frontiers | Research Topics

# Language embodiment, interdisciplinary methodological innovations, volume II

**Edited by**
Connie Qun Guan, Laura M. Morett
and Huili Wang

**Published in**
Frontiers in Psychology
Frontiers in Communication

ISSN 1664-8714
ISBN 978-2-8325-3385-7
DOI 10.3389/978-2-8325-3385-7

## About Frontiers

Frontiers is more than just an open access publisher of scholarly articles: it is a pioneering approach to the world of academia, radically improving the way scholarly research is managed. The grand vision of Frontiers is a world where all people have an equal opportunity to seek, share and generate knowledge. Frontiers provides immediate and permanent online open access to all its publications, but this alone is not enough to realize our grand goals.

## Frontiers journal series

The Frontiers journal series is a multi-tier and interdisciplinary set of open-access, online journals, promising a paradigm shift from the current review, selection and dissemination processes in academic publishing. All Frontiers journals are driven by researchers for researchers; therefore, they constitute a service to the scholarly community. At the same time, the *Frontiers journal series* operates on a revolutionary invention, the tiered publishing system, initially addressing specific communities of scholars, and gradually climbing up to broader public understanding, thus serving the interests of the lay society, too.

## Dedication to quality

Each Frontiers article is a landmark of the highest quality, thanks to genuinely collaborative interactions between authors and review editors, who include some of the world's best academicians. Research must be certified by peers before entering a stream of knowledge that may eventually reach the public - and shape society; therefore, Frontiers only applies the most rigorous and unbiased reviews. Frontiers revolutionizes research publishing by freely delivering the most outstanding research, evaluated with no bias from both the academic and social point of view. By applying the most advanced information technologies, Frontiers is catapulting scholarly publishing into a new generation.

## What are Frontiers Research Topics?

Frontiers Research Topics are very popular trademarks of the *Frontiers journals series*: they are collections of at least ten articles, all centered on a particular subject. With their unique mix of varied contributions from Original Research to Review Articles, Frontiers Research Topics unify the most influential researchers, the latest key findings and historical advances in a hot research area.

Find out more on how to host your own Frontiers Research Topic or contribute to one as an author by contacting the Frontiers editorial office: frontiersin.org/about/contact

# Language embodiment, volume II: Interdisciplinary methodological innovations

**Topic editors**
Connie Qun Guan — Beijing Language and Culture University, China
Laura M. Morett — University of Missouri, United States
Huili Wang — Dalian University of Technology, China

**Citation**
Guan, C. Q., Morett, L. M., Wang, H., eds. (2023). *Language embodiment, volume II: Interdisciplinary methodological innovations*. Lausanne: Frontiers Media SA.
doi: 10.3389/978-2-8325-3385-7

# Table of contents

frontiers | Frontiers in Psychology

TYPE Editorial
PUBLISHED 11 August 2023
DOI 10.3389/fpsyg.2023.1251549



OPEN ACCESS

EDITED AND REVIEWED BY
Xiaolin Zhou,
Peking University, China

*CORRESPONDENCE
Laura M. Morett
✉ lmorett@health.missouri.edu

RECEIVED 01 July 2023
ACCEPTED 07 July 2023
PUBLISHED 11 August 2023

CITATION
Morett LM (2023) Editorial: Language embodiment, volume II: interdisciplinary methodological innovations.
*Front. Psychol.* 14:1251549.
doi: 10.3389/fpsyg.2023.1251549



# Editorial: Language embodiment, volume II: interdisciplinary methodological innovations

Laura M. Morett[1,2]*

[1]Department of Educational Studies in Psychology, Research Methodology, and Counseling, University of Alabama, Tuscaloosa, AL, United States, [2]Department of Speech, Language and Hearing Sciences, University of Missouri, Columbia, MO, United States

KEYWORDS

**language embodiment, research methods, event-related potential (ERP), eye-tracking, self-paced reading, transcranial magnetic stimulation, neuropsychology, emotion**

Editorial on the Research Topic
Language embodiment, volume II: interdisciplinary methodological innovations

This Research Topic expands upon the Research Topic *Language Embodiment: Principles, Processes, and Theories for Learning and Teaching Practices in Typical and Atypical Readers*. Like its predecessor, this Research Topic maintains that the body plays a central role in influencing language processing (Glenberg and Kaschak, 2003). In particular, this Research Topic showcases methodologically innovative work on diverse topics providing support for embodiment in language processing.

Real-time measures of reading provide insight into ease and depth of processing for text conveying content consistent with embodied experience in comparison to text conveying content inconsistent with embodied experience. Using self-paced reading, Liao et al. examined processing of the innovative *Bei* construction in Mandarin, which intrinsically activates negative constructional meaning via embodied social grounding. Phrases conveying the negative constructional meaning of the innovative *Bei* construction were read more quickly than phrases conveying the partial literal meaning of the innovative *Bei* construction and unrelated phrases, indicating that its comprehension is facilitated via construction-based processing. Using eye-tracking, Wang et al. investigated English cataphora resolution by Chinese English as a foreign language (EFL) learners by varying the gender of the first potential antecedent. Reading times for the first potential antecedent were longer when it was congruent than incongruent in gender with the cataphoric pronoun. These results provide evidence that Chinese EFL learners prioritize lexical over syntactic cues in English sentence comprehension, indicating increased reliance on embodied experience. Jia et al. used eye-tracking and key logging to examine the influence of anxiety on translation to and from English in Chinese EFL learners. Both the eye-tracking measures of fixation count and duration and the key logging measures of pause count and duration were higher for forward (Chinese-English) than for backward (English-Chinese) translation, and fixation duration and pause count were positively correlated with Beck Anxiety Inventory scores for both directions of translation. Finally, Zheng and Wang used eye-tracking to probe the influence of positive affect from pun comprehension on ongoing cognitive processing. Although reading times for salient homophones were read faster in congruent control sentences than less salient homophones in sentences with homophone puns, regressions from the homophone and sentence final regions were more likely in congruous control sentences than sentences with homophone puns, and sentence reading time was negatively correlated with humor ratings. Taken together, the results of Jia et al. and Zheng and Wang provide evidence that embodied affect exerts a powerful influence on language processing, consistent with the tenets of embodied theories of language processing (Foolen, 2012).

Valence categorization provides insight into the impact of explicit embodied affective processing on language comprehension. Zhang and Fan used a priming paradigm to illuminate the effects of hot (i.e., emotion-related) and cold (i.e., non-emotion-related) executive function on language switch costs during Chinese-English emotional word categorization. Larger language switch costs were observed when primes and targets were congruent rather than incongruent in emotion and for negative than positive emotional words when primes and targets were congruent in emotion, as well as for participants with high than low inhibitory control for negative target words congruent with primes. Tang et al. compared categorization of emotion-label (i.e., words labeling emotional states) and emotion-laden (i.e., words evoking emotions via connotation) words in Chinese and English by Chinese-English bilinguals. Facilitated processing of emotion-label over emotion-laden words in both Chinese and English was observed, and only negative English emotion-laden words were not processed more quickly than neutral words. Together, these findings of these two studies provide further evidence of the strength of the influence of embodied affect on language processing, providing additional support for embodied theories of language processing.

Event-related potentials (ERPs) provide evidence of implicit sensitivity to content eliciting embodied experience conveyed via language that may not be evident in behavioral measures such as responses and reading times. Gu et al. investigated how new words learned with connotations of disgust and sadness expressed via faces are integrated into sentences conveying disgust and sadness. A larger negative waveform was observed for sad than disgusting words in the 146–228 ms time window, whereas a larger positive waveform and greater current densities in emotion- and language-related brain structures were observed for emotionally congruent than incongruent trials in the 304–462 ms time window. Shen et al. compared processing of Chinese and English scientific metaphors by Chinese-English bilinguals. Relative to Chinese scientific metaphors, English scientific metaphors elicited a larger N400, a smaller late positive component (LPC), and a larger late negativity. Cao et al. examined processing of pictorial metaphors in conjunction with their verbalizations. A larger posterior P300 was observed for pictorial juxtapositions in conjunction with verbal metaphors of the structure A is like B and for literal images in conjunction with verbal metaphors of the structure A is B than for other combinations. Considered as a whole, these findings provide new insight into the neural bases of emotion and metaphor processing, contributing to the substantial and growing literature on this topic (Buccino et al., 2016).

Neurostimulation and neurological disorders provide causal evidence for the role of neural structures in embodied language processing. Vitale and de Vega used low-frequency repetitive transcranial magnetic stimulation to demonstrate that primary motor cortex, but not primary visual cortex, subserves memory for action language processing. Phillips et al. examined comprehension and production of tactile metaphors by an individual born without somatosensation and found that it was comparable to that of individuals with typical somatosensation. These findings challenge strong views of embodied cognition positing that direct sensory experience enables somatosensory simulation, which is necessary to comprehend and produce tactile metaphors. Together, these studies demonstrate how causal data permits conclusions about how the brain enables simulation of embodied experience during language processing.

In summary, the articles in this Research Topic leverage a variety of innovative methods to provide evidence of the body's influence on language processing, complementing other recent work that does so (Tian et al., 2020; Morett et al., 2021; Herbert, 2022). In doing so, they contribute to the advancement of the understanding of embodied cognition, particularly with respect to language processing, as well as the methodological repertoire used to advance it. Thus, they provide methodological inspiration for future research on embodied language processing, broadening the methodological scope used to reveal how sensorimotor experience influences written and spoken language processing.

## Author contributions

The author confirms being the sole contributor of this work and has approved it for publication.

## Acknowledgments

The author acknowledges her co-editors for their efforts co-editing this Research Topic.

## Conflict of interest

The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

## Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

## References

Buccino, G., Colagè, I., Gobbi, N., and Bonaccorso, G. (2016). Grounding meaning in experience: a broad perspective on embodied language. *Neurosci. Biobehav. Rev.* 69, 69–78. doi: 10.1016/j.neubiorev.2016.07.033

Foolen, A. (2012). The relevance of emotion for language and linguistics: moving ourselves, moving others: motion and emotion in intersubjectivity. *Conscious. Lang.* 12, 349–369. doi: 10.1075/ceb.6.13foo

Glenberg, A. M., and Kaschak, M. P. (2003). "The body's contribution to language," in *Psychology of Learning and Motivation*, ed B. H. Ross (Cambridge, MA: Academic Press), 93–126.

Herbert, C. (2022). Early, emotional and embodied? Processing of emotional words and body words in the native and a second language–evidence from early event-related brain potential modulation and rapid serial visual presentation. *Lang. Cogn. Neurosci.* 22, 1–28. doi: 10.1080/23273798.2022.2137210

Morett, L. M., Fraundorf, S. H., and McPartland, J. C. (2021). Eye see what you're saying: contrastive use of beat gesture and pitch accent affects online interpretation of spoken discourse. *J. Experiment. Psychol. Learn. Memory Cogn*. 21, 986. doi: 10.1037/xlm0000986

Tian, L., Chen, H., Zhao, W., Wu, J., Zhang, Q., De, A., et al. (2020). The role of motor system in action-related language comprehension in L1 and L2: an fMRI study. *Brain Lang.* 201, 104714. doi: 10.1016/j.bandl.2019.104714

frontiers | Frontiers in Psychology

TYPE Original Research
PUBLISHED 06 December 2022
DOI 10.3389/fpsyg.2022.1037525

# Comprehending scientific metaphors in the bilingual brain: Evidence from event-related potentials

Lexian Shen[1†], Xiaoguang Li[1†], Shaojuan Huang[1], Yanhong Huang[1], Xinyu Gao[1], Ziqing You[1], Zirun Mao[2] and Xuemei Tang[1]*

[1]School of Foreign Studies, Anhui Polytechnic University, Wuhu, China, [2]Jinling High School, Nanjing, China

While the processing mechanisms of novel and conventional metaphors were widely investigated in previous monolingual studies, little attention has been devoted to how metaphoric utterances are processed by the bilingual brain as well as how scientific context might modulate such processes. Using event-related potentials (ERPs), this paper investigates the way in which scientific metaphors are electrophysiologically processed in Chinese (L1) and English (L2), with the aim of investigating the different mechanisms for understanding metaphorical language in first (L1) and second (L2) languages. By time-locking the N400 and later LPC time windows, the research show how meaning integration differs between L1 and L2 at different stages when comprehending figurative language. We found that compared with Chinese scientific metaphors, English scientific metaphors elicited greater N400, smaller late positive component (LPC), and greater late negativity, and English literals elicited greater late negativity. Our findings suggest that the dynamics of processing figurative meaning in bilingual brains over time show a complex pattern, with language, context, inference and salience jointly modulating temporal dynamics and possible cerebral asymmetries, supporting the revised hierarchical model.

