The role of motor inhibition in implicit negation processing: two Go/NoGo behavioral studies

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Abstract

Several studies demonstrated that the processing of explicit forms of negation recruits motor inhibitory mechanisms. However, whether this is also true for implicit negation, in which the negative meaning is implicated but not explicitly lexicalized in the sentence (e.g., “I ignore”), has never been studied before.

This study aims to address this issue via two Go/NoGo experiments applied to the processing of affirmative, explicit and implicit negation sentences, which differed for the response time-windows to the Go stimulus available to participants. We investigated whether: (i) the processing of implicit negations recruits inhibitory mechanisms; (ii) the inhibitory control mechanisms are differently modulated by implicit and explicit negations. Since we posit that motor inhibitory mechanisms are modulated by both (i) the polarity of the sentence and (ii) the Go/NoGo paradigm, two after-effect analyses on reaction times in Go trials were carried out. Results suggest that implicit negation sentences determine stronger involvement of motor inhibitory mechanisms than the explicit ones. The different processing of the two forms of negation could be explained by the more negative emotional valence of implicit negation and by its inferential nature, which might require deeper processing of the negative meaning, leading to greater activation of the sensory-motor system.

Keywords: Go/NoGo task; implicit negation; motor inhibition; sentence negation

Declarations

Conflicts of Interest

The authors declare that they have not conflict of interest.

Funding

This work was supported by Mutti’s donation to V.G. and by FFABR UNIME 2020 to V.C.

Author contributions

MM, MC, VC designed the experiment. MM and MC performed data acquisition and analyses. MM, MC, VC, MAU and VG interpreted the results. MM and VC wrote the manuscript. All authors have contributed to, seen and approved the manuscript.

Data availability statement

The datasets analysed during the current study are available from the corresponding author on reasonable request.

Acknowledgments

The authors wish to thank Prof. Giovanni Mirabella for his valuable suggestions on the development of the experimental design.

1. Introduction

Negation is a unique feature of human language, universally present in all natural languages and with no equal in any animal communication system (Speranza & Horn, 2010). Negation allows us to revert the truth value of a sentence (Horn, 1989), i.e., the property of a sentence to be true or false, determining a semantic opposition between a negated expression and its positive counterparts. Many of our distinctive human practices, such as dealing with mathematical reasoning, arguing about philosophical hypotheses, or developing counterfactual reasoning (i.e., the tendency to imagine scenarios that could have taken place but did not occur), would not be possible without the use of negation. Even ethics and law would not be possible without negation, since following moral and juridical rules implies the capacity to discern between what we ought to do and what we ought not. For these reasons, negation is a central topic in several fields. Within the sciences of language, negation has been object of investigation at all language levels. Indeed, morpho-syntactic, syntactic, semantic and pragmatic aspects of negation have been widely investigated (Horn, 2001). Within these studies, pragmatics certainly offers a privileged perspective for the understanding of the mechanisms underlying this logic operator since it focuses on the use of negation in context. In other words, a usage-based pragmatic approach allows to ground the use of this operator in the dimension of human communication processes, thus relating the functioning of negation to the socio-cognitive mechanisms underlying it (Cuccio, 2011, 2012). Furthermore, a pragmatic investigation of negation also allows us to advance and deepen our knowledge of how negation works at all the other language levels. For example, based on a pragmatic perspective, the definition of negation as a semantic opposition (see above) has been reconsidered since negative statements are communicatively much more than inverted assertions and imply a different inferential impact, for example, on quantifiers or scalar words with respect to affirmative sentences.

In the last decades, the cognitive processes underlying negation and its neural underpinnings have also been object of investigation. As for the former, it has been shown that the processing of negation is cognitively more demanding compared to the processing of affirmative sentences as it is reflected in higher error rates (ERs) and longer reaction times (RTs). The cognitive load associated to the processing of sentential negation has been explained by cognitive effects such as a reduced accessibility of the negated concept (Kaup, 2001; Kaup & Zwaan, 2003; MacDonald & Just, 1989), the elicitation of a complementary scenario (Kaup et al., 2005; Orenes et al., 2014) and an increase of the cognitive effort (Carpenter & Just, 1975; Chase & Clark, 1972; Kaup et al., 2006). There are evidence that processing of polarity (i.e., defining whether a sentence is in the affirmative or negative form) in hand action-related sentence modulates the hand motor-related areas (Alemanno et al., 2012; Aravena et al., 2012; Bartoli et al., 2013; Foroni & Semin, 2013; Liuzza et al., 2011; Tettamanti et al., 2008; Tomasino et al., 2010). More recently, it has been proposed that processing linguistic negation might recruit the neural mechanisms underlying motor response inhibition (Beltrán et al., 2018, 2019; De Vega et al., 2016; Foroni & Semin, 2013; García-Marco et al., 2019; Liu et al., 2019, 2020; Montalti et al., 2021; Papeo et al., 2016). This hypothesis is coherent with an embodied account of language, which posits that the comprehension of language is grounded in our sensory-motor system (Cuccio & Gallese, 2018; Di Cesare et al., 2017; Gallese & Cuccio, 2018). Indeed, the functional links between language and motor activity have been widely investigated in the last years and a vast amount of experimental data corroborated the hypothesis that the same mechanisms that integrate action and perception may also play a crucial role in the processing of different types of linguistic information (Barsalou, 2010; Cuccio et al., 2014; Fischer & Zwaan, 2008; Glenberg et al., 2013; Jirak et al., 2010; Spadacenta et al. 2014; Mirabella et al., 2012; Pulvermüller et al., 2014). In this framework, findings in support of the hypothesis that the processing of linguistic negation share the resources with motor inhibition have also been provided. For example, de Vega and colleagues (2016) carried out an electroencephalographic (EEG) study in which participants were asked to read negative and affirmative action-related sentences while performing a Go/NoGo task. This study showed that negative sentences modulate theta bands, a marker of motor inhibition, over the frontal cortex. In another EEG experiment, Beltrán et al., (2018) presented participants with negative and affirmative action-related sentences while they were performing a Stop-Signal Task (SST; Logan et al., 1984) which is used to evaluate reactive inhibition. Results showed that two event-related potentials (ERPs; N1 and P3) were enhanced by successful inhibition. Furthermore, these findings also showed that N1 amplitude was higher for negative sentences compared to affirmative ones in successful stop trials. Via source analysis (e.g., LAURA, Menendez et al., 2001; Spinelli et al., 2000), the authors suggested that N1 modulation depended upon the right inferior frontal gyrus (rIFG), an area known to play a key role in inhibitory control (Aron et al., 2014).

