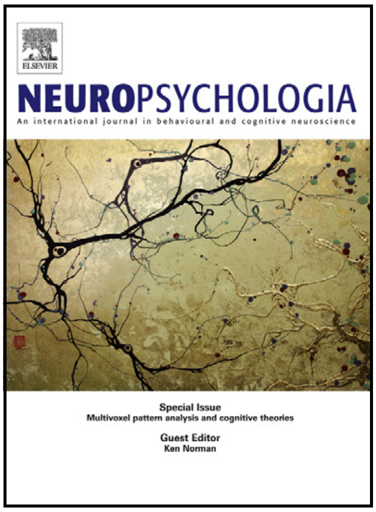

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The effects of rTMS over the primary motor cortex: the link between action and language

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Abstract.

Is the primary motor cortex (M1) necessary for language comprehension? The present study investigates the role of the primary motor cortex during verbs comprehension, within the framework of the embodied theories of language. We applied rTMS over the right and left hand portion of M1 and tested the effects of the stimulation toward the processing of hand-related action verbs versus abstract verbs. Results underlined a specific inhibition effect following left stimulation, only with hand-related action verbs. These findings seem to corroborate the hypothesis of a functional role of M1 in action verbs comprehension.

Keywords: embodied language, rTMS, action verbs, comprehension, semantics

1. Introduction.

According to traditional theories of cognition, concepts are represented in the brain as symbols, and managed, during cognitive processes, following arbitrary and abstract mental operations (Fodor, 1975). From this point of view, low-level processes such as perception and action are both operationally and neurologically distinct from higher-level processes, such as language. In recent decades, the separation between modal (vision, audition, motion and proprioception) and amodal processes (language, thought, categorization) has been challenged in favour of a new perspective that, refusing the strict distinction above mentioned, proposes a radically different view of the mind: the theory of Embodied Cognition (Barsalou, 2008; Gibbs, 2006; Wilson, 2002).

According to embodied cognition hypothesis, cognitive processes rely on body states and experiences, and concepts are mapped within the sensory-motor system. In this framework, embodied theories predict that the neural structures involved in processing sensory information are also active when processing words whose meaning embeds prominent sensory features (Martin & Chao, 2001; Thompson-Schill, 2003); furthermore, it assumes that neural structures required to perform an action are also involved in processing words describing the same action. Both these predictions are supported by experimental data. On the one hand, it has been found that the generation of colour word triggers the activation of the ventral temporal cortex close to the colour perception areas (Martin, Haxby, Lalonde, Wiggs, & Ungerleider, 1995); furthermore, Goldberg and collaborators (Goldberg, Perfetti, & Schneider, 2006) found that the retrieval of words with specific auditory, visual, tactile or gustative features activate the correspondent sensory areas in the brain.

Within this conceptual frame, one of the most intriguing topic, whose investigation generated a large corpus of data, is the link between language and motor system. Hence, many researchers are interested in understanding if, and to what extent, the motor brain areas are involved in action words comprehension. The role of the premotor cortices has been widely investigated with different methodics and different kind of language tasks. Tettamanti et al. (Tettamanti et al., 2005), scanning brain activity by means of fMRI while participants listened to sentences describing actions performed with either the hand, the foot or the mouth, found a somatotopic activation of the same visuomotor network that subserves action execution. Similarly, in another study by Hauk et al. (Hauk, Johnsrude, & Pulvermuller, 2004), action verbs referring to different body parts, when presented in a passive reading task, activated the motor strip in regions adjacent to or overlapped with the areas required for the actual movement of the same body parts. Moreover, the role of the premotor cortex seems to be functional in language understanding: according to Willems et al. (Willems, Labruna, D'Esposito, Ivry, & Casasanto, 2011), theta burst transcranial magnetic stimulation (TBS) over the hand area of the left premotor cortex in right handers yielded a facilitation in a lexical decision task for manual action verbs (but not for non manual-verbs), with respect to the stimulation of the correspondent area in the right premotor cortex.