KEYWORDS

**scientific metaphors, bilingual, event-related potentials, N400, late negativity**



OPEN ACCESS

EDITED BY
Huili Wang,
Dalian University of Technology, China

REVIEWED BY
Ying Li,
Zhengzhou University,
China
Yue Wang,
Zhengzhou University,
China

*CORRESPONDENCE
Xuemei Tang
tangxuemei@ahpu.edu.cn

†These authors have contributed equally to this work and share first authorship

SPECIALTY SECTION
This article was submitted to Language Sciences, a section of the journal Frontiers in Psychology

RECEIVED 06 September 2022
ACCEPTED 16 November 2022
PUBLISHED 06 December 2022

CITATION
Shen L, Li X, Huang S, Huang Y, Gao X, You Z, Mao Z and Tang X (2022) Comprehending scientific metaphors in the bilingual brain: Evidence from event-related potentials.
*Front. Psychol.* 13:1037525.
doi: 10.3389/fpsyg.2022.1037525



## Introduction

Metaphors are often used in the scientific field to talk about a less familiar domain (e.g., *lymph*) with a more familiar domain (e.g., *police*). In the LYMPH IS POLICE metaphor, the systematic function parallelisms of patrolling (in our body and in a place) is formed across languages. Such linguistic pattern suggests that the use of concrete terms is quite practical to describe abstract even intangible scientific concepts.

According to previous studies (Tang et al., 2017a,b), the target and source domains in scientific metaphors (e.g., *The lymph is a policeman*) are from different contexts, namely, the scientific target (*lymph*) and the daily source (*policeman*). Consequently, retrieving the stored conceptual knowledge associated with scientific metaphors is much more demanding than retrieving knowledge of literal expressions. Besides, the processing of scientific metaphors might also involve a secondary integration of meaning compared with literal expressions.

Moreover, the processing of scientific metaphors may also involve a later conceptual mapping according to some psycholinguistic models. The structural-mapping model (Gentner, 1983) and the career of a metaphor model (Gentner and Wolff, 1997; Bowdle and Gentner, 2005) suggested the mapping process involves comparing similarities between the source and the target. Accordingly, with more complicated contexts and deeper integration for analogical inference, compared with conventional metaphors (e.g., *Books are friends*), scientific metaphors should show more clearly the slower and more difficult mapping process of metaphors due to the absence of well-defined associations between the two domains. For example, in "*The intervening lymph nodes can trap and destroy the cancer cells.*," the target concept LYMPH and the source concept POLICE are aligned by the predicate "*trap and destroy*," and therefore, the role played by the lymphatic system in the body's immune system "*lymph*" is described as the role played by the political system in a place.

Then, what is the basic mechanism underlying understanding scientific metaphors in L2 (second language) for late learners, and to what extent do they overlap with the mechanisms involved in scientific metaphor processing in L1 (first language)? According to the non-selective access/integrated view, words in the L2 should behave like low-frequency words in the L1 (Dijkstra et al., 1998; Lemhofer et al., 2008). However, according to the revised hierarchical model (Kroll and Stewart, 1994), it would be an unlikely possibility for late learners of L2 to process words in the similar way L1 learners do, and the mechanisms for processing words in L2 and L1 are quite different. At least, anecdotally, many L2 learners report using translation into L1 as a general heuristic for processing L2 words (van Der Meij et al., 2011), resulting in the switch cost (slower response latencies; Verhoef et al., 2009; Calabria et al., 2011).

Actually, the comparison between performance in L2 and that in L1 might be modulated by the frequency characteristics of the words in each language (Midgley et al., 2009). Exposure to L1 words is generally much higher than exposure to L2 words. Therefore, the subjective frequencies of L2 words might be lower than those of L1 words, which could be driving the behavioral effects. Furthermore, age-of-acquisition could be another factor (Wang and Chen, 2020), and L2 words are learned later than the majority of L1 words. Finally, the lexical-semantic connection between L2 words is much weaker than that between L1 words (Midgley et al., 2009; Naranowicz et al., 2022). In order to observe the modulation effects of the factors mentioned above, the current study adopted scientific metaphors as the target stimuli. Scientific terms used in scientific metaphors distinguish them from other kinds of metaphors. Generally speaking, either in L1 or L2, exposure to scientific words is lower than exposure to daily words; they are used and learned later than daily words; the interconnection between scientific words and daily words are weaker than that between different daily words.

The aim of the present study was to examine the neural mechanisms for bilingual speakers (L1 Chinese and L2 English) to process figurative language with scientific metaphors as the stimuli. Adopting scientific metaphors with complicated contextual structure and knowledge-inferencing process might be of more significance to show the difference between the processing of L1 and L2.

## Models for metaphor processing

According to the graded salience hypothesis (Giora, 2003), the time-course of meaning processing is mainly determined by the degree of meaning salience which refers to those meanings foremost in speakers' minds at time of speaking characterized by conventionality, prototypicality, familiarity, and frequency. The meaning of literal expressions is commonly salient, and is processed first in the left hemisphere. In contrast, for a novel or unfamiliar metaphor, the salient meaning is the literal one, and the figurative meaning is inferred later by contextual mechanisms and is processed mainly in the right hemisphere. In other words, how linguistic stimuli are processed is determined by the salience-non-salience continuum instead of the literal metaphoric distinction. This hypothesis predicts a later and right-hemisphere biased processing of nonsalient meanings (such as scientific metaphors in L1) and an earlier and left-hemisphere biased processing of salient meanings (such as literal expressions in L1).

The Fine-Coarse Semantic Coding Theory (Beeman, 1998, 2005) is another psycholinguistic theory that addresses hemispheric functions in semantic processing, which proposed that language is processed qualitatively differently by the two cerebral hemispheres. The right hemisphere loosely activates and maintains larger semantic fields containing more distant associates and more unconventional meanings (coarse semantic coding) whereas the left hemisphere focuses on a single dominant interpretation (fine semantic coding). Since the distance between the source and target domains is usually semantically longer than that for literal expressions, the theory predicts semantic processes in the right hemisphere may be more apt for scientific metaphor comprehension in L1.

More importantly, these two models might have some important implications when comparing L1 and L2 metaphor processing. For native speakers, a literal expression possesses a highly salient interpretation since native speakers have naturally encountered the expressions quite often in their daily life. Thus, on encountering a highly conventional expression, the left hemisphere engages in a fine coding and strong activation of small semantic fields. And for scientific metaphors, it might be of little difficulty for L1 speakers to understand the literal meaning of scientific metaphors. It might be difficult for them to achieve the mapping between the distant domains covering two different contexts and to make scientific inference to get some sort of new knowledge, probably involving a coarse processing of meanings in the right hemisphere.

However, for later learners of L2, the picture is more complicated. At the early stage of processing the meaning, the literal meaning of scientific metaphors may be less salient, resulting in relatively longer period of processing and stronger activation of the right hemisphere of coarse semantic coding. At the later stage of mapping and inference, it might be very difficult to deeply integrate the meaning in L2, probably resulting in delayed reintegration of meaning, stronger activation of the left hemisphere of fine semantic coding and the weaker activation of large and diffuse semantic fields in the right hemisphere.

## Event-related potentials (ERPs) and bilingual metaphor processing

The mean amplitudes of N400 were widely investigated to reveal the processing mechanism of metaphors. Previous studies show that N400 amplitudes are sensitive to semantic violations (Kutas and Hillyard, 1980) and are modulated by several variables on the mechanism of figurative language processing, such as familiarity, difficulty, context or task (Schmidt and Seger, 2009). Meanwhile, some bilingual ERP studies reported a modulation of N400 amplitudes by language (Newman et al., 2012; Heidlmayr et al., 2015), with L2 eliciting lower N400 compared with L1.

The late positive component (LPC) is considered to reflect integration or reprocessing at the sentence level (Kaan et al., 2000) and is found to be modulated by the degree of conventionality (Weiland et al., 2014) with novel metaphors eliciting greater LPCs than conventional metaphors and literal expressions. Other studies reported a late negativity overlapping in the LPC time window resulting in smaller LPCs elicited by novel metaphors compared with conventional metaphors indicating a sustained difficulty in fusing two concepts of the source domain and the target domain (Arzouan et al., 2007a,b; Goldstein et al., 2012; Rutter et al., 2012).

The feasibility of investigating the processing mechanism of scientific metaphors using amplitudes of N400 and late negativity was confirmed in our previous monolingual studies (Tang et al., 2017a,b). Compared with conventional metaphors and literal expressions, scientific metaphors and poetic metaphors elicited higher N400s reflecting the modulation of conventionality. More importantly, scientific metaphors elicited larger late negativity compared with poetic metaphors and conventional metaphors (Tang et al., 2017b).

Moreover, for the bilingual studies, N400 peak latency was also proved to be susceptible to biological and cognitive influences (Moreno et al., 2008). For example, a delay in N400 latency is associated with increasing the age of participants and increasing stimulus presentation rate (Midgley et al., 2009). Most of the studies examined the N400 event-related response with a semantic violation paradigm and reported a significant delay in its peak latency for L2 compared with L1 (Hahne and Friederici, 2001; Moreno and Kutas, 2005). For example, the peak latency of the N400 effect elicited by non-dominant language target word was significantly later (approximately 27 ms) than that elicited by dominant language target words (Moreno and Kutas, 2005). It appears that both the age of exposure to the language and the proficiency of the language are factors in the delay of the peak latency of the N400 response to semantic incongruities. However, the factors contributing to delays in the N400 response in bilinguals in their L2 vs. L1 demands further investigation because an early age of exposure does not always guarantee a fast response to semantic incongruity. Other modulations of N400 parameters such as amplitude, onset latency, and scalp distribution are not consistent across studies (Anna and Roberto, 2011; Mashal et al., 2015).

## The present study

While much research has been done on novel and conventional metaphor comprehension in the monolingual context, little attention has been devoted to how metaphoric utterances are processed by the bilingual brain as well as how scientific context might modulate such processes. The present study aims to investigate the electrophysiological correlates of scientific metaphor comprehension in intermediate Chinese-English bilingual speakers. Our predictions are as follows. In the N400 window, due to the complicated contextual structure, scientific metaphors, either English or Chinese, might elicit higher N400 reflecting higher cognitive load in retrieving the stored information for meaning integration. More importantly, there should be N400 differences when processing Chinese (L1) and English (L2) scientific metaphors due to the fact that the lexical-semantic connection of Chinese scientific metaphors is stronger than that of English ones for the native Chinese speakers. English scientific metaphor processing should show higher amplitude, longer latency, and right-biased activation when compared with Chinese ones.

In the LPC window, scientific metaphors might elicit more negative late negativity for further integration of meaning to achieve the later knowledge-understanding inference. Moreover, there should be different patterns of late components when processing Chinese (L1) and English (L2) scientific metaphors due to the fact that the L2 structure especially involving complicated reasoning tends to be processed in a different way with the L1 structure. Chinese scientific metaphors with looser semantic relations might elicit greater right hemisphere activity compared with literal expressions. However, it should be very difficult for deep-level reintegration of meaning to occur in L2. Thus, compared with Chinese scientific metaphor processing, English scientific metaphor processing should show lower amplitude, shorter latency, and left-biased activation.

