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The generalizability of inhibition-related processes in the comprehension of linguistic negation. ERP evidence from the Mandarin language

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ABSTRACT

The recently proposed Reusing Inhibition for Negation (RIN) hypothesis posits that the inhibitory control mechanism is reused to understand sentential negation. The RIN hypothesis has only been tested in alphabetic languages, and its novelty requires additional support from non-alphabetic languages, like logographic non-Indo-European languages. This study examined the RIN hypothesis in the context of Mandarin, which has unique linguistic features and neural underpinnings. Participants read either affirmative or negative action-related sentences while performing an embedded Go/NoGo task. Reduced inhibition-related N2 was detected in NoGo-negative compared to NoGo-affirmative condition. Brain source estimation of the N2 interaction effect revealed strongest activation in the right inferior parietal lobule, a typical inhibition-related brain region. These results confirm the generalizability of the RIN hypothesis, suggesting that comprehension of negation in logographic Mandarin also recruits the inhibitory control mechanism.

1. Introduction

Negation, which is common to all human languages, refers to the absence of a concept and can reverse the truth value of sentence meaning (Hasson & Glucksberg, 2006). Early behavioural studies revealed that negation increases the cognitive demand for understanding a sentence and suppresses the accessibility of the information within its scope (Carpenter & Just, 1975; Kaup, 2001; Kaup & Zwaan, 2003; MacDonald & Just, 1989). For example, in the classic study of MacDonald and Just (1989), participants were asked to do a word recognition task immediately after reading sentences like "Almost every weekend, Elizabeth bakes some bread but no cookies for the children" and they responded more quickly to the probe word "bread" than "cookies", indicating that negation renders the negated concept less accessible.

Studies working with action language also reported inhibitory effects of negation on motor network activations. Neuroimaging studies demonstrated that understanding negative action-related sentences reduced both activations and connection strengths of the primary motor and the premotor cortex compared to their affirmative counterparts (Tettamanti et al., 2008;

Tomasino, Weiss, & Fink, 2010). Convergently, a TMS study showed that reading affirmative but not negative manual action language selectively reduced cortico-spinal excitability (Liuzza, Candidi, & Aglioti, 2011), indicating the recruitment of motor networks only in affirmative condition. In other words, negation held back the involvement of motor networks in the comprehension of action language. Other studies explored the modulation of peripheral activities by means of online grasp force (Aravena et al., 2012) and kinematic measures (Bartoli et al., 2013) during the comprehension of action-related sentences, reporting effects on these measures for affirmative rather than negative sentences.

These studies revealed the inhibitory effects of negation on cognitive and neural representations of the negated information, without digging further the underlying neural mechanism of negation processing itself that may trigger the inhibitory effects. One highly possible explanation is that comprehension of negation reuses the inhibitory control mechanism, herein the Reusing Inhibition for Negation (RIN) hypothesis (Beltrán, Muñetón-Ayala, & de Vega, 2018; de Vega et al., 2016; Papeo & de Vega, in press). The RIN hypothesis relies on the neural principle of reuse, according to

which ancient cognitive circuits can be extended to new cognitive functions, while retaining the original ones (Anderson, 2010; Fitch, 2011). The RIN hypothesis was motivated by the following premises: (1) the inhibitory control mechanism operates on motor networks to suppress an action (Johnstone et al., 2007); (2) comprehension of action language activates motor networks (Aziz-Zadeh, Wilson, Rizzolatti, & Iacoboni, 2006; de Vega et al., 2014; Moody & Gennari, 2010); (3) negation reduces the involvement of motor networks during action language comprehension (Liuzza et al., 2011; Tettamanti et al., 2008; Tomasino et al., 2010). Therefore, the inhibitory control mechanism is very likely to be reused during negation processing, which may account for the consistently reported negation-induced inhibitory effects.

Only a few studies have tested the RIN hypothesis recently. It was proved that the silent period following transcranial magnetic stimulation on M1 increased for negative action-related sentences compared to affirmative ones, as an index of the inhibitory activity of the GABAergic system (Papeo, Hochmann, & Battelli, 2016). Specially relevant for the present research are the EEG studies showing that negative action-related sentences, compared to their affirmative counterparts, reduced the inhibition-related frontal theta rhythms of NoGo trials in a Go/NoGo task (de Vega et al., 2016), and enhanced the inhibition-related N1 component of successful stop trials in a stop-signal task (Beltrán et al., 2018). Furthermore, negation was reported to delay keyboard-based typing execution for manual-action verbs (Garcia-Marco et al., 2019). These studies are compatible with the RIN hypothesis, suggesting that negation in the context of action language reuses neural resources of the inhibitory control network. According to a very recent study performed in our laboratory, the RIN hypothesis could be generalised beyond motor action sentences to mental event domains (Beltrán, Morera, García-Marco, & de Vega, 2019).