The involvement of the primary motor cortex (M1) in language processes, instead, has been primarily studied using transcranial magnetic stimulation (TMS), which allows to establish a causal relationship between experimental manipulations (i.e. site of stimulation) and behavioural task. Applying single pulse TMS over M1, several researchers found a modulation of motor evoked potentials (MEP) recorded from the correspondent effector during different linguistic tasks (Fadiga, Craighero, Buccino, & Rizzolatti, 2002; Fourkas, Avenanti, Urgesi, & Aglioti, 2006; Oliveri et al., 2004; Pulvermuller, Hauk, Nikulin, & Ilmoniemi, 2005), and at different timings (Papeo, Vallesi, Isaja, & Rumiati, 2009). For example Buccino et al. (Buccino et al., 2005) reported a decrease of MEPs amplitude registered from hand muscle while participants heard hand-related action verbs, compared to action verbs involving other body parts. The opposite findings are described by Papeo et al. (Papeo et al., 2009), who noticed an increase of M1 activity following semantic processing of action verbs compared with non-action verbs, but only when the stimulation was delivered 500 ms post stimulus presentation; the timing of the effect, according to authors, indicates that M1 is not automatically activated by lexical-semantic processing, but rather is involved in post-conceptual processing triggered by the retrieval of motor representations.

This issue opens a critical question about the role played by the sensorymotor areas in language processes: are they *necessary* for the comprehension of action-verbs, or is their recruitment epiphenomenal? Supporters of a strong embodied position agree with the first hypothesis (Gallese & Lakoff, 2005; Pulvermuller et al., 2005), whereas the alternative perspective points out that the activation of motor circuits could be interpreted as a "side effect" of the real semantic process (Mahon & Caramazza, 2008), and not a constituent part of the semantic process per se. The early cross-talk (within 200 msec) between language processes and overt motor behaviour, as reported by Boulenger et al. (Boulenger et al., 2006), suggests that the language-related activity in the motor regions is part of the language process and not a consequence of it. Nevertheless, the co-occurrence between the modulation of cortical excitability and the linguistic tasks, evidenced using single-pulse stimulation, as suggested by Willems et al. (Willems & Casasanto, 2011), doesn't allow researchers to distinguish between the alternative hypotheses.

One way to disentangle this issue is through patient studies: the prediction of embodied theories is that lesions in sensorymotor regions should affect the processing of words associated to those sensorymotor features. However, to date this vein of research did not provide clear-cut evidences for two main reasons. On one hand, findings are somehow contrasting: Arevalo (Arevalo, Baldo, & Dronkers, 2012) failed to find a link between the site of the cortical region (primary and premotor cortex) and the correct responses to hand and mouth items compared with neutral control items; other studies, yet, highlighted a specific impairment of verbs processing in patients with different pathologies affecting motor functions, including vascular diseases (Berndt, Mitchum, Haendiges, & Sandson, 1997), progressive aphasia (Hillis et al., 2006), motor neuron disease (Bak, 2010; Bak & Chandran, 2012), Parkinson's disease (Boulenger et al., 2008; Herrera, Rodriguez-Ferreiro, & Cuetos, 2012). Crucially, in these studies, despite their divergent data, authors mostly contrasted verbs versus nouns but never action-verbs versus non action-verbs, so that they can not rule out the possibility that findings were due to the fact that verbs in general are more difficult to process than nouns due to semantic, syntactic and morphological features (Meteyard, Cuadrado, Bahrami, & Vigliocco, 2012; Vigliocco et al., 2006).

An alternative way to address the "necessity question" (Fischer & Zwaan, 2008) is to exploit the capabilities of repetitive transcranial magnetic resonance (rTMS), which is able to induce a transient virtual lesion and to test the specific effect of the temporary deactivation of the stimulated area on a given task. This procedure recently has been applied by Gerfo et al. (Gerfo et al., 2008): authors asked participant to perform a morphological task following an offline session of low frequency (1 HZ) rTMS delivered on the left M1, and found a selective delay of the reaction times while processing action words, compared with state words.