## Experiment 1: Comprehension of scientific metaphors in native language (Chinese)

Experiment 1 was set up as a control experiment to examine whether subjects showed the same pattern when processing scientific metaphors in L2 as in L1.

### Participants

All participants were undergraduate students at Shaanxi Normal University who were paid for participation. Twenty-three (10 males, 13 females, average age 20.6) right-handed subjects spoke Chinese as their native language and started to learn English from elementary period. They have passed CET-4 but have not passed CET-6 (CET is a national test of English for non-English majors in China), which means their proficiency of English is not high. Past or present mental or neurological disorders or major head injury, or crime are exclusion criteria. Handedness was tested using the Edinburgh Handedness Scale (Oldfield, 1971). The resulting average score was above 40 ($M = 120.71$, SD = 36.67), which means all participants were right-handed (left-handedness: lower than-40; ambidexter: between-40 and 40). The local Human Participation Research Review Board approved the experimental criteria for the study. Prior to participation, each subject provided written informed consent. However, due to a lack of available trials (lower than 85% of the total 80 trials based on artifact detection), data from six subjects were not included in the analysis, resulting in a final sample size of 17 subjects (eight males and nine females).

### Stimuli

For experiment 1, the materials were from our previous study (Tang et al., 2017a), in which several pretests had been done on familiarity, metaphoricity, and meaningfulness (see Table 1).

The stimulus pool consisted of 80 sentences, all in Chinese (see Table 2 for examples), which fell into two categories: scientific metaphoric (SM) and daily literal (LT), with 40 sentences in each sentence category. Grammar and syntactic structures were matched across different categories by adopting the “X 是 (shi) Y” format in all sentences and the lengths of the target words were balanced between categories, thus excluding possible confounding factors such as sentence length or complex syntactic processing. The frequencies of the target words were tested through BCC Corpus (Xun et al., 2016). A paired sample t-test showed that there was no significant difference ($t = -1.93$, $p = 0.061$) of the frequencies between the target words of Chinese scientific metaphors ($M = 34032.9$, SD = 7032.32) and those of Chinese literal expressions ($M = 72092.1$, SD = 19377.3). In order to control the concreteness of the target words across categories, only words considered as concrete were selected as stimuli and 40 raters with similar educational backgrounds, English levels and ages to the participants were asked to judge whether each target word is concrete or not on a 1–7 scale (1 = highly abstract, 7 = highly concrete). A paired sample t-test showed that there was no significant difference ($t = -0.46$, $p = 0.648$) of the concreteness between the target words of scientific metaphors ($M = 5.3$, SD = 0.22) and those of literal expressions ($M = 5.36$, SD = 0.28). Several pretests of meaningfulness, figurativeness and familiarity were conducted in our previous study.

TABLE 1 The results of pretests.

| | Meaningfulness | | Figurativeness | | Familiarity | |
|---|---|---|---|---|---|---|
| | *M* | SD | *M* | SD | *M* | SD |
| SM | 3.5 | 0.6 | 3.3 | 0.24 | 2.85 | 0.59 |
| LT | 4.09 | 0.44 | 1.4 | 0.19 | 4.12 | 0.24 |

### Procedure

The experiment took place in a sound-attenuated, electrically shielded room. The sentences were presented in white color on a black background word by word in a quasi-random order. Stimuli on each trial were presented in the following time sequence: fixation cross (800 ms), blank (200–500 ms), subject (1,000 ms), verb (600 ms), blank (200–500 ms), object (1,000 ms) and question mark (3,000 ms). At the sight of the question mark, participants gave their judgments about whether the sentence was metaphoric or not by pressing a corresponding key with the right and left index fingers. Response period was limited to 3 s and was followed by a 1 s intertrial interval. The overall sequence of events for a trial is illustrated in Figure 1. Before the ERP experiment, in order to make sure that the academic knowledge involved in scientific metaphors could be understood during the experiment, participants firstly were asked to read a list of scientific terms, from which scientific metaphors were created, together with their brief explanations. Before the main session of the experiment, there was a brief practice session to familiarize the participants with the experimental procedure.

### Electrophysiological recording

Scalp voltages were collected with the CURRY 7 system (Compumedics Neuroscan, Texas, United States) with 64 Ag/AgCl electrodes, monitored by the CURRY recorder software and connected to a SynAmp amplifier (Compumedics Neuroscan, Texas, United States). Amplified analog voltages were digitized at 1,000 Hz. Impedances of individual sensors were kept below 5 kΩ. Eye movements were monitored through bipolar electrodes which were placed above and below the right eye, as well as at the left and right canthi. EEG was measured online with reference to the left mastoid, with a ground electrode on the medial frontal aspect, and later was analyzed offline with re-reference to an average of the left and right mastoids.

EEG was analyzed with the SCAN 4.5 software (Compumedics Neuroscan, Texas, United States) and Matlab using the ERPLAB toolbox (Lopez-Calderon and Luck, 2014). The EEG was digitally filtered at 0.1–30 Hz bandpass. Eye movements were corrected with an ocular artifact correction algorithm (Gratton et al., 1983). Artifacts with amplitudes exceeding ±75 μV were removed from analyses. ERPs were time-locked to the onset of the last word of the sentence and were obtained by stimulus-locked averaging of the EEG recorded in each condition. Epochs were 1,000 ms long with a 200 ms pre-stimulus baseline and the epochs baseline corrected using the-200–0 ms time window. The time windows of N400 (300–500 ms) and LPC (550–800 ms) were selected based on the Grand average ERP waveforms. Within these time intervals, the mean amplitude values of N400 and LPC as well as the 25% fractional area latency of N400 were determined. The resulting amplitudes of N400 and LPC as well as N400 latency values were entered into repeated measures analyses of variance (ANOVA). All ANOVA results were Greenhouse–Geisser corrected if assumption of sphericity was violated.

Event-related brain potentials were time-locked to the onset of the last word of the sentence. The resulting amplitudes of N400 were entered into 2 type (scientific metaphors, literal expressions) × 3 region (frontal F3, Fz, F4, central C3, Cz, C4, parietal P3, Pz, P4) × 3 hemisphere (left F3, C3, P3, midline Fz, Cz, Pz, right F4, C4, P4) three-way ANOVAs for repeated measures.

TABLE 2 Chinese sample stimuli.

| | | | |
|---|---|---|---|
| Scientific metaphors | 淋巴是警察。 | lin ba shi jing cha | Lymph is police. |
| | 电子是行星。 | dian zi shi xing xing | Electrons are planets. |
| | 导体是隧道。 | dao ti shi sui dao | Conductors are tunnels. |
| | 染色体是姐妹。 | ran se ti shi jie mei | Chromosomes are sisters. |
| | 病毒是杀手。 | bin du shi sha shou | Virus is killer. |
| Literal expressions | 教授是学者。 | jiao shou shi xue zhe | A professor is a scholar. |
| | 汉语是语言。 | han yu shi yu yan | Chinese is a language. |
| | 伦敦是城市。 | lundun shi cheng shi | London is a city. |
| | 蚂蚁是昆虫。 | ma yi shi kun chong | An ant is an insect. |
| | 小狗是宠物。 | xiao gou shi chong wu | The dog is a pet. |

## Results

### Behavioral performance

To achieve the target of this analysis, we calculated the mean response time for correct trials and the accuracy rate for each sentence type for each participant. A paired samples t-test revealed significant effects of type for both reaction times ($t = 3.7$, $p = 0.002$) and accuracy rates ($t = -3.66$, $p = 0.002$). Reaction times were longer for scientific metaphors ($M = 520.11$ ms, SD = 216.94 ms) than for literal expressions ($M = 459.55$ ms,

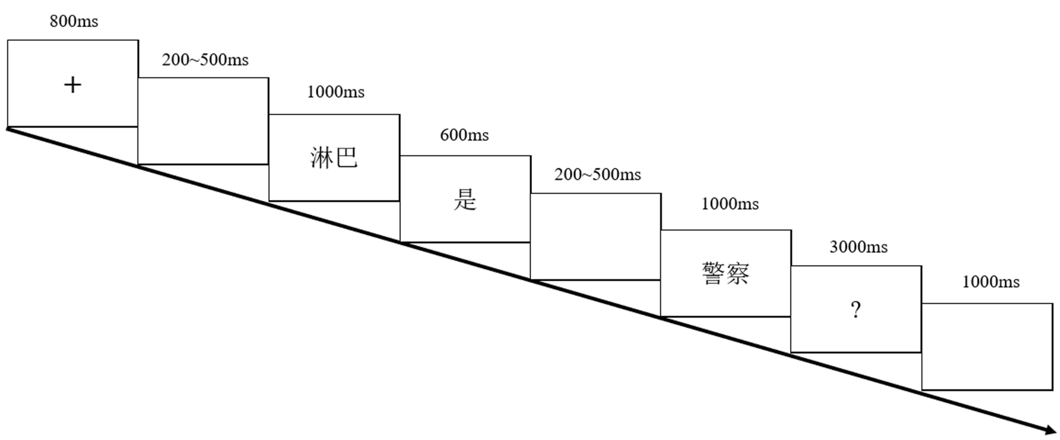


FIGURE 1
Experimental paradigm of experiment 1.

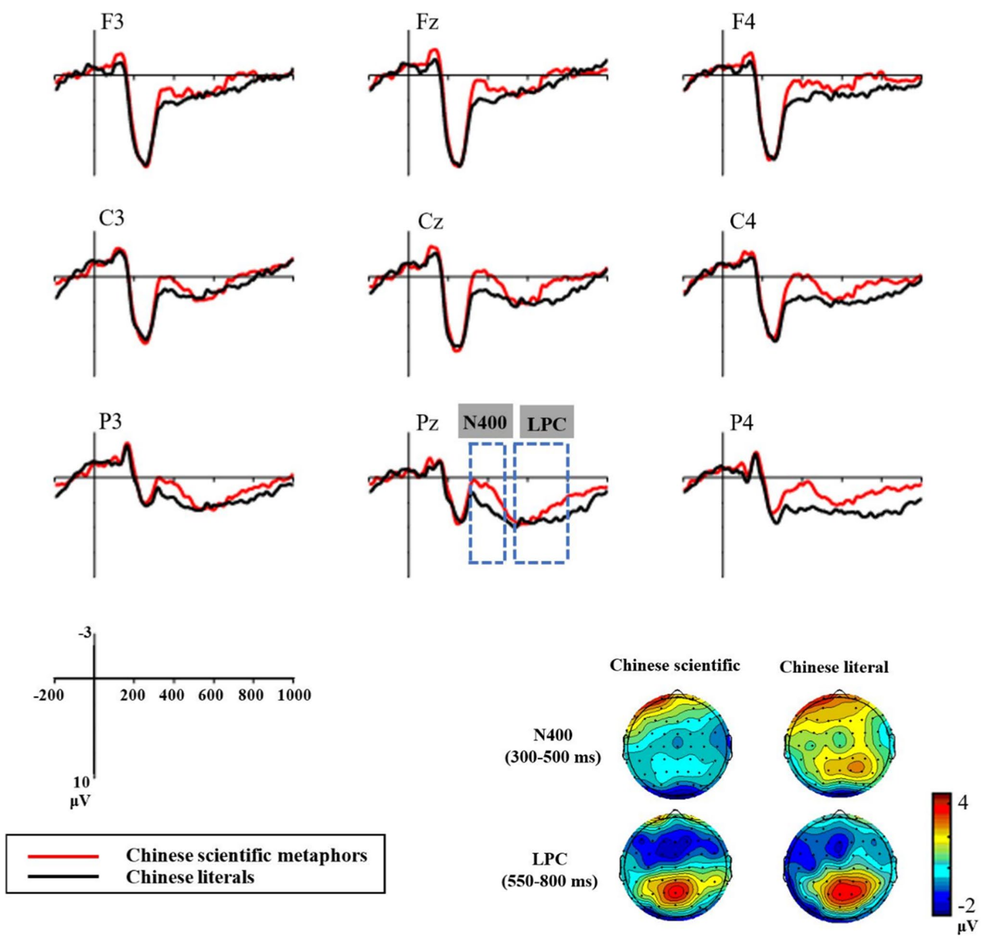


FIGURE 2
Grand average event-related potential (ERP) waveforms recorded at the 9 chosen electrodes of Chinese pairs.