Notably experimental research carried out on the cognitive and neural underpinnings of linguistic negation processing is mainly carried out on sentential negation, i.e., through the processing of forms of negation explicitly lexicalized at the sentence level using morpho-syntactic expressions such as “not”, “no” or “don’t” which overtly convey a negative meaning. Few

studies have been carried out on other forms of negation which rely more heavily on a pragmatic dimension (e.g., Xiang et al., 2016; Marrero et al., 2020). Particularly interesting in this regard is the distinction proposed by Clark (1976; but see also Horn, 1996) between explicit and implicit negation. While the latter is a non-asserted negative meaning, explicit negation is present at the level of the asserted meaning of a sentence. Examples of explicit negation are not only “no”, “not” or “don’t” but also expressions such as “few” and “little” and prefixes such as im-moral or a-symmetry. In other words, explicit forms of negation are both the morpho-syntactic elements which convey a negative meaning and those expressions which, through entailments, determine the representation of a negative meaning in the minimal sentence. By contrast, implicit negation conveys a negative meaning that is not present at the level of the minimal sentence, but in the intended meaning of a sentence and it relies on presuppositions or implicatures. According to Clark (1976), example of implicit negation are verbs such as “forget”, “prevent”, “avoid” etc. To make this point clear, we might recall the classic distinction between explicit and implicit meaning of a sentence which dates back to Grice (1989). According to Grice (1989), in each sentence we can identify the level of what is literally said and the level of what is intended or implicated by that sentence. The construction of the sentence meaning i.e., its explicit meaning, relies on inferences, known as entailments, directly drawn from the literal meaning of the sentence components, whereas the construction of the intended meaning relies on contextually based inferences known as implicatures. We will not review the debate on the inferential processes underlying both levels of sentences representation (for a discussion, Carapezza and Cuccio, 2018). Suffice to say here that there is no agreement on the nature of such processes. On the contrary, the distinction between the explicit and the implicit meaning can be considered as one of the defining features of any pragmatic account of language.

The present study addresses the issue of the grounding of linguistic implicit negation in the mechanisms of motor inhibition. The study aims to determine whether the processing of sentences formulated in the affirmative form but containing implicit negation (e.g., the Italian verbs *digiunare*, *tacere*, *vietare*, *ignorare*, *rifiutare* - to fast, to shut up, to forbid, to ignore, and to refuse-) recruits the mechanisms of motor response inhibition as it is the case for explicit negative sentences. We predict an involvement of resources for motor inhibition during the processing of both explicit and implicit negation sentences compared to the affirmative ones. As for the involvement of the motor inhibitory system in the two different types of negation, several different scenarios could be expected. A first possibility is that, since both explicit and implicit negative sentences contain a negation, they recruit the motor inhibitory system similarly. Alternatively, a gradient effect might be expected, which could be structured in two different ways. In the first case, explicit negation, being explicitly lexicalized in the sentence, might lead to a higher involvement of the motor inhibitory mechanisms compared to implicit negation. In the second case, implicit negation might lead to a higher activation of inhibitory resources, likely due to its inferential nature, which may determine a deeper processing of the negative meaning compared to a likely shallow processing of explicit negation. In the latter case, implicit negation would lead to greater activation of the sensory-motor system (see Egorova et al., 2013 for ERP data on semantic and pragmatic processing; see Kuberberg et al., 2000 for fMRI results on the neural correlates of semantic and pragmatic processing). Due to the scarce literature on this topic, we decided to adopt an exploratory approach. As a consequence, a further alternative scenario should be also taken into consideration. Since implicit negation sentences do not have an explicit syntactic marker for negation, they might be processed in a similar way to affirmatives sentences and thus they might not involve the motor inhibitory mechanisms. However, since we adopt a pragmatic and inferential view of language, we consider this as the less likely scenario.

EXPERIMENT 1

2. Materials and Methods

2.1. Participants

86 healthy young adults (42 females, $M_{age} = 24.30$, Standard Deviation - $SD_{age} = 3.99$, $range_{age} = 18-34$) took part in the study. The sample size was established a priori by means of statistical power analysis (a priori sample size-evaluated for F test for a within repeated measures ANOVA: $\alpha = 0.05$, $1 - \beta = 0.80$, effect size = 0.15, one group, 6 measurements, correlation among rep measures = 0.3 and non-sphericity correction = 0.7; G*Power 3.1.9.4; (Faul et al., 2009)). Inclusion criteria included (i) age range from 18 to 35 years old; (ii) right-hand dominance (Oldfield, 1971); (iii) Italian native speakers; (iv) absence of learning disabilities or other language impairments; and (v) normal or corrected-to-normal vision. Since we ran the experiment online due to the outbreak of the COVID-19 pandemic, we needed to make sure that the timing of both the stimuli presentation and the responses were as accurate and homogeneous as possible. The Labvanced software (version 2.10; Finger et al., 2017; <https://www.labvanced.com/>), used to carry out this online study, evaluated these aspects for the whole duration of the experiment in terms of median and SD of the delay. We excluded participants with a median offset greater

than or equal to 20 ms and with a SD greater than or equal to 12 ms. Hence, we discarded 7 participants from data analysis. Moreover, we excluded 11 participants due to a poor performance in the recognition task (mean accuracy < 75%) and 1 following the outlier analysis. In conclusion, our final sample was composed by 67 healthy subjects (32 females; $M_{age} = 24.01$, $SD_{age} = 3.83$, $range_{age} = 18 - 33$; Education = 34 high school diploma, 24 bachelor degree, 5 master degree, 4 post-graduate training).