The above studies explored the inhibitory mechanism of negation using Indo-European languages with alphabetic writing systems. Given its novelty, the RIN hypothesis needs to be tested for its generalizability in different languages and writing systems, which can differ from Indo-European languages in their neural demands. Mandarin offers us an opportunity to do so, because of its distinctive linguistic features. For instance, Mandarin characters are composed of strokes or radicals that fit into a square-shaped space, while alphabetic words are formed by letters; reading tone-based Mandarin entails orthography-to-phonology transformation, whereas reading accent-based alphabetic languages requires grapheme-to-phoneme conversion (Tan, Laird, Li, & Fox,

2005). These unique features of Mandarin are not trivial and may contribute to shaping distinctive brain organisation in the processing of Mandarin compared to alphabetic languages. Neuroimaging studies have shown that the processing of Mandarin but not alphabetic languages in native speakers selectively activates the left middle frontal gyrus (LMFG) and the right inferior frontal gyrus (rIFG) (Kuo et al., 2001; Tan, Feng, Fox, & Gao, 2001; Wu, Ho, & Chen, 2012). Moreover, impaired reading of Mandarin is more associated with the dysfunction of the LMFG instead of the left temporoparietal regions responsible for reading disability of alphabetic languages (Siok, Perfetti, Jin, & Tan, 2004). Accordingly, it was suggested that LMFG and rIFG coordinate and integrate the unique phonological and visual-spatial analyses demanded by Mandarin (Tan et al., 2003; Tan, Liu, et al., 2001). Notably, LMFG and rIFG also play critical roles in the inhibitory control mechanism (Chambers, Garavan, & Bellgrove, 2009; Nakata et al., 2008; Zheng, Nao, & Song, 2008).

The partial overlap of brain regions implementing both Mandarin reading and inhibitory control processes could undermine the applicability of the RIN hypothesis to Mandarin. Specifically, comprehension of negation in Mandarin might not reuse the inhibitory control mechanism, since part of the inhibitory neural resources would be utilised for the visual-spatial computation and orthography-to-phonology encoding of Mandarin characters, limiting thereby their availability for negation processing. Therefore, testing the generalizability of the RIN hypothesis in Mandarin is highly relevant and could shed new light on how the human brain configures neural resources for the comprehension of negation in non-alphabetic languages.

The present Event-related potentials (ERP) study was conducted to empirically examine the robustness and generalizability of the RIN hypothesis with Mandarin-speaking participants, using the same embedded Go/NoGo paradigm employed by de Vega et al. (2016) with Spanish-speaking participants. In a typical Go/NoGo paradigm, participants are requested to press a button, as quickly as possible to a frequent Go cue and not to respond to a less frequent NoGo cue. ERP studies adopting the Go/NoGo paradigm usually report enhanced fronto-central N2 and P3 in NoGo condition, the former is considered to indicate response inhibition while the latter could reflect performance evaluation, error detection and/or preparation for future trials (Falkenstein, Hoormann, & Hohnsbein, 1999; Hoyniak, 2017; Roche, Garavan, Foxe, & O'Mara, 2005). Importantly, the amplitude of the NoGo N2 component, commonly known as a direct indicator of response inhibition, correlates positively with task difficulty (Benikos, Johnstone, &

Roodenrys, 2013). Like in de Vega et al.'s (2016) experiments, participants were asked to read and comprehend both affirmative and negative action-related sentences while responding to a visual Go/NoGo cue presented online above the action verb. Language comprehension was measured by answering a probe question after the presentation of the whole trial.

Given that the RIN hypothesis is based on the neural principle of reuse (Anderson, 2010; Fitch, 2011), we suppose it should be applicable to the processing of negation in not only alphabetic Indo-European languages but also logographic Mandarin, despite their different neural demands. If so, we could expect an interaction between negation and response inhibition with our embedded Go/NoGo paradigm. This interaction could materialise in reduced N2 amplitude in NoGo-negative compared to NoGo-affirmative condition, resulting from the facilitation effect of negation on subsequent response inhibition as reported by de Vega et al. (2016).

2. Materials and methods

2.1. Participants

A total of 24 undergraduate students (13 females) aged 17–25 ($M = 21.5$ years) from Liaoning Normal University and Dalian University of Technology participated in the experiment. All participants were right-handed native Chinese speakers with normal or corrected-to-normal eyesight and had no reported history of neurological illness. They gave informed consent and received 50 yuan RMB (about $7) for their participation. One participant was removed from the analysis because of excessive artifacts.