SD = 186.75 ms). Accuracy rates were significantly lower for scientific metaphors ($M$ = 0.83, SD = 0.087) than for literal expressions ($M$ = 0.95, SD = 0.069).

## Electrophysiological data

In the time window of N400 (300 ~ 500 ms), the type (Chinese scientific metaphors, Chinese literal expressions) × region × hemisphere ANOVA revealed a significant main effect of type for amplitudes elicited by Chinese pairs [$F$ (1, 16) = 103.2, $p$ < 0.001, $\eta^2_p$ = 0.87]. Scientific metaphors elicited more negative N400 ($M$ = 0.55 μV, $SD$ = 3.37 μV) than literals ($M$ = 3.42 μV, SD = 3.2 μV; see Figure 2). For the N400 latency values, a similar repeated measures ANOVA revealed no significant main effect of type ($p$ = 0.381).

In the time window of LPC (550 ~ 800 ms), the type × region × hemisphere ANOVA revealed a significant main effect of type for Chinese pairs [$F$ (1, 16) = 9.09, $p$ = 0.008, $\eta^2_p$ = 0.36]. Consistent with Tang et al. (2017a), as shown in Figure 2, the ERPs of scientific metaphors ($M$ = 1.53 μV, SD = 3.94 μV) were less positive than those of literal sentences ($M$ = 3.15 μV, SD = 4.38 μV). There were significant type × region interactions [$F$ (2, 32) = 5.55, $p$ = 0.014, $\eta^2_p$ = 0.26]. Simple effect tests showed significant differences between scientific metaphors and literal sentences in the parietal and central regions [Parietal: $F$ (1, 16) = 11.37, $p$ = 0.004, $\eta^2_p$ = 0.42; Central: $F$ (1, 16) = 5.8, $p$ = 0.028, $\eta^2_p$ = 0.27] but not in the frontal region ($p$ = 0.42; See Figure 2).

# Discussion

The two main findings regarding N400 for the contextual factor and the late negativity for the knowledge-understanding inference factor are consistent with the findings of other studies (Tang et al., 2017a,b). From the conceptual blending view (Coulson and Van Petten, 2002; Yang et al., 2013), during the semantic processing to integrate these elements in metaphor comprehension, the amplitudes of N400 indicate the degree of difficulties in retrieving the stored conceptual knowledge. Consistent with previous studies (Rutter et al., 2012; Lai and Curran, 2013; Schneider et al., 2014), this study found that scientific metaphors elicited more negative N400s relative to literal expressions. Another possible explanation for these effects is the different salience between scientific metaphors and literal expressions. According to the graded salience hypothesis (Giora, 2003), the metaphoric meanings of scientific metaphors are less salient than the literal meanings which results in a more cognitive costly processing for meaning retrieving than literal expressions. In addition, consist with our previous study which reported higher N400 elicited by Chinese scientific metaphorical and literal expressions compared with Chinese daily literal expressions (Tang et al., 2016), the electrophysiological differences of N400s between Chinese scientific metaphors and Chinese literal expressions in present study might be related not only to metaphoric factor but also to scientific factor reflecting the modulation of complex scientific context of scientific metaphors.

Consistent with previous studies (Jankowiak et al., 2017, 2021; Tang et al., 2017a,b), scientific metaphors might elicit a more negative component partly overlapping in space and time with the LPC reducing the amplitudes of LPC. Such a late negativity might reflect secondary semantic integration processes of novel metaphors (Arzouan et al., 2007a,b; Goldstein et al., 2012; Rutter et al., 2012), showing a sustained reinterpretation process after an initial failure to reach meaning (Jiang et al., 2009) supporting the structural-mapping model (Gentner, 1983) and the career of a metaphor model (Gentner and Wolff, 1997; Bowdle and Gentner, 2005). Moreover, such electrophysiological differences of late negativity might be related to scientific factor consist with our previous study reflecting higher cognitive cost caused by the late knowledge-understanding inference of scientific language (Tang et al., 2016).

# Experiment 2: Comprehension of scientific metaphors in non-native language (English)

## Participants

The participants of Experiment 2 were the same as those of Experiment 1. In order to avoid the learning effects, experiment 2 was conducted 1 month later.

TABLE 3 English sample stimuli.

| | |
|---|---|
| Scientific metaphors | Lymph is police. |
| | Electrons are planets. |
| | Conductors are tunnels. |
| | Chromosomes are sisters. |
| | Virus is killer. |
| Literal expressions | A professor is a scholar. |
| | English is a language. |
| | London is a city. |
| | An ant is an insect. |
| | The dog is a pet. |

## Stimuli

The 80 English sentences form the stimulus pool and these sentences are the counterparts of the Chinese stimuli (see Table 3 for examples), which fell into two categories: literal and scientific metaphoric, with 40 sentences in each sentence category (Table 4). Similar to the pilot surveys we have done on the Chinese stimuli in our previous study used in Experiment 1 (Tang et al., 2017a), the English stimuli were tested by several groups of raters who did not participate in the ERP experiment. Only participants who had majored in a scientific discipline were selected so that they could avoid difficulties in understanding the scientific terms associated with the scientific metaphor categories (Table 4).

Firstly, 40 raters were asked to decide whether each English sentence is meaningful or not on a 1–3 scale (1 = not meaningful, 2 = somewhat meaningful, 3 = highly meaningful). According to the results of the meaningfulness judgment, sentences rated by at least 75% of the judges as metaphorically/literally plausible (>2.5) were selected as expressions with either a metaphoric or a literal meaning. Then those selected sentences were rated by another group of 40 raters on a 1–3 scale regarding their figurativeness (1 = not figurative, 2 = somewhat figurative, 3 = highly figurative). In the present study, literal expressions, i.e., expressions averaging less than 1.5, and scientific metaphors averaging greater than 2.5. Finally, we asked another group of 40 raters to rate these expressions on a 7-point familiarity scale ranging from 1 (highly unfamiliar) to 7 (highly familiar). Expressions scoring more than 4 on this scale were selected as scientific metaphors (mean rating 5.33) and literal expressions (mean rating 6.32).

The frequencies of the target words of those English stimuli were also tested through Brown Corpus. A paired sample t-test showed that there was no significant difference ($t = -0.99$, $p = 0.33$) of the frequencies between the target words of English scientific metaphors ($M = 77.08$ per million, SD = 25.9) and those of English literal expressions ($M = 106.98$ per million, SD = 28.45).

## Procedure

Experiment 2 was conducted following the same procedure of Experiment 1 but in English (see Figure 3).

## Electrophysiological recording

The electrophysiological recording of Experiment 2 was the same as that of Experiment 1.

## Results

### Behavioral performance

For the purposes of this analysis, we calculated the mean response time for correct trials and the accuracy rate for each

TABLE 4 Experimental materials.

| | English scientific metaphors | English literal expressions | Chinese scientific metaphors | Chinese literal expressions |
|---|---|---|---|---|
| 1 | A charge is flow. | A professor is a scholar. | 电荷是水流。 | 教授是学者。 |
| 2 | Lymph is police. | Chinese is a language. | 淋巴是警察。 | 汉语是语言。 |
| 3 | Conductors are tunnels. | A boss is a man. | 导体是隧道。 | 老板是富人。 |
| 4 | Chromosomes are sisters. | The Great Wall is a monument. | 染色体是姐妹。 | 丝绸是面料。 |
| 5 | Virus is killer. | Silk is fabric. | 病毒是杀手。 | 长城是古迹。 |
| 6 | Numbers are spouses. | Strawberries are fruits. | 数字是配偶。 | 草莓是水果。 |
| 7 | Sound is wave. | London is a city. | 声音是波浪。 | 伦敦是城市。 |
| 8 | A sequences is a queue. | Peking Opera is drama. | 数列是排队。 | 京剧是戏剧。 |
| 9 | Chemical bonds are springs. | Stamp collecting is a hobby. | 化学键是弹簧。 | 地震是灾害。 |
| 10 | Dendrites are antennae. | Michael is a writer. | 树突是天线。 | 老舍是作家。 |
| 11 | A capacitor is a container. | An ant is an insect. | 电容是容器。 | 蚂蚁是昆虫。 |
| 12 | Benzene is a snake. | Earthquakes are disasters. | 苯环是小蛇。 | 集邮是爱好。 |
| 13 | Functions are machines. | Buddhism is a religion. | 函数是机器。 | 佛教是宗教。 |
| 14 | The nucleus is the sun. | Mary is a student. | 原子核是太阳。 | 小明是学生。 |
| 15 | A carbon atom is a orange. | Running is exercise. | 碳原子是桔子。 | 跑步是运动。 |
| 16 | A cell is a factory. | Grandma is an old man. | 细胞是工厂。 | 奶奶是老人。 |
| 17 | Inertia is the bank. | Eggplant is a vegetable. | 惯性是银行。 | 茄子是蔬菜。 |
| 18 | Circuits are bridges. | Cooking is a chore. | 电路是桥梁。 | 做饭是家务。 |
| 19 | Gears are teeth. | Christmas is a festival. | 线粒体是密码。 | 春节是节日。 |
| 20 | A root sign is a hat. | The dog is a pet. | 根号是帽子。 | 小狗是宠物。 |
| 21 | The virus is a worm. | Ginseng is a medicinal material. | 电子云是马蜂群。 | 人参是药材。 |
| 22 | A motor is a squirrel cage. | Painting is art. | 电机是鼠笼。 | 绘画是艺术。 |
| 23 | Helium gas is a lazy man. | China is a country. | 气体是懒虫。 | 中国是大国。 |
| 24 | Triangles are containers. | Parents are workers. | 三角形是容器。 | 父母是工人。 |
| 25 | Atomic groups are collectives. | The teacher is a woman. | 原子团是集体。 | 教师是职业。 |
| 26 | Operations are traffic. | Mosquitoes are pests. | 运算是交通。 | 蚊子是害虫。 |
| 27 | An empty set is an empty classroom. | Rice is a staple food. | 空集是空教室。 | 大米是主食。 |
| 28 | The power is a cotton coat. | Sofas are furniture. | 次方是棉衣。 | 沙发是家具。 |
| 29 | Matter is the signal. | Dumplings are foods. | 物质是信号。 | 饺子是美食。 |
| 30 | The bolt is a fishtail. | Colds are diseases. | 作用力是爸爸。 | 感冒是疾病。 |
| 31 | Fractions are mother and child. | West Lake is a lake. | 分数是母子。 | 西湖是湖泊。 |
| 32 | A hydrogen atom is an apple. | Refrigerators are electronic equipments. | 氢原子是苹果。 | 沙发是家具。 |
| 33 | Chemical reaction is scuffle. | Air crashes are accidents. | 反应是混战。 | 空难是事故。 |
| 34 | The sign of absolute value is pants. | The Yangtze River is a river. | 绝对值是裤子。 | 李白是诗人。 |
| 35 | Electrons are planets. | Mosquitoes are pests. | 电子是行星。 | 蚊子是害虫。 |
| 36 | Glass is foam. | Coleridge is a poet. | 玻璃是泡沫。 | 长江是河流。 |
| 37 | Catalysts are stimulants. | Frank is a champion. | 催化剂是兴奋剂。 | 林丹是冠军。 |
| 38 | Energy is money. | New York is a city. | 能量是钱币。 | 西安是城市。 |
| 39 | Atoms are jujube cakes. | Trees are plants. | 原子是枣糕。 | 武警是军人。 |
| 40 | Collections are letterboxes. | Fingerprints are evidence. | 集合是信箱。 | 指纹是证据。 |

sentence type for each participant. A paired samples t-test revealed significant effects of type for accuracy rates ($t = -4.89$, $p < 0.001$). Accuracy rates were significantly lower for English scientific metaphors ($M = 0.84$, SD = 0.07) than for English literal expressions ($M = 0.85$, SD = 0.07). The difference in reaction times between scientific metaphors and literal expressions was not found to be significant ($p = 0.471$, SM: $M = 591.04$ ms, SD = 176.21 ms; LT: $M = 591.59$ ms, SD = 177.64 ms).

