Is motor inhibition involved in the processing of sentential negation? An assessment via the Stop Signal Task

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The present study is carried out in the framework of an Embodied account of language, according to which different aspects of language are grounded in the sensory-motor system (Cuccio and Gallese, 2018). While the use of simulation mechanism may be considered straightforward as for the processing of concrete concepts and words, the processing of abstract concepts, like the logical operators, represents one of the main challenges for embodied cognition models, leading to a still open and highly controversial debate.

Previous findings have shown reduced activation of the hand-motor areas during the processing of hand action-related negative sentences with respect to their affirmative counterpart (Bartoli et al. 2013; Foroni and Semin 2013; Liuzza et al. 2011). The latter results seem to support the idea that the comprehension of negation is grounded in our sensorimotor system. However, the neurocognitive mechanisms underlying the processing of sentential negation have not been understood yet. Recently, it has been proposed that a good candidate for this role is the neural mechanism of motor response inhibition (Beltrán et al. 2018, 2019; De Vega et al. 2016; Foroni and Semin 2013; Papeo et al. 2016). Thus, in the present study we will explore the hypothesis that the processing of action-related negative sentences is grounded in the mechanism of motor inhibition. To this end, we exploited the Stop Signal task (SST; Logan et al. 1984), which allows one to estimate the Stop Signal Reaction Time (SSRT), a covert reaction time underling reactive inhibition (the ability to stop a response when a stop instruction is presented). To the best of our knowledge, there is only another study (Beltrán et al. 2018), that used the SST with the aim to investigate linguistic negation. Beltrán and colleagues (2018), by recording the electroencephalographic (EEG) activity, investigated whether the event-related complex associated to sentential negation differs with respect to the one associated with affirmative sentences. Their behavioural results showed that participants were faster to inhibit their responses during the presentation of affirmative than negative sentences.

In this framework, and to further Beltrán and colleagues pioneering approach, the present study has a twofold aim: (*i*) to assess whether mechanisms for motor inhibition underpin the processing of sentential negation, thus, providing stronger evidence for a bodily grounding of this logic operator; (*ii*) to determine whether the SST, which has been used to investigate motor inhibition, could represent a good tool to explore this issue. In our experimental design, we chose to maintain the same main structure of Beltrán et al., (2018), presenting the stimuli word by word in the centre of the screen. Each trial starts with a fixation cross, followed by the polarity-referred word (i.e., "*Io/I*" for affirmative condition and "*Non/I don't*" for negative condition). Then, we first present the verb, followed by a left- or right-pointing arrow (Go stimulus) appearing on it. At the appearance of the Go stimulus, participants are instructed to respond as quickly and accurately as possible to its direction using the mouse with their right hand, pressing the right- or the left-button for the right- or left-pointing arrow, respectively. The Stop trial structure is similar to the Go one, but the Go stimulus is followed by a 100 ms auditory Stop-Signal. The delay between the onset of Go stimulus and the onset of Stop-Signal (i.e., SSD) is established by a staircase procedure: it is dynamically adjusted as a result of participant's performance, increasing and decreasing on the basis of the participant's ability or inability to withhold his/her response to the arrow, respectively. Participants are instructed to try to withhold their response to the Go-task. In 12.5% of the total trials sample, the ITI is followed by the same yes/no recognition task. However, we decided to replicate their experiment by introducing some important changes: (*i*) the occurrence of the Stop-Signal was set to 33% instead to 50%, as suggested by the authors of the SST (Logan et al. 1984). Indeed, the frequency of the Stop-Signal is crucial because, as it increases, the probability of using proactive strategies also increases; (*ii*) we used ten short two-word hand action-related sentences (polarity and verb), both in affirmative and negative polarity (total number of stimuli = 960). We employed very short sentences for two main reasons. First, to help participants focusing their attention only on the relevant aspects of the experimental trial. Second, to shorten as much as possible the duration of the task. Besides, whereas Beltrán and colleagues (2018) used the second person singular of the simple future tense, we used the first person singular of the present tense. This choice was based on recent literature suggesting that an interference effect is more likely to be obtained with the first and third person singular compared to the second person singular (Borghi, 2012); (*iii*) the presentation of the verb, before the appearance of the arrow signal, was set randomly between 250 and 900 ms, with the aim to avoid response anticipation; (*iv*) we modulated the staircase procedure in steps of 33 ms to obtain a greater modulation and sensitivity; and (*v*) we measure proactive inhibition (i.e., the ability to shape the motor strategy according to the context). To this end, we gave 48 Go-trials to measure the "baseline" RTs in Go trials and comparing them with the RTs obtained during the execution of Go trial in the SST (Mirabella et al., 2008).