2.2. Design and materials

A two within-subjects factorial design was adopted: task cue (Go, NoGo) × sentence polarity (affirmative, negative). A total of 240 Chinese imperative sentences were constructed as experimental materials, each in two versions: affirmative and negative. All had similar structures starting with the temporal adverbial "现在" (xianzai; now) right before the polarity operator, either affirmative "请"(qing; please) or negative "别"(bie; don't). The critical manual verb followed closely the polarity operator before the object which was the sentence end. To maintain participants' attention on each part of the sentence, 30 filler sentences were constructed which differed from the experimental sentences in the first word only: "现在" (xianzai; now) was replaced by "稍后" (shaohou; later) in the filler sentences. To ensure that participants paid attention to the meaning of the sentences while doing the Go/NoGo task, 35% of the trials were followed by a recognition task. The recognition sentence could be identical to the foregoing experimental sentence or modified in the polarity, verb or noun part. The identical sentence required a "yes" response, while the modified sentence required a "no" response. Sample experimental, recognition and filler sentences are listed in Table 1.

The experimental sentences were divided into 2 groups: 168 sentences (70%) were assigned to Go trials and the other 72 sentences (30%) were assigned to NoGo trials. The stimuli were divided into three blocks, with each containing 80 experimental sentences and 10 fillers. For each block, 70% of the sentences were Go trials and the remaining 30% of the sentences were NoGo trials. Among the Go and NoGo trials, half were affirmative and half were negative sentences. Frequency, strokes and imageability of the verbs and nouns were controlled between Go and NoGo conditions as shown in Table 2. Statistical testing did not find any significant difference between Go and NoGo homologous words ($p > 0.5$).

2.3. Procedure

The experiment was conducted in a dimly-lit room which was soundproof and electrically-shielded. The stimuli were programmed and presented with E-prime software on a 24-inch monitor. Participants were seated

Table 1. Examples of experimental, recognition, and filler sentences with their pronunciations and English translations.

Experimental sentences			
AFF	现在/请/擦/桌子。	Xianzai/qing/ca/zhuozi.	Now/please/wipe/the table.
NEG	现在/别/擦/桌子。	Xianzai/bie/ca/zhuozi.	Now/don't/wipe/the table.
Possible recognition sentences (take affirmative sentence as example)			
Identical	现在/请/擦/桌子。	Xianzai/qing/ca/zhuozi.	Now/please/wipe/the table.
PM	现在/别/擦/桌子。	Xianzai/bie/ca/zhuozi.	Now/don't/wipe/the table.
VM	现在/请/搬/桌子。	Xianzai/qing/ban/zhuozi.	Now/please/move/the table.
NM	现在/请/擦/椅子。	Xianzai/qing/ca/yizi.	Now/please/wipe/the chair.
Filler sentences			
AFF	稍后/请/洗/衣服。	Shaohou/qing/xi/yifu.	Later/please/wash/the clothes.
NEG	稍后/别/洗/衣服。	Shaohou/bie/xi/yifu.	Later/don't/wash/the clothes.

Note: PM, VM and NM represent polarity-modified, verb-modified and noun-modified versions of the recognition sentences, respectively.

Table 2. Mean scores of lexical frequencies, strokes, and imageability of verbs and nouns in Go and NoGo conditions.

	Verb		Noun	
	Go	NoGo	Go	NoGo
Frequency	20.70 (17.32)	21.75 (18.06)	20.68 (28.35)	22.47 (30.14)
Strokes	10.80 (3.27)	10.81 (3.44)	16.80 (4.55)	17.08 (4.62)
Imageability	4.76 (0.43)	4.78 (0.42)	4.77 (0.42)	4.81 (0.40)

Statistical testing did not find any significant difference between Go and NoGo homologous words ($p > 0.5$).
Standard deviations are in the parentheses.

comfortably in front of the desk at a distance of about 100 cm from the monitor. After receiving instructions, participants were asked to do a practice round containing 30 trials similar to the experimental ones. After the practice round, participants were given 3 blocks of 80 experimental sentences and 10 fillers. Sentences were presented randomly within each block and the order of the 3 blocks was counterbalanced among participants.

Each sentence began with a 500-ms fixation cross, then the temporal adverbial and the sentence polarity operator were presented one character a time for 300 ms, with each followed by a 200-ms blank. After that, the critical manual verb was presented for 300 ms, then a Go/NoGo cue (a yellow dot for Go trials and a blue dot for NoGo trials) appeared above the verb and stayed for 200 ms. Participants were required to respond as soon as possible to the Go/NoGo cue by pressing "L" on the keyboard with the index finger of the right hand after seeing a yellow dot and withhold the pressing after seeing a blue dot. Reaction times for the Go trials as well as commission and omission errors were recorded for later analyses. The verb stayed on the screen for another 200 ms, and after a 200-ms blank, the noun was presented one character a time for 300 ms with a 200-ms blank in between.