## Electrophysiological data

### 300~500ms

As shown in Figure 4, in the time window of N400 (300 ~ 500 ms), there were significant main effects of type (English scientific metaphors, English literal expressions) [$F$ (1, 16) = 62.26, $p < 0.001$, $\eta^2_p = 0.79$]. Scientific metaphors elicited more negative N400 ($M = -1.35$ μV, SD = 3.01 μV) than literal sentences ($M = 1.5$ μV, SD = 2.59 μV). For the N400

10.3389/fpsyg.2022.1037525

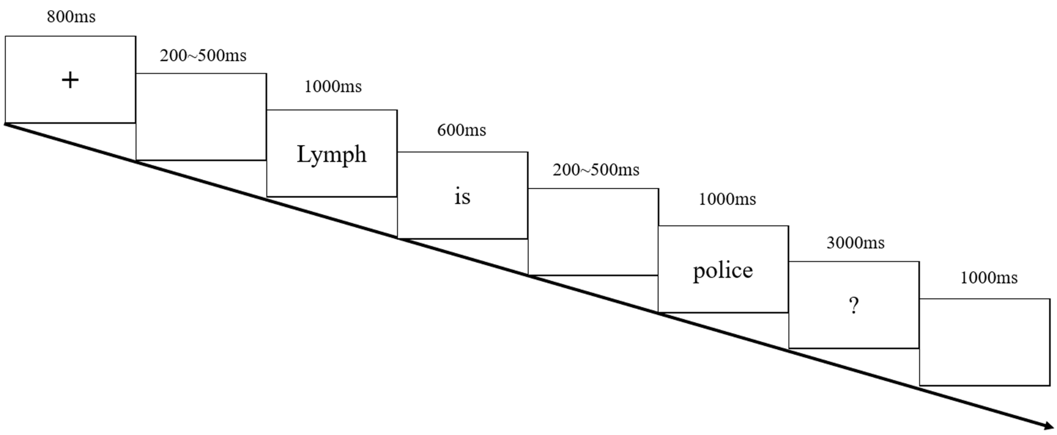


FIGURE 3
Experimental paradigm of experiment 2.

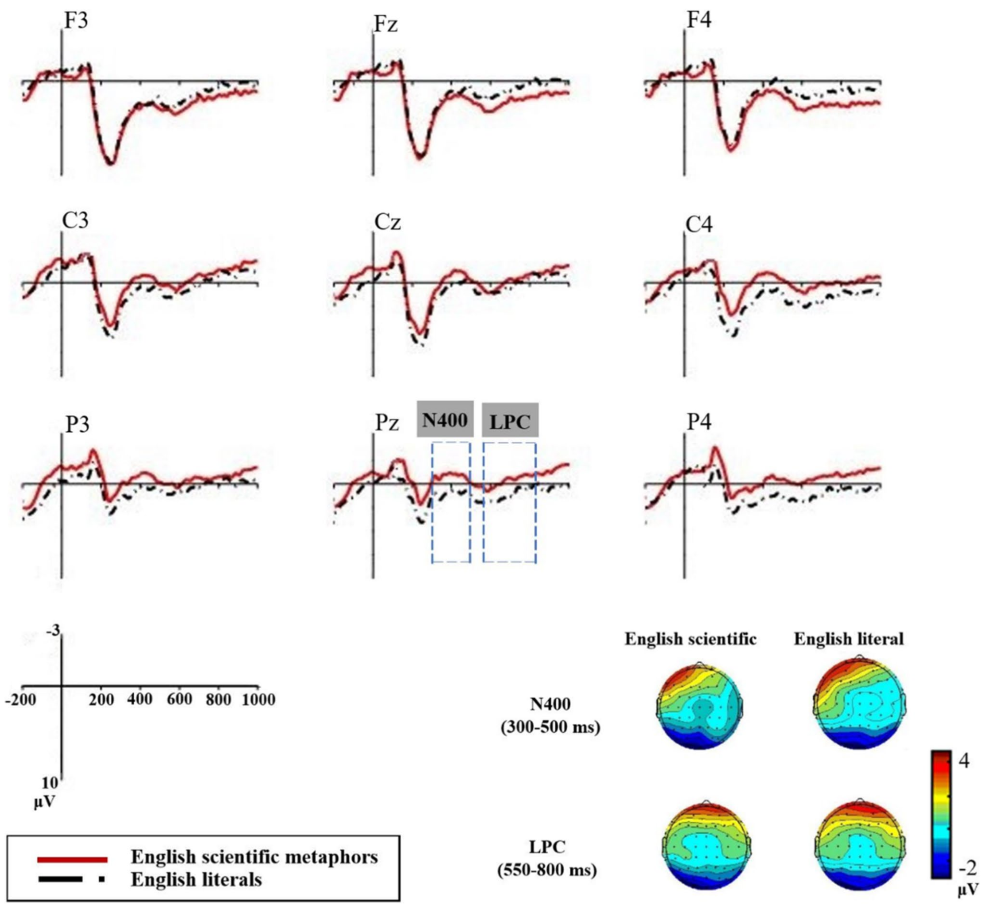


FIGURE 4
Grand average ERP waveforms recorded at the nine chosen electrodes of English pairs.

latency values, similar to the result of experiment 1, no significant main effect of type ($p = 0.288$) was found.

### 550~800ms

**LPC**

In the time window of LPC (550 ~ 800 ms), there were significant main effects of type [$F$ (1, 16) = 57.63, $p < 0.001$, $\eta^2_p = 0.78$]. As shown in Figure 4, the ERPs of scientific metaphors ($M = -1.43$ μV, SD = 3.08 μV) were less positive than those of literal sentences ($M = 0.98$ μV, SD = 2.85 μV). There were significant type × region interactions [$F$ (2, 32) = 13.89, $p < 0.001$, $\eta^2_p = 0.47$]. Simple effect tests showed great significant differences between English scientific metaphors and literal sentences in the parietal and central regions [Parietal: $F$ (1, 16) = 61.73, $p < 0.001$, $\eta^2_p = 0.79$; Central: $F$ (1, 16) = 76.51, $p < 0.001$, $\eta^2_p = 0.83$] (see Figure 4).

## Discussion

Similar to the Chinese pairs, English (L2) scientific metaphors also elicited more negative N400 than literal ones reflecting more demanding retrieving of stored conceptual knowledge due to the mapping between the scientific target and the daily source. Two aspects could be explained this discrepancy: either English scientific metaphors are difficult to process because of the need to reject literal meanings and retrieve appropriate metaphorical meanings (Wang and Jankowiak, 2021), or bilinguals have difficulty transferring explicit L2 knowledge to their implicit language skills (Chen et al., 2013). Furthermore, English scientific metaphors also elicited more negative late negativity reflecting the secondary integration of meaning due to the late analogical comparison involved in processing scientific metaphors.

# Comparative analysis between L1 and L2

## Results

### Behavioral performance

A further language (Chinese, English) × type (scientific metaphor, literal expression) repeated-measures ANOVA revealed significant effects of language for accuracy rates [$F$ (1, 16) = 4.81, $p = 0.043$, $\eta^2_p = 0.12$]. The accuracy rates were significantly lower for English expressions ($M = 0.85$, SD = 0.02) than those for Chinese expressions ($M = 0.89$, SD = 0.01). Moreover, a repeated-measures ANOVA revealed significant effects of language for reaction times [$F$ (1, 16) = 4.66, $p = 0.046$, $\eta^2_p = 0.23$]. The reaction times of English expressions ($M = 591.32$ ms, SD = 42.91 ms) were significantly longer than those of Chinese expressions ($M = 489.83$ ms, SD = 48.4 ms).

### Electrophysiological data

### 300~500ms

**N400**

A language (Chinese, English) × type (scientific metaphors, literal expressions) × region × hemisphere repeated-measures ANOVA was performed for the N400 amplitudes of English and Chinese scientific metaphoric pairs and literal pairs. As shown in Figure 5, the main effects of language were salient [SM: $F$ (1, 16) = 6.47, $p = 0.022$, $\eta^2_p = 0.29$; LT: $F$ (1, 16) = 8.39, $p = 0.011$, $\eta^2_p = 0.34$], with English stimuli eliciting more negative N400 than Chinese stimuli [English stimuli: $M = 0.08$ μV, SD = 0.43 μV; Chinese stimuli: $M = 1.99$ μV, SD = 0.61 μV].

Significant language × region interactions were found in both pairs [SM: $F$ (2, 32) = 6.47, $p = 0.022$, $\eta^2_p = 0.29$; LT: $F$ (2, 32) = 8.49, $p = 0.011$, $\eta^2_p = 0.34$]. Simple effect tests showed that English sentences elicited more negative N400 in the central and parietal regions ($ps < 0.05$). Language × hemisphere interactions were not significant for the scientific metaphoric pairs ($p = 0.14$), but marginally significant for the literal pairs [$F$ (2, 32) = 3.33, $p = 0.064$, $\eta^2_p = 0.17$]. Simple effect tests showed that English and Chinese literals differed significantly in the midline and the right hemisphere ($ps < 0.05$). The results indicate that both hemispheres play a significant role in the comprehension of English sentences by Chinese-English bilinguals, with the right parietal area of the right hemisphere necessarily involved.

For the N400 latency values, a similar repeated-measure ANOVA revealed no significant language effect for both scientific metaphoric pairs and literal pairs (SM: $p = 0.145$, LT: $p = 0.978$). Language × region interactions were not significant ($p = 0.408$). However, there were significant language × hemisphere interactions [$F$ (2, 32) = 4.79, $p = 0.018$, $\eta^2_p = 0.23$]. Simple effects tests showed that the mean N400 latency of English stimuli ($M = 380.45$ ms, SD = 1.34 ms) was marginally significantly later than that of Chinese stimuli ($M = 376.35$ ms, SD = 1.76 ms) in the midline ($p = 0.073$). Moreover, language × type × hemisphere interactions were marginally significant [$F$ (2, 32) = 3.46, $p = 0.066$, $\eta^2_p = 0.18$]. Simple effects tests showed that the N400 latencies of English scientific metaphors were significantly later than that of Chinese scientific metaphors in the midline and the right hemisphere ($ps < 0.05$) where no significant difference between N400 latencies of English and Chinese literal expressions was found.