The present study fits in with this line of research, and aims at sheding further light on the role of the primary motor cortex during language comprehension.

We applied offline rTMS over the hand portion of right and left M1 in right-handers, and we evaluated the effects of the stimulation toward semantic comprehension of action verbs (compared with abstract words).

Our hypotheses are:

- if M1 is necessary for accessing semantic information of concrete action verbs, then the transient disruption of this area should affect the process, and should result in slower RTs compared to abstract verbs

- if action verbs comprehension processing is linked to the actual motion execution system, as predicted by embodied cognition theories, then the inhibitory effect of stimulation in right handers should be observed only after left stimulation.

2. Material and method

2.1Participants.

Twenty right-handed students, (6 males and 14 females; (age: range 19-36 years; mean: 24.45; st. dev.: 5.07; years of education: range 14-18; mean: 16.2; st. dev.:1,67), attending different classes at the Catholic University of Sacred Heart, have been recruited for the experiment, and rewarded for their participation with a breakfast coupon. Handedness was assessed using the inventory by Briggs and Nebes (Briggs & Nebes, 1975). Participants were all native Italian speakers, and had normal or corrected-to-normal vision. None of them was aware of the specific purposes of the study. Inclusions criteria followed the most recent guidelines for the use of TMS in experimental settings (Rossi, Hallett, Rossini, & Pascual-Leone, 2009). All the participants signed an informed consent in order to join the experiment. The experimental procedure, and the specific consent form describing it, had been previously approved by the University Ethic Committee.

2.2 Stimuli.

Twenty-four concrete verbs and twenty-four abstract verbs were selected and matched for number of letters [$F(1,47)= 0.026$; $p= 0.873$], number of syllables [$F(1,47)= 0.648$; $p= 0.425$], and frequency [$F(1,47)= 0.033$; $p= 0.856$] in order to form different blocks (see below for details concerning the blocks).

The concrete verbs described actions performed with the hand. They were selected from a larger corpus of 40 hand related verbs, which had been previously and independently evaluated by 30 students, comparable to the experimental sample for age and education level. In this pre-test phase, individuals were asked to indicate if the action depicted by the verb requires a body part to be performed, which one, and to rate the degree of imageability. The items included in the experiment have been unambiguously identified as hand-action verbs and with high imageability (See tables 1 and 2 for the list of items employed in the study).

After this pre-test phase, which allowed us to select the appropriate stimuli, three blocks had been constituted (each block was composed by 48 items). Items in each block were shown in a specific conjugated form[1], chosen among the first three singular persons of the simple past tense. This choice was made for two reasons: the first three singular persons were used in order the blocks to be differentiated; the simple past tense was used in order to be sure that presented verbs would be unambiguously considered as verbs, since a few of them could be intended as names if presented in a different form (i.e present tense).

Insert table 1 and 2 about here

2.3 Procedure.

Participants were welcomed in a quiet room by an experienced researcher.

After reading and signing the consent form the experimental procedure started.

The main experimental task, that participants, as will be explained shortly, were asked to perform a few times, required participants to sit in front of a computer screen at a distance of approximately 50 cm. First of all, they read the experimental instructions, that were the

[1] Italian verbs have different morphological suffixes added to the verb root to indicate the different persons and the past tense. In our experiment we selected the simple past tense, wich requires to add the morpheme –av/-ev/-iv depending on the conjugation wich the verb belong to, plus the three singular persons (wich are respectively identified by –o/-i/-a). For example, the verb "firmare" (to sign) was presented in the three blocks in the following conjugated forms: firmavo; firmavi; firmava

following: " In the present experiment you will see one verb at a time in the centre of the screen; you have to press 0 if the verb is concrete, and 9 if it is abstract; please try to be as accurate and quick as possible". The keys 0 and 9 were replaced by 1 and 2 when the participants responded with their left hand. Then, in the centre of the screen, a fixation point was presented for 2 seconds; afterwards, an item (the first verb – verbs were presented in randomised order) appeared and the participants had to press the relevant key, according to the instructions received. The choice was made by pressing a specific key on the keyboard (one key was associated to concrete verbs, another, close to it on the keyboard, to the abstract ones). After the choice was made, or, in case of missing response, after 5 seconds, the item was replaced by the fixation point – and then by the subsequent item. The entire task lasted about 5 minutes. Reaction times were recorded using E-prime software.