For trials with no recognition task, 1200 ms after the last character, a new trial started. For trials with a recognition task, the last character was followed by a question mark indicating the coming of a recognition sentence, then the sentence appeared and participants were required to make a yes/no judgment by pressing the "1" or "2" key on the keyboard with the left hand. The sentence remained on the screen until participants made a response. Half of the recognition sentences were identical ones that required a "yes" response, while the other half were modified versions demanding a "no" response. Reaction times of correct responses and accuracy data were collected for the recognition task. The temporal sequence of a trial is illustrated in Figure 1.

2.4. EEG recording and preprocessing

Continuous electroencephalograph (EEG) signals were recorded by a 64-channel amplifier ANT Neuro EEGO

from unshielded and sintered Ag/AgCl electrodes arranged according to the standard 10–20 system on an elastic cap, with two additional electrodes placed on the left and right mastoids (M1 & M2). Two electrodes GND and CPz were taken as the ground electrode and online reference, respectively. Electrode impedances were always kept below 5 kΩ and the sampling rate was 500 Hz. For each trial, ERP recording was time-locked to the onset of the Go/NoGo cue (the yellow/blue dot).

EEG data preprocessing and analysis were conducted using Fieldtrip Toolbox (Oostenveld, Fries, Maris, & Schoffelen, 2011). Data were re-referenced offline to the average of the two mastoids. Epochs were extracted from 200 ms before to 800 ms after the onset of the Go/NoGo cue, resulting in 1000-ms epochs. Trials with drifting, ocular, or motor artifacts were rejected before analysis. Independent component analysis was conducted to remove the effects of blinks and eye movements. Remaining trials with EEG voltages exceeding 70 μV measured from peak to peak at any channel were also removed.

2.5. ERP amplitude analysis

To compute the ERPs, artifact-free EEG segments were averaged separately for each of the four experimental conditions using as baseline the 200-ms period preceding the Go/NoGo cue. The resulting ERP waveforms were evaluated statistically using the cluster-based random permutation method implemented in Fieldtrip (Maris & Oostenveld, 2007). This statistical method deals with multiple comparisons in space and time by identifying, over the whole ERP segment (here, 32 sample points: 500 time points, from 200 ms prior to 800 ms after cue signal onset, and 64 channels), clusters of significant differences between conditions (sample points in close spatial and temporal proximity) while effectively controlling for type I error.

The RIN hypothesis predicts an interaction between sentence polarity and Go/NoGo cue. Accordingly, our application of the cluster-based randomisation approach aimed to identify temporo-spatial ERP clusters in which this interaction reached significance. Since the randomisation approach is only applicable to pair-wise
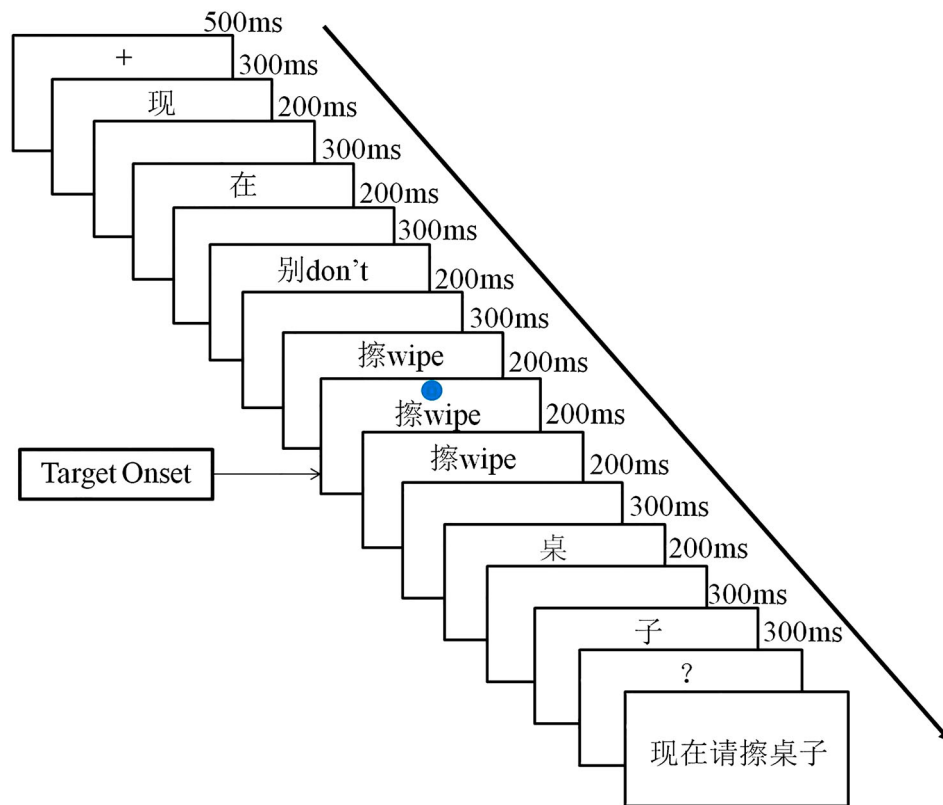
Figure 1. Flow chart of a NoGo trial. EEG recording started at the beginning of the task and ended when participants finished the whole task. ERPs were obtained between 200 ms prior and 800 ms after the onset of the target. The approximate English translation of the sample trial is "Now don't wipe the table". The listed recognition question, a polarity-modified version of the trial, can be translated as "Now please wipe the table".

