuguese. There was a total of 18 repetitions of the action verb by  
99 playlist. These repetitions were interspersed in the word sequence to prevent a sequential  
100 presentation or an identifiable distribution scheme. The interval between two consecutive words was  
101 1000 ms. The six playlists can be found at the supplemental material Table S1: Playlists. The list of  
102 words and its equivalents in English is provided at the supplemental material Table S2: Word list.  
103 The action verb was presented to the participant as a “keyword” without drawing attention to its  
104 grammatical class. Previously the test, the participant was instructed to mentally count the keyword  
105 number of repetitions, in order to keep their attention on the current language stimulation. By  
106 finishing the first block listening, they opened their eyes, put the grip force sensor on the table and  
107 reported the number of repetitions. The procedure was repeated for the second block following a  
108 one-minute rest. They had two-minutes of rest by the ending of the test, and a new test was performed  
109 with a second keyword. The experimentation’s sequence of keywords was randomly defined. The  
110 study dataset can be found at the supplemental material Spreadsheet S1: Dataset.

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

#### 117 2.4. Data Analysis

118 The data were segmented from 200 ms before up to 1000 ms following the keyword onset. The  
119 200 ms average signal before the start of the action verb (baseline) was used to normalize the data for  
120 that verb, and this procedure was repeated for each occurrence. If the signal variation between 200  
121 ms before and 800 ms following the word onset was greater than or equal to 200 mN the data for that  
122 occurrence were rejected. In the same way, the data of an occurrence were rejected if there was a force  
123 increasing at a rate greater than 100 mN within 100 ms [19]. If more than 30% of the repetitions of a  
124 verb were rejected, data from that participant were rejected. Since the comparison between non-  
125 action names and action verbs is currently well documented [20-22], only the action verbs were  
126 analyzed in this study.

127 The baseline was compared to the three phases of the linguistic processing defined by Friederici  
128 [23] by means of a one-factor repeated measures ANOVA to evaluate the occurrence of language  
129 induced GFM for each verb. According to Friederici, the analysis of the syntactic structure  
130 characterizes the Phase 1 (100-300 ms); Phase 2 (300-500 ms) presents a broader analysis that includes  
131 lexical-semantic and morphosyntactic processes; and during the Phase 3 (500-800 ms) the information  
132 generated in the previous phases is reanalyzed and integrated. The occurrence of language induced  
133 GFM was defined as a significant increase in grip force between the baseline and one or more of these  
134 phases [10]. Tukey’s post hoc test (DSH) was used to identify the phase in which the grip force became  
135 significantly different from the baseline. Data from this phase was reordered in 50 ms time intervals  
136 and a new one-factor repeated measures ANOVA was performed to identify the reaction time. Data  
137 of the selected time interval and its predecessor were reorganized in 10 ms micro-intervals and a new  
138 one-factor repeated measures ANOVA was performed to finish the time interval characterization.  
139 The time between the word onset and the first micro-interval significantly different from baseline  
140 was named Reaction Time (RT). The RT was identified for each of the six verbs.

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

## 145 2.5. Statistical Analysis

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

## 154 3. Results

## 155 3.1. Subjects

156 20 healthy subjects aged 20 to 55 years (7 women,  $31.1 \pm 8.8$  years old and 13 men,  $31.1 \pm 9.7$  years old)  
 157 participated in this study, but two data subjects were excluded from the analysis for having lost five  
 158 of the six verbs. They had between 5 and 18 years of schooling (women from 8 to 18 years, mean  $12.3$   
 159  $\pm 3.7$  years, men aged 5 to 15 years, mean  $11.7 \pm 2.7$  years) and scored 80 to 100 according to the  
 160 Edinburgh Handedness Inventory (EHI) as consistent right-handers (women 85 to 100, mean  $88.5 \pm$   
 161  $7.2$ , men 80 to 100, mean  $94.3 \pm 5.3$ ).