The experiment itself was divided into two separated sessions, one for left and one for right stimulation, each consisting in two steps: the baseline condition (the task without stimulation), and the post-stimulation condition.

The order of the steps and of the sessions was counterbalanced across subjects, but always the experimental task was preceded by a training session, in which twenty items not included in the main task were presented in order to allow participants to familiarize with the task.

The first experimental sequence started with the baseline task, then the participant received the stimulation and, immediately after that, the post-stimulation task was performed. The second experimental sequence started with the stimulation, followed by the post-stimulation task, and finally, after at least one hour of delay (in order to allow the complete wash out of the rTMS effects), the baseline task was performed again.

During each session, participants responded with the hand ipsilateral to the side of stimulation.

Repetitive Transcranial Magnetic Stimulation (rTMS) was delivered using a Magstim Super Rapid magnetic stimulator, connected with an eight-shaped coil (diameter of 70 mm). The site of stimulation was the hand portion of the primary motor cortex left and right. The localization of the site was defined as the hot spot whose stimulation evoked the largest muscular twitch. The motor threshold was determined, according to Rossini et al. (Rossini et al., 1994), as the minimum intensity able to evoke a muscle twitch from the controlateral hand in five out of ten consecutive trials. rTMS was delivered in trains of 1 Hz and for a duration of 12 minutes; the intensity was set up at the 100% of the individual motor threshold intensity.

At the end of the experiment, participants were asked, for each concrete verb, to indicate if, and which, body part is required to perform the correspondent action, and to rate the imageability of the action.

3. Data analyses.

As a first step, items to which an incorrect response has been given were excluded from analysis (0.02% of the total numbers of items). Then, we calculated the mean values for each subject and for each condition: the values that exceeded 3 standard deviations with respect to the correspondent mean value were excluded from analysis (0.01% of the total number of items). According to Data Quality Metrics rules, metrics should be directionally correct with an improvement in use of the data (Dasu & Johnson, 2003). So in our case, considering the role of individual differences (i.e. individual mean speed of response) unrelated to the experimental conditions, the raw RTs have been corrected in order to compensate for individual mean response time; for each condition, the following formula has been applied to each single RT:

$(RT_{after\ stimulation} - RT_{baseline})/RT_{baseline}$.

Corrected RTs, obtained from this calculation, expressed the effect of the stimulation in a given condition and were then analysed with repeated measures analysis of variance (ANOVA), with side (left vs right) and verb (abstract vs concrete) as within subjects factors. Multiple comparisons between conditions were calculated with Tukey's Test.

4. Results.

We found a significant main effect of the main factors [side: $F(1, 19)= 10.961$; $p= 0.004$; $\eta^2= 0.881$; verb: $F(1, 19)= 38.442$; $p< 0.001$; $\eta^2= 1$], indicating that, as a general trend, participants were faster when answering after the right stimulation compared to the left stimulation, and when answering to concrete verbs, if compared to abstract verbs. Moreover, a significant effect of the interaction site X verb [$F(1, 19)= 19.568$; $p< 0.001$; $\eta^2= 0.987$] was found (fig. 1). Post-hoc analyses demonstrated that RTs for concrete verbs after left stimulation were significantly slower than for concrete verbs after right stimulation (Tukey's Multiple Comparison Test; $p< 0.05$), as well than for abstract verb after left stimulation (Tukey's Multiple Comparison Test; $p< 0.05$): these results seem to underline a specific effect of left stimulation towards concrete verbs (see table 3 for descriptives).