comparisons, affirmative minus negative difference waveforms were calculated for each cue condition separately and then compared statistically. Next, to explore the whole design, the significant temporo-spatial clusters were submitted to further analyses. More specifically, for each participant and condition, a single amplitude value was obtained by averaging the temporal and spatial points that made up the identified clusters, and submitting this to a two-way, repeated measures ANOVA with two cue (Go, NoGo) and polarity (affirmative, negative) as within-subject factors.

2.6. Source localisation analyses

To estimate the likely generator for the interactive effect of the ERPs, source localisation was performed using the standardised low-resolution electromagnetic tomography (sLORETA). The sLORETA is a functional imaging method based on certain electrophysiological and neuroanatomical constraints; the cortex has been modelled as a collection of volume elements (voxels) in the digitised Montreal Neurological Institute (MNI) coordinates corrected to the Talairach coordinates (Pascual-Marqui, 2002). For each participant, sLORETA images

corresponding to ERP components with significant differences were defined as the mean current density values for the time window of interest and were corrected for multiple comparisons. Statistically significant difference was set to $p < 0.05$.

3. Results

3.1. Behavioural results

3.1.1. Go/NoGo task

Go-trial reaction times in milliseconds were analysed after removing outliers with scores three SDs above the participants' mean (∼1% of Go trials). Sentence polarity did not produce significant effects on reaction times (affirmative: $M = 350.0$, $SD = 37.4$; negative: $M = 347.3$, $SD = 39.5$; $t(22) = 1.617$, $p = 0.12$). There was no significant polarity difference on either omission rates in Go trials (affirmative: $M = 2.6\%$, $SD = 3.0\%$; negative: $M = 2.0\%$; $SD = 2.3\%$; $t(22) = 1.100$, $p = 0.283$) or commission rates in NoGo trials (affirmative: $M = 5.2\%$, $SD = 6.9\%$; negative: $M = 5.3\%$; $SD = 6.8\%$; $t(22) = -0.120$, $p = 0.906$). However, there was a main effect of cue on error rates ($F(1, 22) = 4.632$, $p = 0.042$, $\eta_p^2 = 0.168$),

Table 3. Performance in the recognition task.

		Affirmative	Negative
Go	RT	890.4 (263.2)	958.3 (309.0)
	ER	4.3 (4.7)	7.8 (5.0)
NoGo	RT	942.1 (292.6)	1012.2 (352.9)
	ER	6.5 (6.6)	9.1 (10.9)

Mean reaction times (RTs) in milliseconds and error rates (ERs) as a function of cue (Go/NoGo) and polarity (affirmative/negative). SDs are shown in parentheses.

namely, commission errors for NoGo trials ($M = 5.2\%$; SD $= 6.8\%$) were more frequent than omission errors for Go trials ($M = 2.3\%$; SD $= 2.6\%$).

3.1.2. Recognition task

Participants' performance in the recognition task is shown in Table 3. There was a main effect of cue on reaction times ($F(1, 22) = 15.314$, $p < 0.001$, $\eta_p^2 = 0.410$), with responses faster for Go than for NoGo trials, but not on error rates ($F(1, 22) = 1.880$, $p = 0.184$, $\eta_p^2 = 0.079$). Polarity produced significant effect on reaction times ($F(1, 22) = 7.561$, $p = 0.012$, $\eta_p^2 = 0.256$), with response faster for affirmative than for negative trials, but not on error rates ($F(1, 22) = 4.126$, $p = 0.054$, $\eta_p^2 = 0.158$). According to subsequent pair-wise t-tests: (1) responses were faster for affirmative sentences than for negative sentences in Go trials ($t(22) = -4.402$, $p < 0.001$), but did not differ for NoGo trials ($t(22) = -1.817$, $p = 0.083$); (2) affirmative sentences produced fewer errors than negative sentences in Go ($t(22) = -3.969$, $p < 0.001$) but not in NoGo condition ($t(22) = -0.976$, $p = 0.338$).