All participants provided a written informed consent to participate in the study, which was approved by the local ethical committee of the COSPECS Department at University of Messina and was conducted in accordance with the Declaration of Helsinki (2013).

2.2. Stimuli

The stimuli consisted of 15 two-word sentences (see Table 1 for the complete list of stimuli). To select verbs used in the experiment we carried out a validation study, through an online survey using Psycokit (Stoet, 2010; 2017). A group of 20 participants (10 females; $M_{age} = 41.10$, $SD_{age} = 14.37$, $range_{age} = 24 - 70$; Education = 6 high school diploma, 5 bachelor degree, 4 master degree, 5 post-graduate training), who did not take part to the experiment, participated in the validation study. First, we selected a set of 21 verbs that could be considered as implicit negation plus 11 fillers not expressing implicit negation, with the purpose to decrease the homogeneity of the experimental sample. For each verb, participants were asked to decide whether or not the stimulus conveyed an implicit negation. In the case of a positive answer, they were also required to explain its meaning in a lexical recall task. For example, when presented with the Italian verb “ignorare” (“to ignore”), if participants recognized it as an implicit negation, they were successively asked to explicitly express its negative meaning. The majority of the participants defined “to ignore” as “non sapere” (“to not know”). We selected five verbs that were correctly recognized as expressing an implicit negation by the 80% of participants (see Table 1). This procedure allowed us to select (i) implicit negative verbs; (ii) the verbs that were most recalled by participants in the lexical recall task, which were then used to form the affirmative and explicit negative sentences to be matched with the implicit negative ones. The five selected implicit negative verbs and the ten affirmative and explicit negative counterparts were balanced for frequency of use ($t_{(4)} = -1.43$; $p = .23$; Bambini & Trevisan, 2012), number of syllables ($t_{(4)} = 0.78$; $p = .48$) and number of characters ($t_{(4)} = 0.53$; $p = .62$). Finally, we produced 5 two-words sentences, anticipating the first-person subject to the affirmative and implicit negative verbs, and anticipating the negative particle “non” (in English “I don’t”) for the explicit negative verbs (e.g., affirmative: “Io so”, explicit negative sentence: “Non so”, implicit negative sentence: “Io ignoro”; in English, respectively, “I know”, “I do not know”, “I ignore”). It is important to emphasize that Italian is a pro-drop language, hence subject in negative sentences may be omitted. In this way, each sentence of the task is constituted by two words.

Table 1 – List of all the experimental stimuli.

In *italics* the English translation of the sentence.

Implicit Negative	Affirmative	Explicit Negative
Io digiuno (<i>I fast</i>)	Io mangio (<i>I eat</i>)	Non mangio (<i>I don't eat</i>)
Io taccio (<i>I shut up</i>)	Io parlo (<i>I speak</i>)	Non parlo (<i>I don't speak</i>)
Io rifiuto (<i>I refuse</i>)	Io accetto (<i>I accept</i>)	Non accetto (<i>I don't accept</i>)
Io vieto (<i>I forbid</i>)	Io permetto (<i>I allow</i>)	Non permetto (<i>I don't allow</i>)
Io ignoro (<i>I ignore</i>)	Io so (<i>I know</i>)	Non so (<i>I don't know</i>)

2.3. Experimental procedure

Each affirmative, explicit negative and implicit negative selected sentence was repeated 18 times for a total of 270 trials. Of these, 33% were NoGo trials (6 for each experimental condition, for a total of 90 trials) and 67% were Go trials (12 for each experimental condition, for a total of 180 trials).

Sentences were presented word-by-word at the center of the screen and were written in black capital letters (Arial font size 48 points) on a grey background. Each trial started with a 500 ms fixation cross, followed by the polarity-referred word (i.e., “Io/I” for affirmative and implicit negative conditions and “Non/I don’t” for negative condition), which lasted

250 ms. First we presented the verb, for a variable time of 100- 400 ms, to avoid possible anticipated responses, followed by a yellow (Go trial) or blue (NoGo trial) circle appearing on it. In the Go trials, participants were instructed to respond as quickly and accurately as possible to the appearance of the yellow circle using the space bar with their right index. Participants had 600 ms to respond to the circle, after this time the answer was considered omitted. In the NoGo trials, participants were instructed to withhold their response when the blue circle appeared on the verb. The correct or erroneous responses were marked by a 250 ms positive (i.e., a green mark) or negative (i.e., a red cross) visual feedback. This event was followed by an inter-trial interval (ITI) of 800 ms.

After 32 trials (i.e., 11.85% of the total trials), the ITI was followed by a catch trial, consisting of a yes/no recognition task. First, a white question mark on a black screen lasting 250 ms appeared. Second, a two-word sentence was presented for 1500 ms. Participants were instructed to determine whether the sentence was identical (for both polarity and verb) or different (either for polarity or verb) from the one presented in the previous trial. Participants had to press the space bar when the sentences were identical. In 50% of recognition tasks, the sentences were “identical”, while in the remaining 50% they were “different” (25% in polarity and 25% in verb). The correct or erroneous execution of the recognition task was signalled by a 250 ms positive (i.e., a green mark) or negative (i.e., a red cross) visual feedback, (See Fig. 1 panel B). The catch trials were included (i) to keep participants' attention; and (ii) to ensure that they read the sentences.