Insert figure 1 and table 3 about here

Figure 1: interaction between side (left vs right) and verb (concrete vs abstract). On the y axis, corrected RTs (in milliseconds) calculated with the formula $(RT_{after\ stimulation} - RT_{baseline})/RT_{baseline}$ are displayed.

5. Discussion

The present study aimed to investigate the role of the primary motor cortex during semantic processing of action verbs. In particular, it was focused on addressing the *necessity question*, which wonders whether or not the recruitment of the motor areas is needed in order to understand words entailing motor content. To pursue these goals we applied rTMS over the hand portion of the right and left primary motor cortex and evaluated the effects of the stimulation toward a semantic comprehension task.

The main result of the experiment is that the stimulation affected selectively the processing of action verbs, but not that of abstract verbs: actually, RTs were slower after stimulation, compared to the baseline, only when verbs describing hand-action were presented; no differences in RTs were found between pre and post stimulation with verbs describing intellectual or symbolic activities. The present findings are in line with previous imaging and electrophysiological results (Hauk et al., 2004; Pulvermuller, Harle, & Hummel, 2000, 2001; Pulvermuller, Lutzenberger, & Preissl, 1999; Tettamanti et al., 2005): authors reported a somatotopic activation of the motor areas during linguistic processing of actions performed with different body parts, revealing a recruitment of the motor system elicited by non-motor tasks. Similar conclusions are drawn from several TMS studies, reporting an involvement of the primary motor cortex during language processing (Buccino et al., 2005; Fadiga et al., 2002; Gerfo et al., 2008; Meister et al., 2003; Pulvermuller et al., 2005; Sundara, Namasivayam, & Chen, 2001; Tokimura, Tokimura, Oliviero, Asakura, & Rothwell, 1996; Watkins, Strafella, & Paus, 2003; Willems et al., 2011). However, if the contribution of the motor areas is widely acknowledged, the direction of this involvement is still not clear. Our findings seem to indicate a facilitatory effect of the primary motor cortex on semantic processing, confirmed by the fact that the temporary disruption of that area resulted in a delay of the RTs with action verbs. These results agree with those of Gerfo (Gerfo et al., 2008), who applied offline rTMS over the primary motor cortex right before asking participant to perform a morphological task and described a slowing of the RTs for action words, but not for state words. Moreover, our results are compatible with studies that have found an increase of cortical excitability of the muscle effector, induced by a concomitant linguistic task. For example, Fadiga (Fadiga et al., 2002) showed that listening to phonemes increases the cortical excitability of the brain regions involved in their execution. Similarly, Pulvermuller (Pulvermuller et al., 2005) in an experiment that mirrors our own, reported a facilitation in response latencies to arm action words following arm site stimulation, and to leg action words after leg site stimulation. Authors stated that this differential effect of stimulation refers to a category-specific involvement of the primary cortex during lexical access.

On the other hand, Buccino (Buccino et al., 2005) reported the opposite effect: motor evoked potentials recorded from hand and foot muscles decreased while participants listened to hand and foot action-related sentences respectively. Authors explained these findings referring, among others hypotheses, to an interference effect exerted by a "higher order" motor representation of the heard action on all concrete motor representations needed to perform that action. From our perspective, there could be another possible explanation to integrate these apparently incongruent findings: the passive hearing of sentences, as employed by Buccino, does not imply a deep semantic processing of the material, as required by our task. These different levels of processing could contribute to elicit different responses of the primary cortex, depending on task demands: one could assume that motor areas are silent or slightly inhibited when the subject is not supposed to intentionally process the stimuli; however, as long as the task demands increase and the semantic level is approached, the contribution of the motor cortex become more active causing a facilitatory effect. This hypothesis seems coherent with results reported by Tomasino et al. (Tomasino, Fink, Sparing, Dafotakis, & Weiss, 2008), who compared effect of hand motor cortex stimulation towards different tasks: silent reading, frequency judgment and motor imagery. Authors found a stimulation effect only for the latter, which was not a true linguistic task (the linguistic level of processing- accessing the meaning of the word - is a prerequisite to perform the true task –