### 550~800ms

**LPC**

In the time window of LPC (550 ~ 800 ms), for the LPC amplitudes of English and Chinese scientific metaphoric pairs and literal pairs, the main effects of language were both significant [SM: $F$ (1, 16) = 12.18, $p = 0.003$, $\eta^2_p = 0.43$; LT: $F$ (1, 16) = 4.54, $p = 0.049$, $\eta^2_p = 0.22$], with English stimuli eliciting less positive LPCs than Chinese stimuli [English stimuli: $M = -0.23$ μV,

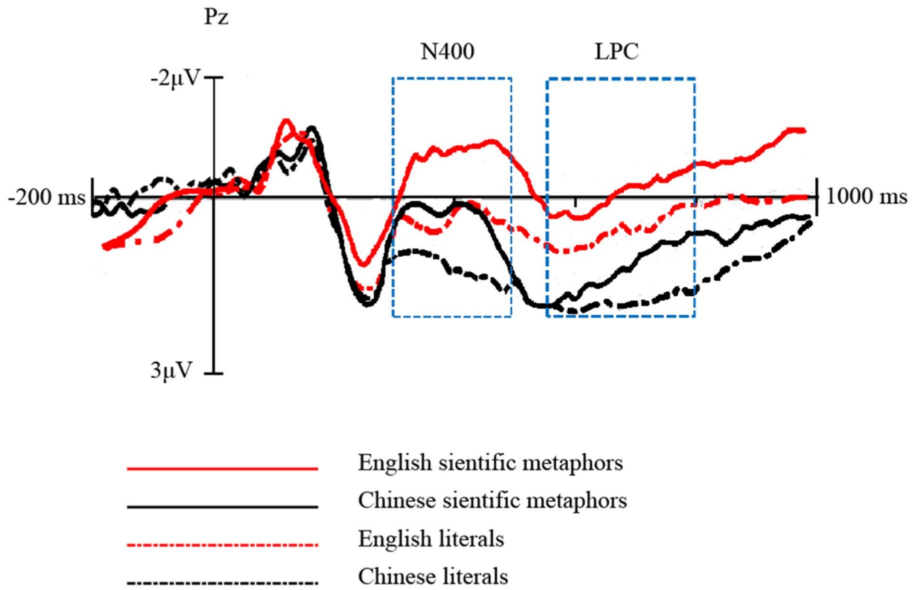


FIGURE 5
Grand average ERP waveforms recorded at the Pz electrodes of four conditions

$SD = 0.48\,\mu V$; Chinese stimuli: $M = 2.34\,\mu V$, $SD = 0.73\,\mu V$]. Significant language × region interactions were found in both pairs [SM: $F\ (2,\ 32) = 14.34$, $p < 0.001$, $\eta^2_p = 0.47$; LT: $F\ (2,\ 32) = 13.21$, $p < 0.001$, $\eta^2_p = 0.45$]. Simple effect tests showed that both English scientific metaphors and literals elicited less positive LPC in the parietal regions ($ps < 0.01$) and English scientific metaphors also elicited less positive LPC in the central region ($p = 0.011$). Language × hemisphere interactions were not significant for the two pairs ($ps > 0.1$).

**The sustained late negativity**

Moreover, the ERP patterns in the late window (550–800 ms) were further illustrated by subtracting the amplitude of Chinese literal expressions from those of English scientific metaphoric, English literal and Chinese scientific metaphoric expressions respectively, and the resulting difference curves are shown in Figure 6. Following their prominent N400 effects, the two English conditions and Chinese scientific metaphors displayed a second negativity peaking around 760 ms. There were significant main effects of type [$F\ (2,\ 32) = 9.25$, $p = 0.005$, $\eta^2_p = 0.37$]. The two English conditions elicited more negative amplitudes than Chinese scientific metaphors (ESM: $M = -4.58\,\mu V$, SD = 5.89 μV; ELT: $M = -2.17\,\mu V$, SD = 5.84 μV; CSM: $M = -1.62\,\mu V$, SD = 3.74 μV; E refers to English while C refers to Chinese). The interaction effects between type and region [$F\ (4,\ 64) = 11.09$, $p < 0.001$, $\eta^2_p = 0.41$] indicated that the differences were more prominent at the central and parietal regions.

For the English pairs, there were main effects of type [$F\ (1,\ 16) = 57.63$, $p < 0.001$, $\eta^2_p = 0.78$]. There were significant type × region interactions [$F\ (2,\ 32) = 13.89$, $p < 0.001$, $\eta^2_p = 0.47$]. Simple effect tests showed significant differences in all the three regions [$Fs\ (1,\ 16) > 15$, $ps < 0.01$] with the more significant differences existing in the central and parietal regions [$Fs\ (1,\ 16) > 60$, $ps < 0.001$].

For English and Chinese scientific metaphoric pairs, there were main effects of language [$F\ (1,\ 16) = 12.18$, $p = 0.003$, $\eta^2_p = 0.43$]. Language × region interactions were significant [$F\ (2,\ 32) = 14.34$, $p < 0.001$, $\eta^2_p = 0.47$]. Simple effect tests showed significant differences in the parietal region [$F\ (1,\ 16) = 37.95$, $p < 0.001$, $\eta^2_p = 0.7$] and the central region [$F\ (1,\ 16) = 8.26$, $p = 0.011$, $\eta^2_p = 0.34$], but not in the frontal region ($p = 0.41$).

For English literal and Chinese scientific metaphoric pairs, type × region interaction was significant [$F\ (2,\ 32) = 7$, $p = 0.004$, $\eta^2_p = 0.31$] with the significant difference existing in the parietal region [$F\ (1,\ 16) = 7.24$, $p = 0.016$, $\eta^2_p = 0.31$], but not in the frontal and central regions ($ps > 0.9$). In order to make a clear comparison between the two conditions, separate pairwise ANOVAs for all the three electrodes in the parietal region were performed. The differences were very significant at the right site [P4: $F\ (1,\ 16) = 16.72$, $p = 0.001$, $\eta^2_p = 0.51$], significant at the central site [Pz: $F\ (1,\ 16) = 5.79$, $p = 0.029$, $\eta^2_p = 0.27$], and not significant at the left site (P3: $p = 0.16$).

## Discussion

### The different familiarities of L1 and L2

Firstly, in this study, English literals elicited more negative N400 than Chinese literals. The N400 indexes the difficulty in retrieving the stored information of a word (Coulson and Van Petten, 2002; Yang et al., 2013). Greater N400 amplitudes for L2

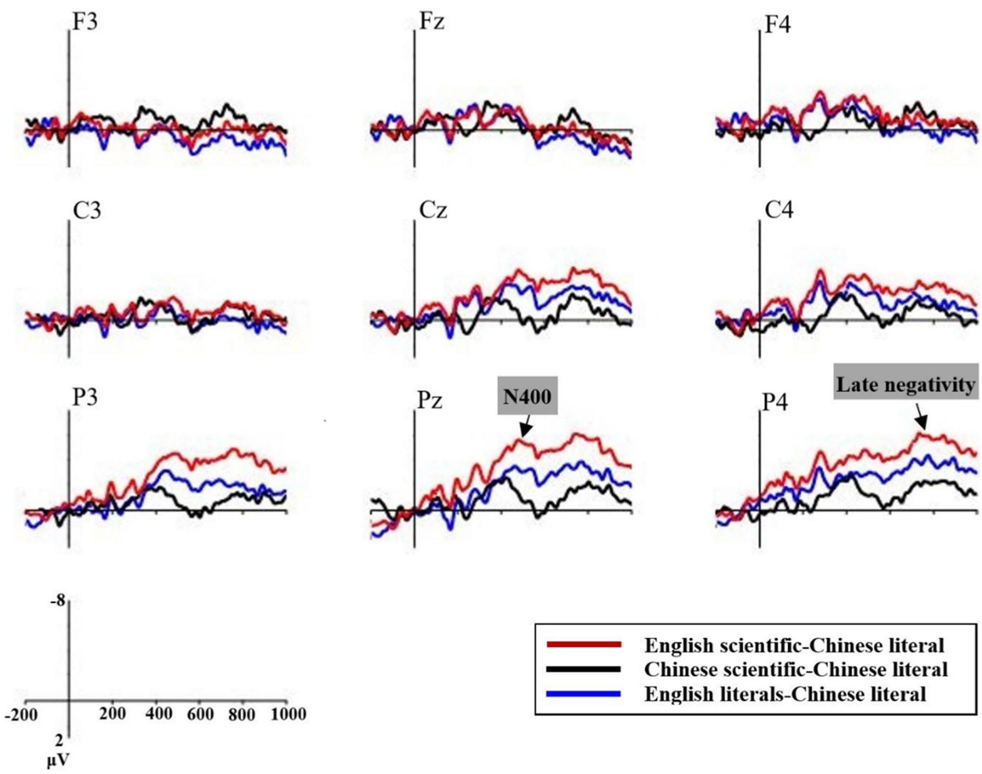


FIGURE 6
Grand average ERP waveforms recorded at the nine chosen electrodes of the late negativity

daily literal expressions might result from their unfamiliarity (Proverbio et al., 2002; Moreno et al., 2008; Midgley et al., 2009; Newman et al., 2012; Heidlmayr et al., 2015). For late learners, L1 daily words are used very frequently in people's life but it is not mostly the case for L2 daily words. Naturally, exposure to L1 words is much higher than exposure to L2 words, resulting in the lower familiarity of L2 words. Therefore, processing the meaning of L2 words appears more difficult than that of L1 words (Wang and Chen, 2020).

Secondly, it is known from previous studies of N400 in bilingual semantic processing (WeberFox and Neville, 1996; Phillips et al., 2004; Moreno and Kutas, 2005; Braunstein et al., 2012) that N400 latencies are longer for English words than for Chinese words. The present study also reported longer N400 latencies of English stimuli compared with that of Chinese stimuli in the midline, which was also consistent with the behavioral results showing reaction times of English stimuli were longer than that of Chinese stimuli. As can be seen from the BIA+ model (Dijkstra and van Heuven, 2002) the time delay assumed by the lower subjective frequency of L2 items may lead to delayed activation of semantic representations in non-native speakers. Thus, automatic operations involved in lexical-semantic access are less frequent when dealing with non-dominant languages with lower resting level activation (Jankowiak et al., 2017). Besides, L2 is acquired in a fundamentally different way from L1, so the lexical-semantic connection of L2 is weaker than that of L1 (Midgley et al., 2009; Palmer et al., 2010). L2 is mostly acquired explicitly during formal classroom instruction at school age, whereas native languages are always acquired implicitly during childhood.

## The N400 regarding the scientific contextual factor

Studies have shown that the N400 observed for metaphor is related to context and may be an index of contextual expectations for upcoming words, guiding lexical access and retrieval (Bambini et al., 2016). In summary, scientific metaphors are more contextually complex than traditional metaphors, as they cover both scientific target domains and everyday source domains. It is clear from the results of this study that the N400 model of L1 and L2 processing of scientific metaphors is different.

Firstly, in this study, consistent with our predictions, English scientific metaphoric elicited more negative N400 than Chinese ones. The words in the source domains of either English or Chinese scientific metaphors were from daily life. As mentioned in the above discussion, retrieving the literal meaning of L2 words should be more difficult due to their lower familiarity and frequencies of usage. More importantly, the words used in the target domains of either English or Chinese scientific metaphors were scientific terms. Compared with daily words, exposure to scientific terms should be lower. Compared with L1 scientific terms, late learners' exposure to L2 scientific terms should be even lower. Therefore, the different degrees of difficulties in processing L1 and L2 words is shown more clearly by adopting scientific terms in this study.

Secondly, following the retrieval of literal meaning of words in the daily source and scientific target domains respectively, processing scientific metaphors involves the integration of the two heterogeneous domains. Another possible reason for greater N400 amplitudes for L2 scientific metaphors lies in their complicated contextual structure, further enhancing the difficulty in integrating meaning. Some studies have shown that the integration of the two domains of L2 conventional metaphors costs more energy because the lexical-semantic connection between L2 words are weaker than that between L1 words (Midgley et al., 2009). Other studies have shown that the integration of the two domains of L1 scientific metaphors is more difficult than that of L1 conventional metaphors due to the longer distance between the two heterogeneous domains of scientific ones than that between those of conventional ones (Tang et al., 2017a,b). Based on the two findings, especially for late L2 learners, integrating the two domains of L2 scientific metaphors should be much more demanding due to the context of weaker lexical-semantic connection of words and longer distance of mapping.