The 270 experimental trials were presented in three blocks (90 trials each) each lasting three minutes. Rest was allowed between blocks. In each block the proportion between Go and NoGo trials was maintained (2:1, respectively), and they were balanced by polarity.

Before starting the experiment, participants carried out a training session of 27 trials to familiarize with the experimental apparatus. Six trials, out of 27, were followed by the recognition task. To avoid habituation, all the training trials included sentences that were not used in the experimental task.

At the end of the experiment, participants were asked to rate arousal and valence of all the verbs (i.e., the 5 implicit negation verbs and the 5 used to create affirmative/explicit negation sentences) on a Visual Analogue Scale (VAS), without any time constraints. As for arousal, participants were asked “How would you judge the intensity of this word?” and they were asked to answer using a VAS from 0 (very low) to 100 (very high). As for valence, participants were asked “How would you judge the valence of this word?” and they were asked to answer using a VAS from -50 (negative) to 50 (positive). The whole experimental paradigm was created and controlled using Labvanced software (version 2.10; Finger et al., 2017; <https://www.labvanced.com>).

Figure 1. The experimental design

Panel A. Italian two-words sentences were presented word by word at the center of the screen. Participants were instructed to perform the Go/NoGo task pressing the space bar to the presentation of a yellow circle while withholding their response to the presentation of a blue circle. **Panel B.** 32 trials (11.85%) were followed by a yes/no recognition task.

2.4. Analysis

Given the low number of commission errors obtained by each participant in NoGo trials ($M_{\text{Aff}} = 0.78$; $SD_{\text{Aff}} = 1.11$; $\text{range}_{\text{Aff}} = 0-5$; $M_{\text{Exp}} = 0.48$; $SD_{\text{Exp}} = 0.86$; $\text{range}_{\text{Exp}} = 0-3$; $M_{\text{Imp}} = 0.51$; $SD_{\text{Imp}} = 0.86$; $\text{range}_{\text{Imp}} = 0-4$), we analysed only RTs of Go trials: via a linear mixed-effect analysis. We excluded trials whose RT exceeded three standard deviations above and below the mean. Following a hierarchical approach, we firstly created a simple model using only one parameter (i.e., Polarity, 3 levels: Affirmative, Implicit Negation, Explicit Negation) as independent fixed variable, and then we added by Participants intercept as random effect with the aim to evaluate whether its inclusion improved model fit. Likelihood ratio tests, Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC) were used to establish whether the inclusion of main effect and random effect would significantly improve model fit. Tukey's test was used for post-hoc comparisons among means. Since the inhibitory mechanisms appears to be doubly modulated by the linguistic dimension of the stimuli, which contain a negation, and by the Go/NoGo task, specifically by the NoGo trials, we chose to perform also two after-effects analyses, by means of a linear mixed effect analysis following the same procedure described above. For the first analysis, we considered RTs of correct Go trials preceded by a correctly executed Go trial. In the second one, we considered RTs of correct Go trials preceded by a correctly inhibited NoGo trial. Finally, as for valence and arousal ratings, we excluded outlier ratings and, since variables were not normally distributed, we performed two robust paired t-test (R package - walrus: Robust Statistical Methods; Love and Mair, 2017). All analyses were performed using MATLAB (version 2019a) and R Studio software (version 1.4.1717; R Core Team, 2019).

2.5. Results

Go RTs

The model explained 95% of the variance of RTs taking into account Participants as random effect ($R^2_{\text{m}} = 0.0015$; $R^2_{\text{c}} = 0.95$). The model showed a significant main effect of Polarity ($\chi^2_{(2)} = 6.40$, $p = .04$), highlighting faster RTs in Affirmative condition than Implicit Negation condition ($t_{(132)} = -2.47$, $SE = 1.35$, $p = .04$; Affirmative: $M = 354$ ms, $CI_s = 346, 363$ ms; Implicit Negation: $M = 358$ ms, $CI_s = 349, 366$ ms). (Figure 2)

Figure 2. Main effect of Polarity. Mixed model analysis showed a significant difference in RTs between Affirmative and Implicit Negation conditions. Error bars represents standard errors (SEs) of the means. * = $p < .05$

After-effect RTs: Go preceded by Go

After-effect analysis didn't show any significant effect.

After-effect RTs: Go preceded by NoGo

The model explained 89% of the variance in RTs taking into account Participants as random effect ($R^2_m = 0.007$; $R^2_c = 0.89$). The model showed a significant main effect of Polarity ($\chi^2_{(2)} = 12.61$, $p = .002$), highlighting faster RTs in Affirmative condition than both Implicit ($t_{(134)} = -3.38$, $SE = 2.4$, $p = .003$; Affirmative: $M = 356$ ms, $CI_s = 346, 366$ ms; Implicit Negation: $M = 364$, $CI_s = 354, 375$) and Explicit Negation ($t_{(134)} = -2.63$, $SE = 2.4$, $p = .03$; Explicit Negation: $M = 362$ ms, $CI_s = 352, 373$ ms) condition (Figure 3).