Our results confirmed the findings from Beltrán et al. (2018), showing longer SSRT for negative sentences respect to the affirmative counterparts. As the SSRT, together with the RT and error rate, are modulated by sentence negation, we suggest that the SST is an excellent paradigm to assess the role of motor inhibition in the processing of sentence negation. These results will also be discussed in the light of data coming from different experimental paradigms that might reflect the contribution of a different mechanism for motor inhibition (e.g., the GO/NOGO paradigm, Beltrán et al. 2019; Liu et al. 2019; De Vega et al. 2016).

Selected references

Bartoli, E., Tettamanti, A., Farronato, P., Caporizzo, A., Moro, A., Gatti, R., et al. (2013). The disembodiment effect of negation: Negating action-related sentences attenuates their interference on congruent upper limb movements. *Journal of Neurophysiology*, *109*(7), 1782–1792. https://doi.org/10.1152/jn.00894.2012

Beltrán, D., Morera, Y., García-Marco, E., & De Vega, M. (2019). Brain inhibitory mechanisms are involved in the processing of sentential negation, regardless of its content. Evidence from EEG theta and beta rhythms. *Frontiers in Psychology*, *10*(JULY), 1–14. https://doi.org/10.3389/fpsyg.2019.01782

Beltrán, D., Muñetón-Ayala, M., & de Vega, M. (2018). Sentential negation modulates inhibition in a stop-signal task. Evidence from behavioral and ERP data. *Neuropsychologia*, *112*(February), 10–18. https://doi.org/10.1016/j.neuropsychologia.2018.03.004

Borghi, A. M. (2012). Action language comprehension, affordances and goals. Language and action in cognitive neuroscience. Contemporary topics in cognitive neuroscience series, 125-143.

Cuccio, V., & Gallese, V. (2018). A Peircean account of concepts: Grounding abstraction in phylogeny through a comparative neuroscientific perspective. *Philosophical Transactions of the Royal Society B: Biological Sciences*. https://doi.org/10.1098/rstb.2017.0128

De Vega, M., Morera, Y., León, I., Beltrán, D., Casado, P., & Martín-Loeches, M. (2016). Sentential negation might share neurophysiological mechanisms with action inhibition. Evidence from frontal theta rhythm. *Journal of Neuroscience*, *36*(22), 6002–6010. https://doi.org/10.1523/JNEUROSCI.3736-15.2016

Foroni, F., & Semin, G. R. (2013). Comprehension of action negation involves inhibitory simulation. *Frontiers in Human Neuroscience*, *7*(MAY), 1–7. https://doi.org/10.3389/fnhum.2013.00209

Liu, B., Wang, H., Beltrán, D., Gu, B., Liang, T., Wang, X., & de Vega, M. (2019). The generalizability of inhibition-related processes in the comprehension of linguistic negation. ERP evidence from the Mandarin language. *Language, Cognition and Neuroscience*, *0*(0), 1–11. https://doi.org/10.1080/23273798.2019.1662460

Liuzza, M. T., Candidi, M., & Aglioti, S. M. (2011). Do not resonate with actions: Sentence polarity modulates cortico-spinal excitability during action-related sentence reading. *PLoS ONE*, *6*(2), 38–41. https://doi.org/10.1371/journal.pone.0016855

Logan, G. D., Cowan, W. B., & Davis, K. A. (1984). On the ability to inhibit simple and choice reaction time responses: A model and a method. *Journal of Experimental Psychology: Human Perception and Performance*, *10*(2), 276–291. https://doi.org/10.1037/0096-1523.10.2.276

Mirabella, G., Pani, P., & Ferraina, S. (2008). Context influences on the preparation and execution of reaching movements. *Cognitive neuropsychology*, *25*(7-8), 996-1010.

Papeo, L., Hochmann, J. R., & Battelli, L. (2016). The default computation of negated meanings. *Journal of Cognitive Neuroscience*. https://doi.org/10.1162/jocn_a_01016