Thirdly, consistent with our predictions, the mean N400 latency of English stimuli was longer than that of Chinese ones in the midline. As mentioned above, recognizing the literal meaning of L2 words, especially scientific terms, takes longer time (Taft et al., 2021). Moreover, the N400 latencies of English scientific metaphors were significantly longer than that of Chinese scientific metaphors in the midline and the right hemisphere revealed the unique time-course processing of scientific metaphors compared with literal expressions. Unlike the difference between L1 and L2 daily words, the scientific terms of both L1 and L2 are mostly learned explicitly with the method of formal classroom teaching at school age. Generally, scientific terms are used in some academic context, where L1 is often used to express difficult and abstract ideas and knowledge. According to the inhibitory control (IC) model (Green, 1998), in the L2 (English) context, it is difficult to inhibit L1 representation for scientific metaphors. The predominantly used non-dominant language may largely incur switching costs (Kalinka et al., 2018).

Moreover, the semantic connection between scientific terms and daily words should be weaker than that between different daily words. Therefore, compared with L1 scientific terms, the semantic connection of L2 scientific terms should be even lower. Hence the mapping of L2 scientific metaphors in the context of two heterogeneous domains might take more time (Jankowiak et al., 2017).

## The late component regarding The reasoning factor

Some studies have shown that traditional and poetic metaphors have emotionally stimulating functions, while scientific metaphors have unique properties of knowledge comprehension, involving late reasoning processes (Tang et al., 2017a,b). The findings of the current research indicate that the late component patterns are much more complicated for L2 processing.

In this study, both English conditions (scientific metaphoric and literal) elicited less positive LPC than their Chinese counterparts. The reason might be that in the late time window when structural integration occurs semantic integration is prolonged (Kaan et al., 2000; Friederici, 2002). Firstly, the LPC has been thought to reflect the level of syntactic processing. The higher amplitudes of LPC for L1 might indicate that processing L1 involves more syntactic analysis while processing L2 mostly involves semantic analysis (Kotz, 2009). Secondly, from the perspective of semantic integration, the enhanced LPC for L1 might show the deeper processing of knowledge-reasoning of L1 scientific metaphors (Jankowiak et al., 2017).

Moreover, a late negativity was elicited in the time window of LPC. The late negativity has been found and reported by some monolingual (Arzouan et al., 2007a,b; Goldstein et al., 2012; Rutter et al., 2012) and bilingual studies on metaphor comprehension (Jankowiak et al., 2017; Jankowiak et al., 2021; Wang and Jankowiak, 2021), marking the ongoing difficulty of the secondary semantic integration especially of novel metaphors (Tang et al., 2017a,b) or the activated non-literal routes when understanding complex semantics in non-native contexts (Jankowiak et al., 2017).

In this study, inconsistent with our predictions, the two English conditions elicited more negative amplitudes than Chinese scientific metaphors. Firstly, the enhanced late negativity of English scientific metaphors might show that comprehending L2 scientific metaphors is more difficult, since the late negativity may mark the ongoing difficulty of integrating the two concepts. However, generally speaking, the depth of semantic integration for L2 metaphors could not reach the same magnitude as that for L1 metaphors (Midgley et al., 2009), especially when the late complicated reasoning process is involved in understanding the abstract concept related with scientific metaphors, which was also supported by the behavioral data showing that the difference of reaction times was not significant between English scientific metaphors and English literal expressions but significant between the two English conditions and Chinese scientific metaphors. Secondly, processing daily literals does not involve the late reasoning process for understanding related knowledge. Therefore, the late negativity with enhanced amplitudes observed for processing English conditions might probably imply a switching from L2 to L1 in the late period of processing L2, which elaborated the amplitudes of English conditions in this study. The late negativity elicited by the codes switch from L2 to L1 (from the weaker language to the dominant language) has been reported to suggest that switching may engage the activation costs of the specific lexical forms in the less active language and effortful sentence-level restructuring mechanisms (Palmer et al., 2010; Shukhan Ng et al., 2014; Litcofsky and Van Hell, 2017; Zeller, 2020).

### The hemispheric involvement

Consistent with our predictions and previous studies (Jankowiak et al., 2017), during the earlier time window (N400), the processing of English (L2) expressions show a right-biased distribution of the brain. The lexical-semantic connection between L2 words is much weaker than that between L1 words (Midgley et al., 2009; Naranowicz et al., 2022), leading to a right-biased distribution. Based on fine-coarse semantic coding theory (Beeman, 2005), the coarse semantic encoding of the right hemisphere loosely activates and maintains a larger semantic domain, in which the semantic associations are more distant and meanings are more unconventional, while the fine semantic encoding of the left hemisphere focuses on a single dominant interpretation. Moreover, the significant difference of N400 latencies between English scientific metaphors and Chinese scientific metaphors in the midline and the right hemisphere also indicates a unique role of the right hemisphere for the processing of scientific metaphors. During the later time window (the late components), inconsistent with our predictions, the processing of English (L2) expressions show a right-biased distribution of the brain. However, probably coarse semantic coding might be much weaker for a non-native than native language (Miriam et al., 2012). That is to say, the coarse semantic processing might be too difficult for L2 learners so that they might switch to the fine semantic processing of L2. That is to say, the integration of two distant domains involving the scientific reasoning increases the difficulties of L2 processing so that L2 users might switch to their L1 in this case. Therefore, the right-biased distribution of the late negativity elicited by English scientific metaphors might result firstly from the code switch from English to Chinese, and secondly from the coarse semantic processing of scientific metaphors (Ng et al., 2014; Litcofsky and Van Hell, 2017).

## Conclusion

Overall, factors that interfere with the processing of metaphors include the different lexical encodings in the two languages of bilinguals (Xue et al., 2014). As demonstrated in the experiments reported here, the dynamics of processing literal and figurative meaning over time suggest a complex pattern, with language, context, inference and salience jointly modulating temporal dynamics and possible cerebral asymmetries, supporting the revised hierarchical model and the graded salience hypothesis. For processing L1 and L2 scientific metaphors, several factors interact complicatedly to determine their different ways throughout the course of semantic integration as well as the unique hemispheric involvement supporting the fine-coarse semantic coding theory.

Due to the unique properties of scientific metaphors, non-native speakers have difficulty experiencing deep integration of meaning. In addition, few studies have addressed the qualitative differences in non-literal representations in the brains of native and non-native speakers. The present study may be of help to give some sort of significant implications for the related further studies. In this important but surprisingly under-researched area, future research could be directed towards comparing the dynamics of processing scientific metaphors with other forms of metaphors such as conventional and poetic metaphors between native and non-native speakers. Meanwhile, the present study only investigated the electrophysiological differences between scientific metaphors and daily literal expressions which could be resulted by both metaphoric effect and scientific effect. Further research could explore the influence of those two effects independently by adding scientific literal expressions as stimuli to reveal the unique processing of scientific metaphors in the bilingual brain.

## Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

## Ethics statement

The studies involving human participants were reviewed and approved by Ethics Committee in Shaanxi Normal University. The patients/participants provided their written informed consent to participate in this study.

## Author contributions

XT contributed to conception and design of the study. XL, YH, and SH performed the data collection. LS, XT, XL, XG, ZY, and ZM performed the analysis. LS and XT wrote the first draft of the manuscript. All authors contributed to the article and approved the submitted version.

## Funding

The current research was funded by the National Social Science Foundation of China (Grant No. 17BYY092).

## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

## Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

## References


Anna, B. C., and Roberto, R. H. (2011). Hemispheric asymmetries in processing L1 and L2 idioms: effects of salience and context. *Brain Lang.* 116, 136–150. doi: 10.1016/j.bandl.2010.09.007

Arzouan, Y., Goldstein, A., and Faust, M. (2007a). Brainwaves are stethoscopes: ERP correlates of novel metaphor comprehension. *Brain Res.* 1160, 69–81. doi: 10.1016/j.brainres.2007.05.034

Arzouan, Y., Goldstein, A., and Faust, M. (2007b). Dynamics of hemispheric activity during metaphor comprehension: electrophysiological measures. *NeuroImage* 36, 222–231. doi: 10.1016/j.neuroimage.2007.02.015

Bambini, V., Bertini, C., Schaeken, W., Stella, A., and Di Russo, F. (2016). Disentangling metaphor from context: an ERP study. *Front. Psychol.* 7:758. doi: 10.3389/fpsyg.2016.00559

Beeman, M. J. (1998). "Coarse semantic coding and discourse comprehension," in *Right Hemisphere Language Comprehension: Perspectives From Cognitive Neuroscience*. eds. M. Beeman and C. Chiarello (Mahwah, NJ: Erlbaum), 255–284.

Beeman, M. J. (2005). Bilateral brain processes for comprehending natural language. *Trends Cogn. Sci.* 9, 512–518. doi: 10.1016/j.tics.2005.09.009

Bowdle, B. F., and Gentner, D. (2005). The career of metaphor. *Psychol. Rev.* 112, 193–216. doi: 10.1037/0033-295x.112.1.193

Braunstein, V., Ischebeck, A., Brunner, C., Grabner, R. H., Stamenov, M., and Neuper, C. (2012). Investigating the influenceof proficiency on semantic processing in bilinguals: an ERP and ERD/S analysis. *Acta Neurobiol. Exp.* 72, 421–438. PMID: 23377272

Calabria, M., Hernández, M., Branzi, F. M., and Costa, A. (2011). Qualitative differences between bilingual language control and executive control: evidence from task-switching. *Front. Psychol.* 2:399. doi: 10.3389/fpsyg.2011.00399

Chen, H., Peng, X., and Zhao, Y. (2013). An ERP study on metaphor comprehension in the bilingual brain. *Chin. J. Appl. Linguist.* 36, 505–517. doi: 10.1515/cjal-2013-0034

Coulson, S., and Van Petten, C. (2002). Conceptual integration and metaphor: an event-related potential study. *Mem. Cogn.* 30, 958–968. doi: 10.3758/bf03195780

Dijkstra, T., and van Heuven, W. J. B. (2002). The architecture of the bilingual word recognition system: from identification to decision. *Biling. Lang. Congn.* 5, 175–197. doi: 10.1017/s1366728902003012

Dijkstra, T., van Heuven, W. J. B., and Grainger, J. (1998). Simulating cross-language competition with the bilingual interactive activation model. *Psychol. Belg.* 38, 177–196. doi: 10.5334/pb.933

Friederici, A. D. (2002). Towards a neural basis of auditory sentence processing. *Trends Cogn. Sci.* 6, 78–84. doi: 10.1016/s1364-6613(00)01839-8

Gentner, D. (1983). Structure-mapping: a theoretical framework for analogy. *Cogn. Sci.* 7, 155–170. doi: 10.1016/s0364-0213(83)80009-3

Gentner, D., and Wolff, P. (1997). Alignment in the processing of metaphor. *J. Mem. Lang.* 37, 331–355. doi: 10.1006/jmla.1997.2527

Giora, R. (2003). *On Our Mind: Salience, Context, and Figurative Language*. New York, NY: Oxford University Press.