3.2. ERP results

Figure 2 displays waveforms (panel A) and scalp distributions (panel B) of the ERP activities analysed with the cluster-based random permutation procedure. Analyses of the main effect of cue produced a significant cluster (Tmaxsum $= 1294$, $p < 0.001$) ranging from 202 ms to

500 ms after cue onset with a fronto-central distribution, covering the time windows of both N2 and P3 components of the Go/NoGo task, demonstrating that the Go/NoGo task was working appropriately in our dual-task paradigm. Tests on the cue × polarity interaction effect resulted in one significant cluster ($p < 0.05$). This cluster extended between 226 and 290 ms, showing a slightly left-lateralized fronto-central distribution. The subsequent cue × polarity ANOVA for this cluster yielded significant effect of cue ($F(1, 22) = 26.91$, $p < 0.001$, $\eta_p^2 = 0.568$), revealing more negative amplitude for NoGo trials than for Go trials. The timing and the scalp distribution of this effect, along with the direction of the difference, were consistent with the extensively reported enhanced N2 activity for NoGo conditions (Johnstone et al., 2007; Jonkman, Lansbergen, & Stauder, 2003; Kaiser et al., 2003; Maguire et al., 2009). There was also a cue × polarity interaction effect ($F(1, 22) = 16.83$, $p < 0.001$, $\eta_p^2 = 0.433$), specifically, N2 amplitudes were smaller for negative trials ($M = -1.63$, SE $= 0.47$) than affirmative trials ($M = -0.62$, SE $= 0.45$) in the NoGo condition ($t(22) = 2.96$, $p = 0.007$), but did not differ in Go condition (Ms $= 1.34$ and 1.07, SEs $= 0.63$ and 0.61, $t(22) = 1.34$).

In sum, ERP activity of the N2 component discriminated between inhibition (NoGo) and non-inhibition (Go) trials, with N2 amplitudes larger in NoGo than in Go condition. More importantly, reduced N2 amplitudes were detected for NoGo-negative relative to NoGo-affirmative trials, thus confirming the interaction effect between cue and polarity predicted by the RIN hypothesis.

3.3. Source localisation results

To better understand the neural processes underlying the interactive inhibition–related effects obtained for
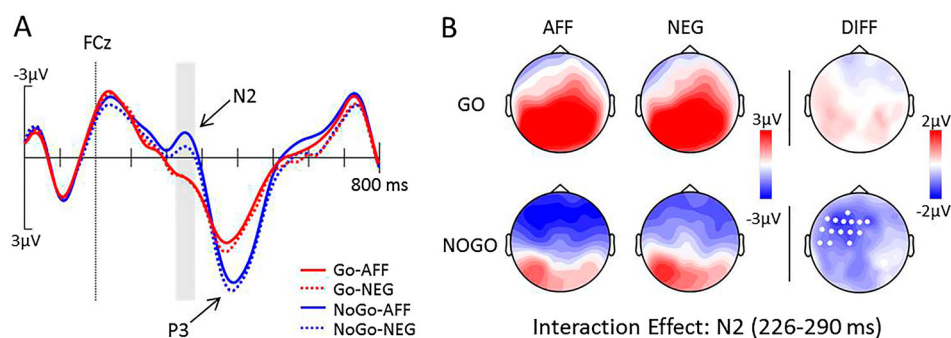
Figure 2. Event-related potentials: (A) Waveforms in one representative electrode (FCz) of the main effect of cue (Go vs. NoGo) in N2 and P3 time windows indicated by the arrows, and the cue × polarity interaction effect in the N2 time window (226–290 ms) identified by cluster-based random permutation analysis and shown here as gray-shaded area; (B) Scalp distributions of the ERP activity in the N2 time window for all cue × polarity conditions (Go-affirmative, Go-negative, NoGo-affirmative and NoGo-negative) with difference between polarity conditions shown on the right side (the white dots correspond to the electrodes with significant differences).

Structure	t-value	MNI coordinates (x, y, z)	Brodmann area
Inferior parietal lobule	4.03	40, −50, 60	BA 40

the N2 component, standardised low-resolution electromagnetic tomography analysis (sLORETA) was conducted to localise the source of the current densities occurring in the N2 time window in three-dimensional space within the brain. There was a significant cue × polarity interaction effect on current densities in the N2 time window, with activations being stronger in NoGo-affirmative than in NoGo-negative condition. This difference was maximum at the right inferior parietal lobule (rIPL) in BA 40 as shown in Table 4 and marked in yellow in Figure 3.

4. Discussion

The present study was conducted to test the robustness and generalizability of the RIN hypothesis in Mandarin. Participants read to comprehend both affirmative and negative sentences describing manual actions in Mandarin while performing an embedded Go/NoGo task. The results supported that the RIN hypothesis also applies to the comprehension of action-related negation in Mandarin. First, there was an interaction effect of Go/NoGo cue and sentence polarity on N2 amplitudes, a typical indicator of response inhibition (Bokura, Yamaguchi, & Kobayashi, 2001; Kok, 1986). Specifically, reduced N2 was detected for NoGo-negative compared to NoGo-affirmative sentences. Furthermore, brain source estimation of the N2 interaction effect revealed that the main source of difference was the rIPL, a brain

region frequently reported as being involved in the inhibitory control network (Garavan, Ross, & Stein, 1999; Goldstein et al., 2007; Nakata et al., 2008; Rubia et al., 2001).