imaging to perform the action and deciding whether it requires a hand rotation), and claimed that the primary motor cortex is involved only when an overt simulation of the action is required. According to our proposal, however, the reason why silent reading and frequency judgment were not modulated by the stimulation is that they do not entail a deep semantic processing (Sato, Mengarelli, Riggio, Gallese, & Buccino, 2008). In line with Tomasino and collaborators' hypothesis (Tomasino et al., 2008) we can suppose that, even in our case, the mechanism underlining the facilitatory effect is simulation: semantic comprehension of action verbs is accomplished by simulating the correspondent motor program; if the simulation process is temporarily blocked, the comprehension in turn is subjected to a delay. Probably M1 is the cerebral region that, among others (i.e. premotor cortex) supports this process of simulation, so the transient reduction of its excitability results in slower comprehension of action verbs.

With specific reference to the role played by the primary motor cortex in semantic processing, our findings support the hypothesis of a functional involvement. The use of rTMS gave us the opportunity to investigate this issue by inducing a transient reduction of cortical excitability and evaluating its impact on the semantic task: data obtained in this study suggest that "turning off" the motor area has a direct, causal effect on the response latencies, and this fact can be considered as a proof of the functional role of this area. Nevertheless, it is too early to claim that the primary motor cortex is *needed* in order to perform the task: the only way to make this claim should be to test the effect of the complete removal of this area on language comprehension. This happens in case of brain damage, but so far studies on patients with pathologies affecting motor system documented mostly a general preferential impairment of verbs, rather than a specific direct relationship between site of lesion and verb loss (Bak, 2010; Bak & Chandran, 2012; Berndt et al., 1997). Hence, for the time being, it is more cautious to posit that the motor system *is* involved in a functional, and not epiphenomenal, way in language processing.

Finally, the laterality effect is another interesting result. Not only, indeed, the effects of rTMS are evident selectively for action verbs, but also selectively for left stimulation. RTs after right stimulation for concrete and abstract verbs, did not actually differ from each other, and furthermore, did not differ from RTs for abstract words following left stimulation. It means that, in right-handers, only the left primary motor cortex is involved in semantic comprehension, whereas the right one is not. The present findings extend those by Willems (Willems, Hagoort, & Casasanto, 2010), who carried out an imaging study to compare premotor activity during action verb understanding in right-handers versus left-handers. The rationale is that if the action understanding process entails motor programs, than the processing of words describing actions that typically people perform with their dominant hand should activate the controlateral premotor cortex, which subserves the planning of the correspondent action.

The results confirmed this prediction, indicating that right-handers preferentially activated the left premotor cortex during lexical decision, whereas left-handers preferentially activated the right premotor cortex. Even if we did not compare right- vs left-handers, our results seem to support the hypothesis that, at least for right-handers, as happened for the premotor cortex, the primary motor cortex activated in language processing is that consistent with handedness. This can be considered as a further clue of the tight link between language and motor system.

6. Conclusion

The present study aimed at extending previous results about the relationship between language processing and motor system. According to the present findings, the primary motor cortex is involved in a functional manner during action verb comprehension and coherently with the handedness: in right-handers, only the left hand portion of the primary motor cortex has a role in the comprehension of verbs indicating hand actions.

This outcome is relevant for different reasons. From a theoretical point of view, it deepens the knowledge about the nature and the origins of language, adding new data in support to the embodiment hypothesis; most importantly, it has some interesting concrete implications in the clinical practice. Aphasic patients often suffer from difficulties in retrieving the correct lexical item or in remembering the meaning of a specific word: the fact that the motor representations and the language representations are interwoven, even at the level of the primary motor cortex, opens new perspectives for the rehabilitation of such disabilities. As pointed out by Pulvermuller (Pulvermuller & Berthier, 2008), aphasia therapy should take advantage from this interplay by stimulating language through action. More specifically, authors proposed that, rather than training naming abilities in closed language settings, "It is advantageous to practise language in relevant action contexts" (*ibidem*).