## 162 3.2. Language-Induced Grip Force Modulation Occurrence

163 The six verbs produced language induced GFM. The RTs were found in Phase 1 of the linguistic  
 164 processing for the verbs "to write" and "to pull" and in Phase 2 for the verbs "to hold", "to draw",  
 165 "to drive" and "to tie". The verb "to write" presented the lowest RT (250-260 ms) and the verb "to  
 166 tie" presented the highest (410-420 ms). Table 1 presents the findings related to the LGFM occurrence  
 167 as well as the RT determination.  
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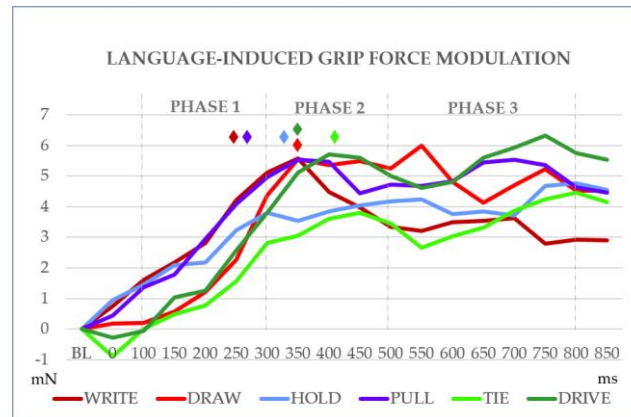
170 **Table 1.** Statistical notation of the language-induced grip force modulation occurrence and reaction  
 171 time determination by interval and micro-interval.

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

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

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

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**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

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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:  $F_{(1;23431)} = 0.144; p = 0.7049$ ).

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### 3.3. Correlation Analysis

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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.

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**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

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<sup>1</sup> Consistence refers to handedness consistence according to Oldfield [11].

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## 4. Discussion

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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

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

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

210 The analysis of the reaction time of the six verbs, however, found differences between them. The  
211 verbs “to write” and “to pull” presented the lowest RT, being the only ones to have their RT in the  
212 first phase of the linguistic processing. The shared action verbs “to tie” and “to draw” showed the  
213 highest reaction times. Since they describe a bimanual action, although asymmetric, it is expected  
214 that the right hemisphere is more activated compared to the right hemisphere activation for writing  
215 [16,17,26,27]. Furthermore, drawing showed the same RT as “to drive”, and the literature describes  
216 greater activation of the right hemisphere to carry out this task. Thus, the RT analysis seem to indicate  
217 that the greater involvement of the right hemisphere in accomplishing the task described by these  
218 action verbs has negatively contributed to growing modulation throughout the first phase of the  
219 linguistic processing. On the contrary, the verb “to write”, whose activation is described as essentially  
220 left-lateralized [28], exhibited the lowest reaction time. In our study, two verbs showed lower RT than  
221 that observed for the left hand unimanual condition by da Silva et al. [10], one verb had a similar RT  
222 and three others presented higher RT. The six verbs average RT of 326.7 ms falls exactly in the range  
223 described in that article, that is 320-330 ms. The RT of the language-induced GFM of the left hand in  
224 unimanual activity is therefore a direct function of the chosen action verb in according to the  
225 participation of the right hemisphere on its linguistic processing.

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

## 235 5. Conclusions

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

243 **Supplementary Materials:** The following are available online at [www.mdpi.com/xxx/s1](http://www.mdpi.com/xxx/s1), Table S1: Playlists,  
244 Table S2: Word List, Spreadsheet S1: Dataset.

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246 Higgins and Victor Frak; Data curation, Ronaldo Luis da Silva and Isabella Maria Gonçalves Mendes; Formal

247 analysis, Ronaldo Luis da Silva; Funding acquisition, Ronaldo Luis da Silva and Victor Frak; Investigation,  
248 Ronaldo Luis da Silva, Francielly Ferreira Santos and Isabella Maria Gonçalves Mendes; Methodology, Ronaldo  
249 Luis da Silva, Francielly Ferreira Santos, Isabella Maria Gonçalves Mendes and Victor Frak; Project  
250 administration, Victor Frak; Resources, Johanne Higgins and Victor Frak; Supervision, Victor Frak;  
251 Visualization, Ronaldo Luis da Silva; Writing – original draft, Ronaldo Luis da Silva, Fátima Aparecida  
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