To clarify the modulatory effect of sentential negation on response inhibition, some purely linguistic factors should be excluded. First, sentence length should not be an influential factor, because the words in the affirmative and negative sentences were the same except for the polarity operator. Second, the N2 difference in NoGo condition could not be attributed to the distinctive features of the verbs, because the verbs were the same and the assignment of either affirmative or negative polarity to the verbs was counterbalanced across participants, for both Go (Go-affirmative and Go-negative) and NoGo (NoGo-affirmative and NoGo-negative) trials. Third, the polarity effect on NoGo N2 was unlikely due to the complexity of processing negative sentences, because negation neither slowed Go reaction time nor produced significant effect on Go N2 amplitudes, and its only influence on behavioural performance was delayed until the recognition task.

In typical Go/NoGo experiments, enhanced N2 component is found for NoGo compared to Go trials, so N2 is traditionally viewed as an index of response inhibition (Bokura et al., 2001; Kok, 1986). Moreover, a positive correlation between NoGo N2 amplitude and the difficulty in inhibiting the prepotent response has been reported (Benikos et al., 2013). In the current study, N2 amplitude was found to be smaller in NoGo-negative compared to NoGo-affirmative condition. Given the fact that the NoGo cue in our study was preceded by the polarity operator and the verb, a likely explanation for the modulatory effect of polarity on NoGo N2 amplitude is that negation presets an inhibitory state by reusing the inhibitory
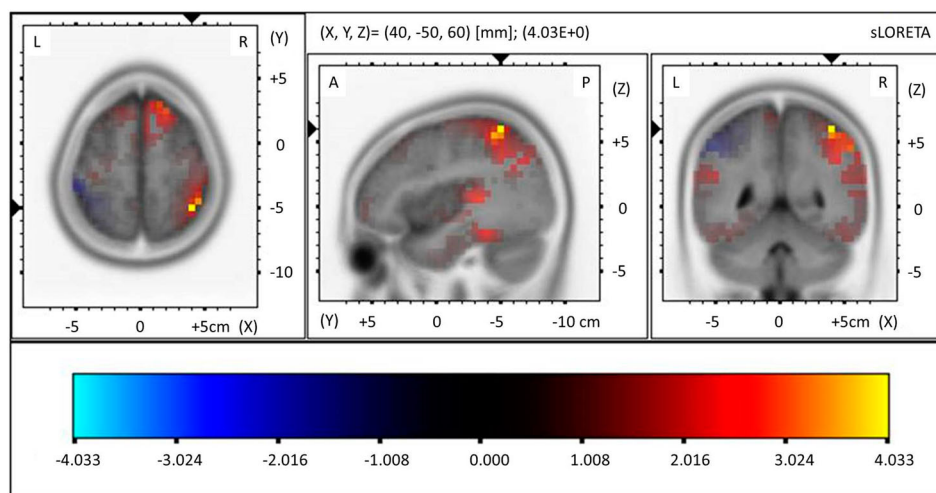
Figure 3. Brain source estimation corresponding to the cue × polarity interaction in the inhibition-related N2 component. The yellow area represents the brain spatial localisation of the N2 source in the right inferior parietal lobule (rIPL).

control mechanism, thus reducing the inhibitory demand of the NoGo cue in NoGo-negative compared to NoGo-affirmative condition. In other words, sentential negation "primes" subsequent response inhibition, lowering the inhibitory load as reflected in reduced N2.

In addition, the brain source estimation of the N2 interaction effect revealed stronger activation in rIPL for NoGo-affirmative relative to NoGo-negative sentences. Neuroimaging studies support the important functional role of rIPL in the inhibitory control network by reporting its recruitment in the inhibition conditions of both Go/NoGo and stop-signal tasks (Garavan et al., 1999; Goldstein et al., 2007; Nakata et al., 2008; Rubia et al., 2001). Note that the N2 effect in the current study corresponds to the inhibitory process induced by the NoGo cue. Therefore, the modulation of sentence polarity on the N2 source activation could also be explained by the facilitation effect of negation on subsequent response inhibition. Specifically, negation primes the NoGo cue and decreases its inhibitory demand, possibly by pre-activating the inhibitory control mechanism, leading to reduced N2 and lower activation in the inhibition-related rIPL for NoGo-negative condition compared to NoGo-affirmative condition. Taken together, the N2 interaction effect and its estimated source in the inhibition-related rIPL confirm the robustness and generalizability of the RIN hypothesis that comprehension of negation reuses the inhibitory control mechanism, extending its functional scope from alphabetic Indo-European languages to logographic Mandarin.