Figure 3. Main effect of Polarity in the After-effect analysis of Go trials preceded by NoGo trials. Mixed model analysis showed a significant difference in RTs between Affirmative and both Implicit Negation and Explicit Negation conditions. Error bars represents SEs of the means. * = $p < .05$; ** = $p < .01$

Valence and Arousal

The two-sided Robust Paired Samples T-Test on Valence ratings showed a significant difference between implicit negation verbs and those used to create affirmative sentences and explicit negation sentences ($t_{(203)} = 25.46$; $p < .0001$): Valence ratings for Implicit Negation verbs were more negative than for Affirmative/Explicit Negation ones ($M_{Imp} = -25.35$; $SD_{Imp} = 19.02$; $M_{AffExp} = 22.63$; $SD_{AffExp} = 19.16$).

The two-sided Robust Paired Samples T-Test on Arousal ratings showed a significant difference between Implicit Negation verbs and those used to create Affirmative sentences and Explicit Negation sentences ($t_{(203)} = -5.25$; $p < .0001$): participants attributed greater arousal to implicit negation verbs than affirmative/explicit negation ones ($M_{Imp} = 68.71$; $SD_{Imp} = 26.78$; $M_{AffExp} = 62.71$; $SD_{AffExp} = 19.81$).

EXPERIMENT 2

Previous studies have shown that action-related and non-action related words are semantically processed, around 200 ms and 250 ms from the stimulus onset, respectively (see Papitto et al., 2021). Negation is clearly an abstract, non-action related word. In light of these results, the timing of the response time-window to the Go stimulus is a crucial element to better understand the interaction between the processing of linguistic negation and the recruitment of the motor inhibitory mechanisms. A 600 ms time-window might be too long to allow us to evaluate the recruitment of resources for motor response inhibition during the processing of both explicit and implicit negative sentences. Therefore, we carried out a second experiment to assess the timing of this interaction, reducing the maximum time to respond to the Go stimulus from 600 ms to 450 ms. Also, this shorter time-window to respond should induce in the participants a greater time pressure, determining higher ERs.

3. Materials and Methods

3.1. Participants

87 healthy young adults (43 females, $M_{age} = 23.75$, $SD_{age} = 3.64$, $range_{age} = 18-35$) took part in the study. We considered the same power analysis parameters to estimate the sample size (i.e., 86 participants) and inclusion and exclusion criteria used in experiment 1 (please, see paragraph 2.1 for more information). Two participants were discarded due to a median standard deviation greater than or equal to 12 ms and 11 participants were excluded due the mean accuracy $< 75\%$ in the recognition task. Thus, our final sample was composed by 74 healthy participants (39 female; $M_{age} = 23.77$, $SD_{age} = 3.66$, $range_{age} = 18 - 35$; Education = 42 high school diploma, 20 bachelor degree, 12 master degree). All participants provided a written informed consent to participate in the study, which was approved by the local ethical committee of the COSPECS Department at University of Messina and was conducted in accordance with the Declaration of Helsinki (2013).

3.2. Stimuli

We used the same stimuli of experiment 1.

3.3. Experimental Design

We used the same design of experiment 1, with the only difference that the time to respond to the go-stimulus, was reduced from 600 ms to 450 ms.

3.4. Analysis

Despite our attempt to make the task more difficult by significantly decreasing the response time-window, we still obtained a low amount of errors ($M_{Aff} = 0.76$; $SD_{Aff} = 0.89$; $range_{Aff} = 0-3$; $M_{Exp} = 0.78$; $SD_{Exp} = 1.13$; $range_{Exp} = 0-4$; $M_{Imp} = 0.58$; $SD_{Imp} = 0.91$; $range_{Imp} = 0-4$). Therefore, we performed the same analysis of experimental 1.

3.5. Results

Go RT

The model explained 94% of the variance in RTs taking into account Participants as random effect ($R^2_m = 0.005$; $R^2_c = 0.94$). The model showed a significant main effect of Polarity ($\chi^2_{(2)} = 18.28$; $p = .0001$), highlighting faster RTs in Affirmative condition than Implicit Negation condition ($t_{(146)} = -4.27$, $SE = 0.95$, $p = .0001$; Affirmative: $M = 337$ ms, $CI_s = 332, 343$ ms; Implicit Negation: $M = 341$ ms, $CI_s = 336, 347$ ms). Please, see Figure 4.

Figure 4. Main effect of Polarity. Mixed model analysis showed a significant difference in RTs between Affirmative and Implicit Negation conditions. Error bars represents SEs of the means. *** = $p < .001$

After-effect RTs: Go preceded by Go

The model explained 77% of the variance in RTs taking into account Subjects as random effect ($R^2_m = 0.012$; $R^2_c = 0.77$). The model showed a significant main effect of Polarity ($\chi^2_{(8)} = 35.11$, $p < .0001$), with six significant contrasts (see Figure 5). For the sake of clarity we report here only results of post-hoc comparison. Please, see Table 2 for more information about mean and confident interval values.

The first significant contrast, showed faster RTs for Affirmative sentences preceded by another Affirmative sentence (i.e., Aff_Aff) compared to an Implicit Negative sentences preceded by an Affirmative sentence (i.e., Imp_Aff) ($t_{(584)} = -3.65$, $SE = 2.04$, $p < .008$). The second significant contrast, showed faster RTs for Affirmative sentences preceded by another Affirmative sentence (i.e., Aff_Aff) compared to an Implicit Negative sentences preceded by an Explicit Negative sentence (i.e., Imp_Exp) ($t_{(584)} = -5.25$, $SE = 2.04$, $p < .0001$). The third significant contrast, showed faster RTs for Affirmative sentences preceded by Explicit Negative sentence (i.e., Aff_Exp) compared to an Implicit Negative sentences preceded by an Explicit Negative sentence (i.e., Imp_Exp) ($t_{(584)} = -3.42$, $SE = 2.04$, $p = .02$). The fourth significant contrast, showed faster RTs for Affirmative sentences preceded by Implicit Negative sentence (i.e., Aff_Imp) compared to an Implicit Negative sentences preceded by an Explicit Negative sentence (i.e., Imp_Exp) ($t_{(584)} = -3.52$, $SE = 2.04$, $p = .01$). The fifth significant contrast, showed faster RTs for Explicit Negative sentences preceded by another Explicit Negative sentence (i.e., Exp_Exp) compared to an Implicit Negative sentences preceded by an Explicit Negative sentence (i.e., Imp_Exp) ($t_{(584)} = -3.53$, $SE = 2.04$, $p = .01$).