Future research is needed to better clarify the role of the primary cortex in different conditions and processes not addressed by this study: different linguistic tasks should be used (with different degrees of semantic processing – i.e. passive hearing, as in Buccino's experiment (Buccino et al., 2005)); the effect of laterality should be confirmed by including left-handers; the link between the content of the verb and the specific primary motor region involved (in our experiment: hand portion of M1 – hand-action verbs) should be tested by including other action verbs (i.e. foot-action verbs) and stimulating other cortical regions (foot portion of M1).

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Highlight

- rTMS over the hand portion of M1 affects hand-action verb comprehension
- RTs are slower for hand-action verbs after stimulation than in the baseline
- Hand-action verbs are affected only after left M1 stimulation
- Our results seem to indicate a functional role of M1 in action verbs comprehension

Table

Stimulus	Translation	Verb type	Frequency	Syllable Length	Letters Length
afferrare	to catch	concrete	126	4	9
abbottonare	to button	concrete	5	5	11
accarezzare	to caress	concrete	58	5	11
accartocciare	to scrunch up	concrete	3	5	13
appallottolare	to crumple	concrete	1	6	14
annodare	to knot	concrete	12	4	8
applaudire	to clap	concrete	65	4	10
colorare	to color	concrete	29	4	8
dipingere	to paint	concrete	134	4	9
disegnare	to draw	concrete	190	4	9
firmare	to sign	concrete	407	3	7
impugnare	to clasp	concrete	46	4	9
intagliare	to carve	concrete	2	4	10
pennellare	to brush	concrete	3	4	10
pettinare	to comb	concrete	11	4	9
pugnalare	to stab	concrete	6	4	9
sbottonare	to unbutton	concrete	2	4	10
sbucciare	to peel	concrete	43	3	9
schiaffeggiare	to slap	concrete	6	4	14
sfogliare	to flip	concrete	44	3	9
slacciare	to untie	concrete	6	3	9
spalmare	to spread	concrete	20	3	8
stappare	to uncork	concrete	4	3	8
strappare	to tear out	concrete	163	3	9

Table 1: list of items describing hand actions, included in the condition: concrete verbs

Table

Stimulus	Translation	Verb type	Frequency	Syllable Length	Letters Length
odiare	to hate	abstract	115	3	6
dirimere	to settle	abstract	4	4	8
stimare	to estimate	abstract	54	3	7
deprecare	to deprecate	abstract	3	4	9
infamare	to defame	abstract	2	4	8
propendere	to be inclined	abstract	11	4	10
rassegnare	to resign	abstract	64	4	10
terrorizzare	to terrify	abstract	26	5	12
fallire	to fail	abstract	121	3	7
apprezzare	to appreciate	abstract	163	4	10
immaginare	to imagine	abstract	353	5	10
scordare	to forget	abstract	42	3	8
preventivare	to budget	abstract	3	5	12
travisare	to misrepresent	abstract	4	4	9
perpetrare	to perpetrate	abstract	10	4	10
precorrere	to anticipate	abstract	6	4	10
calunniare	to slander	abstract	1	4	10
motivare	to motivate	abstract	44	4	8
tergiversare	to shilly-shally	abstract	9	5	12
intraprendere	to undertake	abstract	54	5	13
precludere	to preclude	abstract	8	4	10
semplificare	to simplify	abstract	22	5	12
sublimare	to sublime	abstract	3	4	9
sopportare	to tolerate	abstract	154	4	10