Concerning the behavioural results, sentence polarity did not yield any significant effect on either Go reaction times or Go/NoGo error rates in the Go/NoGo task due to a virtual ceiling effect. These could help to rule out the possibility that the cue × polarity interaction effect obtained in the current study was due to the complexity of the online processing of negative sentences. By contrast, interactive effects of cue and polarity were detected in the recognition task: performance was better for Go-affirmative than for Go-negative trials but did not differ for NoGo trials, indicating in the former a long-term effect of the conflict between the negation-related inhibition and the Go cue, which persist even after producing the motor response.

Our results are compatible with the findings of de Vega et al. (2016). Adopting a similar embedded Go/NoGo paradigm and Spanish imperatives as stimuli, they found reduced theta oscillations for NoGo-negative compared to NoGo-affirmative trials and interpreted this modulatory effect arguing that negation presets response inhibition reducing the inhibitory demand of the incoming NoGo cue. Given that both theta power

and N2 component are accepted indicators of response inhibition (Bokura et al., 2001; Harper, Malone, & Bernat, 2014; Huster, Enriquez-Geppert, Lavallee, Falkenstein, & Herrmann, 2013; Smith, Johnstone, & Barry, 2008), the two studies converge to support the RIN hypothesis that processing negation reuses the inhibitory control mechanism. The behavioural results in the recognition task of the two studies are also consistent; namely, both studies obtained better performance for Go-affirmative than Go-negative trials whereas did not find any difference between NoGo-affirmative and NoGo-negative conditions.

In de Vega et al.'s study, the source estimation of the theta difference between NoGo-negative and NoGo-affirmative conditions did not yield any significant cluster, whereas in this study we provided additional evidence by localising our N2 interaction effect in the rIPL, a well-known inhibition-related region. Notably, we did not find any interactive effect in frontal regions, such as LMFG and rIFG, which play critical roles in the inhibitory control mechanism (Chambers et al., 2009; Nakata et al., 2008; Zheng et al., 2008). There are at least two possible reasons for this absence of effects. The first one is purely technical; the source estimation algorithms applied to EEG data do not provide the detailed neuroanatomical information obtained with the neuroimaging techniques employed in the above studies, and the neural activity in some regions simply cannot be revealed. The second possibility is more theoretical and was mentioned in the introduction; reading Mandarin characters partially utilises the inhibition-related regions LMFG and rIFG, and these neural resources become less available to process sentential negation in this language while performing the embedded Go/NoGo task. However, the inhibitory control mechanism consists of a widely distributed network besides the frontal cortex (Nakata et al., 2008), so that other inhibitory resources could still be available to process negation and response inhibition. The modulation of the rIPL activation by negative sentences in the context of inhibitory control (NoGo trials) reported here, confirms that the RIN hypothesis is also valid to explain the processing of negation in Mandarin.

Despite the different linguistic features and processing mechanisms of Indo-European languages and Mandarin, our findings are consistent with previous studies testing the RIN hypothesis (Beltrán et al., 2018, 2019; de Vega et al., 2016), and thus contribute to supporting the idea that the neural processes underlying linguistic negation are universal. The connection between imperative negation and response inhibition in both Mandarin and Indo-European languages can be traced back to the early stage of language acquisition, when a mother

might use negative imperatives like "don't touch that" to stop her child from doing some dangerous things (Austin, Theakston, Lieven, & Tomasello, 2014; Wode, 2008). Therefore, the pragmatic function of negative imperatives might be learnt during childhood as stop signals leading to suppression of actions. The frequent co-occurrence of imperative negations and response inhibition may strengthen the connections between brain regions involved in the lexical representation of negation and those in charge of response inhibition (de Vega et al., 2016), which could explain the N2 modulation and its source localisation in the inhibition-related rIPL in the current study.

Further research using neuroimaging techniques would be necessary to examine in detail the neural mechanism shared by sentential negation and inhibitory control, shedding additional light on the roles played by both the motor and the inhibitory control network in sentential negation. Also, the RIN hypothesis must be tested beyond verb phrases or sentences, employing other semantic domains, such as existential negation (e.g. there is no bread). This would help to clarify whether a general-purpose inhibitory control mechanism, rather than one specific for verbs, is operating in the comprehension of sentential negation.

5. Conclusions

In conclusion, this research examined the robustness and generalizability of the RIN hypothesis in the context of Mandarin action-related language. The RIN hypothesis was supported by the modulation of sentential negation on NoGo N2 amplitudes and the corresponding brain source, namely, reduced N2 was detected in NoGo-negative compared to NoGo-affirmative condition and the estimated source for this effect is the inhibition-related rIPL.

Disclosure statement

No potential conflict of interest was reported by the authors.

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