The sixth significant contrast, showed faster RTs for Implicit Negative sentences preceded by another Implicit Negative sentence (i.e., Imp_Imp) compared to an Implicit Negative sentences preceded by an Explicit Negative sentence (i.e., Imp_Exp) ($t_{(584)} = -3.60$, $SE = 2.04$, $p = .01$).

Table 2 – Significant effects in After-effect RTs Go preceded by Go.

Legend: Aff = Affirmative; Exp = Explicit Negation; Imp = Implicit Negation.

The first element in a pair refers to the Polarity of Target Go trial, while the second one represents the Polarity of the previous Go trial (e.g., “Imp_Aff” indicates an Implicit Negation trial preceded by an Affirmative trial).

Comparison	Test	Means and CIs (ms)
Aff_Aff vs Imp_Aff	$t_{(584)} = -3.65$, $SE = 2.04$, $p < .008$	Aff_Aff: M = 331, CIs = 325, 337 Imp_Aff: M = 339, CIs = 333, 334
Aff_Aff vs Imp_Exp	$t_{(584)} = -5.25$, $SE = 2.04$, $p < .0001$	Aff_Aff: M = 331, CIs = 325, 337 Imp_Exp: M = 342, CIs = 336, 348
Aff_Exp vs Imp_Exp	$t_{(584)} = -3.42$, $SE = 2.04$, $p = .02$	Aff_Exp: M = 335, CIs = 329, 341 Imp_Exp: M = 342, CIs = 336, 348
Aff_Imp - Imp_Exp	$t_{(584)} = -3.52$, $SE = 2.04$, $p = .01$	Aff_Imp: M = 335, CIs = 329, 341 Imp_Exp: M = 342, CIs = 336, 348
Exp_Exp - Imp_Exp	$t_{(584)} = -3.53$, $SE = 2.04$, $p = .01$	Exp_Exp: M = 335, Cis = 329, 341 Imp_Exp: M = 342, CIs = 336, 348
Imp_Exp - Imp_Imp	$t_{(584)} = -3.60$, $SE = 2.04$, $p = .01$	Imp_Exp: M = 342, CIs = 336, 348 Imp_Imp: M = 334, Cis = 328, 340

Figure 5. Main effect of Polarity in the After-effect analysis of Go trials preceded by Go trials. Mixed model analysis showed a significant difference in RTs. See Table 2 for more information about significant comparisons. Error bars represents SEs of the means. * = $p < .05$; ** = $p \leq .01$; *** = $p < .0001$

After-effect RTs: Go preceded by NoGo

The model explained 84% of the variance in RTs taking into account Participants as random effect ($R^2_m = 0.008$; $R^2_c = 0.84$). The model showed a significant main effect of Polarity ($\chi^2_{(2)} = 10.76$, $p = .005$), highlighting faster RTs in Affirmative condition than Implicit Negation condition ($t_{(146)} = -3.25$, $SE = 1.69$, $p = .004$; Affirmative: $M = 339$ ms, $CI_s = 333, 344$ ms; Implicit Negation: $M = 344$ ms, $CI_s = 338, 350$ ms). Please, see Figure 6.

Figure 6. Main effect of Polarity in the After-effect analysis of Go trials preceded by NoGo trials. Mixed model analysis showed a significant difference in RTs between Affirmative and Implicit Negation conditions. Error bars represents SEs of the means. ** $p < .01$

Valence and Arousal

The two-sided Robust Paired Samples T-Test on valence ratings showed a significant difference between implicit negation verbs and those used to create affirmative sentences and explicit negation sentences ($t_{(221)} = 29.94$; $p < .0001$): valence ratings for implicit negation verbs were more negative than for affirmative/explicit negation ones ($M_{\text{Imp}} = -25.96$; $SD_{\text{Imp}} = 17.20$; $M_{\text{AffExp}} = 21.98$; $SD_{\text{AffExp}} = 18.52$).

The two-sided Robust Paired Samples T-Test on arousal ratings showed a significant difference between implicit negation verbs and those used to create affirmative sentences and explicit negation sentences ($t_{(221)} = -6.59$; $p < .0001$): participants attributed greater arousal to implicit negation verbs than affirmative/explicit negation ones ($M_{\text{Imp}} = 72.71$; $SD_{\text{Imp}} = 21.72$; $M_{\text{AffExp}} = 64.01$; $SD_{\text{AffExp}} = 20.27$).

AROUSAL AND VALENCE ASSESSMENT: A FOLLOW-UP SURVEY

The ratings of arousal and valence in the previous experiments were carried out using single verbs in the infinitive mood. We asked our participants to rate arousal and valence of the verbs used in the Affirmative and Explicit Negative sentences (e.g., “to know”) on one hand, and the ones used in the Implicit Negative sentences on the other hand (e.g., “to ignore”). However, this procedure didn’t allow us to compare arousal and valence for all experimental conditions since, by using single verbs, we could not compare arousal and valence in the two different types of negation. To better address this issue, using an online survey, we asked an independent sample of participants to rate the arousal and valence of the 15 experimental whole sentences (e.g., “I know”, “I don’t know”; “I ignore”).