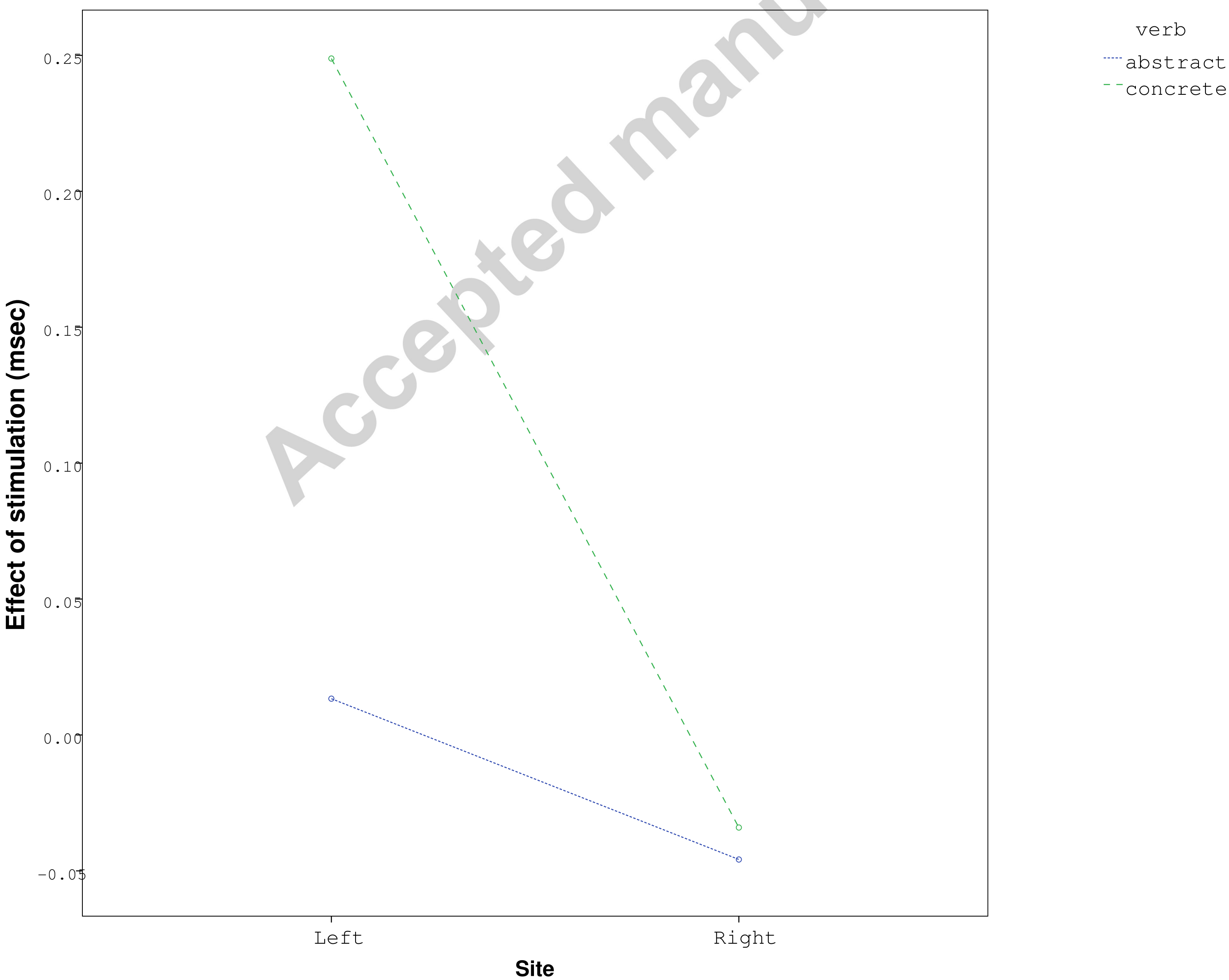
Table 2: list of items describing intellectual or symbolic activities, included in the condition: abstract verbs

Table

Site	Verb	Mean	Std. Deviation
Left	Abstract	.013	.224
	Concrete	.249	.326
Right	Abstract	- .046	.170
	Concrete	- .034	.131

Table 3: descriptives of the effects of stimulation

Figure



0.25
0.20
0.15
0.10
0.05
0.00
−0.05
Effect of stimulation (msec)
Left
Right
Site
verb
abstract
concrete