4.1. Participants

29 participants (16 females, $M_{\text{age}} = 30.14$, $SD_{\text{age}} = 8.24$, $\text{range}_{\text{age}} = 21\text{--}58$; Education = 8 high school diploma, 6 bachelor degree, 10 master degree, 5 post-graduate training) took part in the study. All participants provided a written informed consent to participate in the study, which was approved by the local ethical committee of the COSPECS Department at University of Messina and was conducted in accordance with the Declaration of Helsinki (2013).

4.2. Method

We made an online questionnaire using Psytoolkit (Stoet 2010; 2017). Participants were instructed to rate valence and arousal of the 15 experimental sentences, five for each of the three experimental condition. Sentences were randomly presented at the center of the screen two times, one for each of the following questions: (i) valence: “*How would you judge the emotional valence expressed by the sentence?*”; (ii) arousal: “*How would you judge the emotional intensity expressed by the sentence?*”. Participants were asked to answer to the question using a VAS constituted by a horizontal bar which (i) for the valence ranged from -50 (negative) to 50 (positive), the central point corresponded to neutral; (ii) for the arousal ranged from 0 (very few) to 100 (very much). Participants were informed that they could respond at any point on the bar.

4.3. Analysis

For both valence and arousal, after outliers exclusion, variables were still not-normally distributed. Thus, we performed two robust ANOVA (R package: WRS2: A Collection of Robust Statistical Methods; Mair et al., 2021). Analyses were performed using R Studio software (version 1.4.1717; R Core Team, 2019).

4.4. Results

For the valence rating, the robust ANOVA showed a significant main effect of Condition ($F_{(2, 171.61)} = 136.02$; Effect Size = .81; $CI = 0.75, 0.88$); $p < .0001$) indicating that all the experimental conditions differed from each other. Affirmative sentences were rated as more positive than both Explicit Negative ($M_{\text{Aff}} = 16.28$; $SD_{\text{Aff}} = 16.64$; $M_{\text{Exp}} = -18.74$; $SD_{\text{Exp}} = 18.41$; $CI = 26.62, 29.33$; $p < .0001$) and Implicit negative sentences ($M_{\text{Imp}} = -23.75$; $SD_{\text{Imp}} = 16.99$; $CI = 33.09, 45.07$; $p < .0001$). Moreover, the Explicit Negative sentences were rated as more positive than Implicit Negative ones ($CI = -0.09, 12.30$; $p = .02$). For the arousal rating, the robust ANOVA didn’t show significant effects.

5. Discussion

The purpose of the present study was to investigate the role of motor inhibitory mechanisms underlying the processing of linguistic implicit negation, a form of negation that is not asserted through morpho-syntactic elements or other expressions which, through entailments, determine the representation of negative meaning in the minimal sentence. Implicit negation is only present in the intended meaning of a sentence, and it relies on presuppositions or implicatures. So far, all studies that have dealt with negation have investigated explicit forms of negation (Beltrán et al., 2018, 2019; De Vega et al., 2016; Foroni & Semin, 2013; García-Marco et al., 2019; Liu et al., 2019, 2020; Montalti et al., 2021; Papeo et al., 2016). To address this issue, we ran two online experiments using a Go/NoGo paradigm.

Since we obtained a small number of errors in NoGo trials of both experiments, the analyses focused only on the distribution of GO RTs. Both experiments showed a significant difference between the Affirmative and Implicit Negation conditions, with faster RTs for the Affirmative condition. However, we didn't find any significant difference between Explicit Negation and the other two conditions. This latter result is in line with previous Go/NoGo studies carried out by Beltrán and colleagues where a significant difference in RTs between Affirmative and Explicit Negative sentences has never been found (Beltrán et al., 2019; De Vega et al., 2016; Liu et al., 2019, 2020).

In the current experiments the activation of the mechanisms for motor response inhibition is modulated in two ways: (i) by linguistic processing, as linguistic stimuli contain negative sentences. In this case, since the pre-activation of the inhibitory system is given by linguistic features of the stimulus, a weak involvement of motor inhibition resources is expected; (ii) by the Go/NoGo task, specifically by the NoGo trials. In this case, the motor inhibitory system is strongly pre-activated by a successful response inhibition. To distinguish between these two modulations, we carried out two after-effects analyses, considering the RTs of correct Go trials preceded by correct Go and NoGo trials, respectively.

The first after-effect analysis (Go trials preceded by Go trials, both correctly executed) was carried out to investigate whether the performance of Go trials was modulated by both their polarity and the polarity of the previous trial. Results showed significant effects only in experiment 2 (i.e., shorter response-time window - 450 ms). Taking into account previous behavioural studies (Beltrán et al., 2019; De Vega et al., 2016; Liu et al., 2019, 2020), we hypothesize that the inhibition after-effect given only by the linguistic feature of the stimulus (Go trial with negative polarity) leads to a weak activation of the motor inhibition mechanism. Hence, the absence of significant results in experiment 1 could likely be explained by a less intense inhibition after-effect caused by the fast decay of the processing of negative sentences, which is not visible with a longer time window for the response.

Results in experiment 2 showed six significant contrasts (see Table 2). In the first one (Aff_Aff vs. Imp_Aff), both the target Go trials were preceded by an affirmative sentence, which didn't pre-activate the inhibitory system, thus the involvement of the motor inhibitory mechanisms was given only by the polarity of the target sentence (Aff vs. Imp). The result showed significantly longer RTs for the Implicit Negation sentences compared to Affirmative ones, highlighting an involvement of the motor inhibitory mechanisms during the processing of sentences formulated with a positive polarity, but containing an implicit negation. The other five significant contrasts showed longer RTs in the condition in which an Implicit Negation is preceded by an Explicit Negation (i.e., Imp_Exp). We hypothesize that the processing of Implicit Negation sentences might determine a stronger involvement of the motor inhibitory mechanisms compared to Explicit Negation form. This conclusion seems to be suggested by the contrast Exp_Exp - Imp_Exp. In this case, both the target Go trials were preceded by an Explicit Negation sentence and the Implicit Negation condition had the longer RTs. However, this might depend on the fact that in the Exp_Exp condition (Explicit Negation preceded by Explicit Negation), the two trials belong to the same stimulus type. However, this result occurred also when an Implicit Negation was preceded by another Implicit Negation. One might assume that this condition should determine a greater involvement of the motor inhibition mechanism compared to the other conditions. However, this was not the case, likely because of a facilitation effect due to the presentation of two consecutive sentences belonging to the same stimulus type. Overall, the results of the Go-Go after-effect analyses show that the polarity effect is difficult to identify at the behavioural level, as it can be assumed that the activation of the motor inhibitory mechanisms is weak when it is modulated only by linguistic processing. Indeed, during Explicit Negation processing it was never found a significant differences at the behavioural level, but only at the electrophysiological one (Beltrán et al., 2018, 2019; De Vega et al., 2016; Liu et al., 2019, 2020).

Since in our experiments the activation of the inhibitory mechanisms is modulated both by the linguistic processing and by motor inhibitory NoGo task, we carried out a second after-effects analysis considering the RTs of correct Go trials preceded by NoGo trials. Results of this analysis showed, for both the experiments, that Implicit Negative sentences had significantly longer RTs than Affirmative ones. Furthermore, only for experiment 1 we also found that Affirmative sentences had faster RTs than Explicit Negation ones. To better understand the latter result we need to consider two critical factors: 1. the two

experiments only differed for the response time-window; 2. contrary to the first after-effect analysis, investigating the inhibitory after-effect due to the features of the linguistic stimuli, this second after-effect analysis investigated the inhibitory after-effect due to a successful motor inhibition (a successful NoGo trial). Thus, we hypothesize that, the recruitment of motor inhibition resources during the linguistic processing of a Go trial preceded by a successful NoGo trial can be better assessed when the maximum response time is longer. This might depend on the fact that the inhibitory after-effect due to the NoGo trials generates a ceiling effect in the shorter maximal response time-window, making it difficult to appreciate RTs modulations due solely to linguistic processing.

Finally, as for valence and arousal ratings, results from experiment 1 and experiment 2 showed a significant difference between Implicit Negation verbs compared to the verbs used in Affirmative and Explicit Negation sentences: Implicit Negation verbs were judged as more negative and more arousing than their counterparts. As for valence, these results might not be surprising, as these verbs already contain a negation in their meaning. The presence of a negation, although implicitly expressed, might also be the reason why they are considered more arousing compared to the other verbs. However, our data do not allow us to draw this conclusion since we did not compare Implicit verbs to verbs combined with an Explicit Negation. To overcome this limitation, we carried out an online survey where Implicit Negative, Affirmative and Explicit Negative sentences were evaluated for valence and arousal. Analysis showed significant results only for valence, with Implicit Negation sentences considered more negative than the other two experimental conditions. This result suggests that an implicit, inferential, negation, because of its higher negative value, is more effective than an explicit negation in the activation of the motor inhibitory mechanisms. As for the arousal ratings, contrary to the results of the two experiments, in the follow-up survey we didn't find any significant difference. This might depend on the fact that in experiments 1 and 2, participants were asked to rate single verbs: in the Affirmative and Explicit Negation, isolated verbs have a positive connotation whereas the verbs of the Implicit Negation condition have a negative connotation. Consequently, this may have led participants to polarize their ratings. This phenomenon was not found considering the whole sentences, probably because the presence of the Explicit Negation sentences might have mitigated the polarization in ratings (e.g., "I know", "I don't know"; "I ignore").

The study has some other limitations: the two levels of modulation of the inhibitory mechanisms should be further investigated, improving the control of the experimental setting by running new studies in presence with well suited experimental designs. These limitations notwithstanding, our findings allow us to provide some conclusions. We consider the analysis based on after-effect in Go trials preceded by NoGo trials as the most informative one. These results suggest that sentences in which negation is implicitly asserted lead to a greater involvement of the motor inhibitory mechanisms. On this basis, we might assume a gradient in the processing of linguistic negation, where implicit negation strongly recruits the inhibitory mechanisms compared to explicit forms of negation. This might be the case because implicit negation, having an inferential nature, may determine a deeper processing of the negative meaning compared to a likely shallow processing of explicit negation, thus leading to greater activation of the sensory-motor system (Egorova et al., 2013; Kuberberg et al., 2000). Also, and less speculatively, results on valence rating support the gradient hypothesis, as the three experimental conditions differ from each other. Indeed, Affirmative sentences were those judged with the more positive scores, Implicit Negative sentences with the more negative ones, with Explicit Negative sentences in between.

The present study has two main theoretical implications. Firstly, it provides further evidence of the fact that even abstract concepts such as linguistic negation have a bodily grounding in the sensorimotor system. Secondly, and most importantly, it provides support to the idea that implicit and inferential meaning (i.e., pragmatic information) is grounded too in the same mechanisms that integrate action with perception. The latter point is particularly relevant since it will expand our knowledge of the embodied ground of a pragmatic account of language. Studying the involvement of the sensorimotor system in the processing of implicit, inferential and usage-based linguistic meaning represents a frontline research for any embodied account of language. The study of the embodiment of the pragmatic aspects of language is certainly one of the most intriguing and cutting-edge line of research in the embodied cognition paradigm.

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