Goldstein, A., Arzouan, Y., and Faust, M. (2012). Killing a novel metaphor and reviving a dead one: ERP correlates of metaphor conventionalization. *Brain Lang.* 123, 137–142. doi: 10.1016/j.bandl.2012.09.008

Gratton, G., Coles, M. G. H., and Donchin, E. (1983). A new method for off-line removal of ocular artifact. *Electroencephalogr. Clin. Neurophysiol.* 55, 468–484. doi: 10.1016/0013-4694(83)90135-9

Green, D. (1998). Mental control of the bilingual lexico-semantic system. *Biling. Lang. Congn.* 1, 67–81. doi: 10.1017/s1366728998000133

Hahne, A., and Friederici, A. D. (2001). Processing a second language: late learners' comprehension mechanisms as revealed by event-related brain potentials. *Biling. Lang. Congn.* 4, 123–141. doi: 10.1017/s1366728901000232

Heidlmayr, K., Hemforth, B., Moutier, S., and Isel, F. (2015). Neurodynamics of executive control processes in bilinguals: evidence from ERP and source reconstruction analyses. *Front. Psychol.* 6:17. doi: 10.3389/fpsyg.2015.00821

Jankowiak, K., Naranowicz, M., and Rataj, K. (2021). Metaphors are like lenses: electrophysiological correlates of novel meaning processing in bilingualism. *Int. J. Biling.* 25, 668–686. doi: 10.1177/1367006921996820

Jankowiak, K., Rataj, K., and Naskręcki, R. (2017). To electrify bilingualism: electrophysiological insights into bilingual metaphor comprehension. *PLoS One* 12:e0175578. doi: 10.1371/journal.pone.0175578

Jiang, X., Tan, Y., and Zhou, X. (2009). Processing the universal quantifier during sentence comprehension: ERP evidence. *Neuropsychologia* 47, 1799–1815. doi: 10.1016/j.neuropsychologia.2009.02.020

Kaan, E., Harris, A., Gibson, E., and Holcomb, P. J. (2000). The P600 as an index of syntactic integration difficulty. *Lang. Cognit. Process.* 15, 159–201. doi: 10.1080/016909600386084

Kalinka, T., Christoffels, I. K., and Albert, C. (2018). On the flexibility of bilingual language control: the effect of language context. *Biling. Lang. Congn.* 22, 555–568. doi: 10.1017/s1366728918000329

Kotz, S. A. (2009). A critical review of ERP and fMRI evidence on L2 syntactic processing. *Brain Lang.* 109, 68–74. doi: 10.1016/j.bandl.2008.06.002

Kroll, J. F., and Stewart, E. (1994). Category interference in translation and picture naming: evidence for asymmetric connections between bilingual memory representations. *J. Mem. Lang.* 33, 149–174. doi: 10.1006/jmla.1994.1008

Kutas, M., and Hillyard, S. A. (1980). Reading senseless sentences: brain potentials reflect semantic incongruity. *Science* 207, 203–205. doi: 10.1126/science.7350657

Lai, V. T., and Curran, T. (2013). ERP evidence for conceptual mappings and comparison processes during the comprehension of conventional and novel metaphors. *Brain Lang.* 127, 484–496. doi: 10.1016/j.bandl.2013.09.010

Lemhofer, K., Dijkstra, T., Schriefers, H., Baayen, H., Grainger, J., and Zwitserlood, P. (2008). Native language influences on word recognition in a second language: a mega-study. *J. Exp. Psychol. Learn. Mem. Cogn.* 34, 12–31. doi: 10.1037/0278-7393.34.1.12

Litcofsky, K. A., and Van Hell, J. G. (2017). Switching direction affects switching costs: behavioral, ERP and time-frequency analyses of intra-sentential codeswitching. *Neuropsychologia* 97, 112–139. doi: 10.1016/j.neuropsychologia.2017.02.002

Lopez-Calderon, J., and Luck, S. J. (2014). ERPLAB: an open-source toolbox for the analysis of event-related potentials. *Front. Hum. Neurosci.* 8:213. doi: 10.3389/fnhum.2014.00213

Mashal, N., Borodkin, K., Maliniak, O., and Faust, M. (2015). Hemispheric involvement in native and non-native comprehension of conventional metaphors. *J. Neurolinguistics* 35, 96–108. doi: 10.1016/j.jneuroling.2015.04.001

Midgley, K. J., Holcomb, P. J., and Grainger, J. (2009). Language effects in second language learners and proficient bilinguals investigated with event-related potentials. *J. Neurolinguistics* 22, 281–300. doi: 10.1016/j.jneuroling.2008.08.001

Miriam, F., Elisheva, B. A., and Nili, V. (2012). Semantic processing in native and second language: evidence from hemispheric differences in fine and coarse semantic coding. *Brain Lang.* 123, 228–233. doi: 10.1016/j.bandl.2012.09.007

Moreno, E. M., Fornells, A. R., and Laine, M. (2008). Event-related potentials (ERPs) in the study of bilingual language processing. *J. Neurolinguistics* 21, 477–508. doi: 10.1016/j.jneuroling.2008.01.003

Moreno, E. M., and Kutas, M. (2005). Processing semantic anomalies in two languages: an electrophysiological exploration in both languages of Spanish–English bilinguals. *Cogn. Brain Res.* 22, 205–220. doi: 10.1016/j.cogbrainres.2004.08.010

Naranowicz, M., Jankowiak, K., Kakuba, P., Bromberek-Dyzman, K., and Thierry, G. (2022). In a bilingual mood: mood affects Lexico-semantic processing differently in native and non-native languages. *Brain Sci.* 12:316. doi: 10.3390/brainsci12030316

Newman, A. J., Tremblay, A., Nichols, E. S., Neville, H. J., and Ullman, M. T. (2012). The influence of language proficiency on lexical semantic processing in native and late learners of English. *J. Cogn. Neurosci.* 24, 1205–1223. doi: 10.1162/jocn_a_00143

Ng, S., Gonzalez, C., and Wicha, N. Y. Y. (2014). The fox and the Cabra: an ERP analysis of reading code switched nouns and verbs in bilingual short stories. *Brain Res.* 1557, 127–140. doi: 10.1016/j.brainres.2014.02.009

Oldfield, R. C. (1971). The assessment and analysis of handedness: the Edinburgh inventory. *Neuropsychologia* 9, 97–113. doi: 10.1016/0028-3932(71)90067-4

Palmer, S. D., Van Hooff, J. C., and Havelka, J. (2010). Language representation and processing in fluent bilinguals: electrophysiological evidence for asymmetric mapping in bilingual memory. *Neuropsychologia* 48, 1426–1437. doi: 10.1016/j.neuropsychologia.2010.01.010

Phillips, N. A., Segalowitz, N., O'Brien, I., and Yamasaki, N. (2004). Semantic priming in a first and second language: evidence from reaction time variability and event-related brain potentials. *J. Neurolinguistics* 17, 237–262. doi: 10.1016/s0911-6044(03)00055-1

Proverbio, A. M., Cok, B., and Zani, A. (2002). Electrophysiological measures of language processing in bllinguals. *J. Cogn. Neurosci.* 14, 994–1017. doi: 10.1162/089892902320474463

Rutter, B., Kroger, S., Hill, H., Windmann, S., Hermann, C., and Abraham, A. (2012). Can clouds dance? Part 2: an ERP investigation of passive conceptual expansion. *Brain Cogn.* 80, 301–310. doi: 10.1016/j.bandc.2012.08.003

Schmidt, G. L., and Seger, C. A. (2009). Neural correlates of metaphor processing: the roles of figurativeness, familiarity and difficulty. *Brain Cogn.* 71, 375–386. doi: 10.1016/j.bandc.2009.06.001

Schneider, S. R., Alexander, M., Haeußinger, F. B., Ernst, L. H., Hamm, F., Fallgatter, A. J., et al. (2014). Beyond the N400: complementary access to early neural correlates of novel metaphor comprehension using combined electrophysiological and haemodynamic measurements. *Cortex* 53, 45–59. doi: 10.1016/j.cortex.2014.01.008

Taft, M., Li, J., and Aryanti, T. (2021). Why do non-native English speakers show masked form priming when native speakers do not? *J. Second Lang. Stud.* 4, 204–223. doi: 10.1075/jsls.21007.taf

Tang, X., Qi, S., Jia, X., Wang, B., and Ren, W. (2017a). Comprehension of scientific metaphors: complementary processes revealed by ERP. *J. Neurolinguistics* 42, 12–22. doi: 10.1016/j.jneuroling.2016.11.003

Tang, X., Qi, S., Wang, B., Jia, X., and Ren, W. (2017b). The temporal dynamics underlying the comprehension of scientific metaphors and poetic metaphors. *Brain Res.* 1655, 33–40. doi: 10.1016/j.brainres.2016.11.005

Tang, X., Wei, R., and Hu, W. (2016). An ERP study on the cognitive neural mechanism of scientific language. *J. Psychol. Sci.* 38, 1071–1079. doi: 10.16719/j.cnki.1671-6981.20160508

van Der Meij, M., Cuetos, F., Carreiras, M., and Barber, H. (2011). Electrophysiological correlates of language switching in second language learners. *Psychophysiology* 48, 44–54. doi: 10.1111/j.1469-8986.2010.01039.x

Verhoef, K., Roelofs, A., and Chwilla, D. J. (2009). Role of inhibition in language switching: evidence from event-related brain potentials in overt picture naming. *Cognition* 110, 84–99. doi: 10.1016/j.cognition.2008.10.013

Wang, J., and Chen, B. (2020). A database of Chinese-English bilingual speakers: ratings of the age of acquisition and familiarity. *Front. Psychol.* 11:554785. doi: 10.3389/fpsyg.2020.554785

Wang, X., and Jankowiak, K. (2021). Electrophysiological insights into the role of proficiency in bilingual novel and conventional metaphor processing. *Linguist. Approach. Bilingualism* 4. doi: 10.1075/lab.20051.wan

WeberFox, C. M., and Neville, H. J. (1996). Maturational constraints on functional specializations for language processing: ERP and behavioral evidence in bilingual speakers. *J. Cogn. Neurosci.* 8, 231–256. doi: 10.1162/jocn.1996.8.3.231

Weiland, H., Bambini, V., and Schumacher, P. B. (2014). The role of literal meaning in figurative language comprehension: evidence from masked priming ERP. *Front. Hum. Neurosci.* 8, 1–17. doi: 10.3389/fnhum.2014.00583

Xue, J., Yang, J., and Zhao, Q. (2014). Chinese–English bilinguals processing temporal–spatial metaphor. *Cogn. Process.* 15, 269–281. doi: 10.1007/s10339-014-0621-5

Xun, E., Rao, G., Xiao, X., and Zang, J. (2016). The construction of the BCC corpus in the age of big data. *Corpus. Linguist.* 3, 93–109+118.

Yang, F. G., Bradley, K., Huq, M., Wu, D. L., and Krawczyk, D. C. (2013). Contextual effects on conceptual blending in metaphors: an event-related potential study. *J. Neurolinguistics* 26, 312–326. doi: 10.1016/j.jneuroling.2012.10.004

Zeller, J. P. (2020). Code-switching does not equal code-switching. An event-related potentials study on switching from L2 German to L1 Russian at prepositions and nouns. *Front. Psychol.* 11:1387. doi: 10.3389/fpsyg.2020.01387

frontiers | Frontiers in Psychology

TYPE Original Research
PUBLISHED 25 January 2023
DOI 10.3389/fpsyg.2023.1087513

Check for updates

OPEN ACCESS

EDITED BY
Huili Wang,
Dalian University of Technology, China

REVIEWED BY
Mengling Xu,
Huzhou University,
China
Ying Wang,
Shandong University,
China

*CORRESPONDENCE
Lin Fan
✉ fanlinqd@163.com

SPECIALTY SECTION
This article was submitted to Language Sciences, a section of the journal Frontiers in Psychology

RECEIVED 02 November 2022
ACCEPTED 03 January 2023
PUBLISHED 25 January 2023

CITATION
Zhang J and Fan L (2023) The effects of executive functions on language control during Chinese-English emotional word code-switching.
*Front. Psychol.* 14:1087513.
doi: 10.3389/fpsyg.2023.1087513



# The effects of executive functions on language control during Chinese-English emotional word code-switching

Jiao Zhang[1] and Lin Fan[2]*

[1]Faculty of Foreign Languages, Ningbo University, Ningbo, China, [2]National Research Centre for Foreign Language Education, Beijing Foreign Studies University, Beijing, China

Executive functions (EFs) have great impact on language control indexed by language switch costs during production-based language switching. Yet, how they influence language control during comprehension-based language switching between embodied first language (L1, Chinese) emotional words and less embodied second language (L2, English) emotional words is less understood. Employing an emotional priming paradigm, this study recruited Chinese-English bilinguals as participants, and used emotional faces and words as experimental materials to explore the effects of cool (i.e., inhibitory control ability, IC ability) and hot (i.e., emotional valence and emotional congruency) EFs on language switch costs (i.e., language control) during Chinese-English emotional word comprehension. The results showed larger language switch costs in the emotional congruent condition relative to emotional conflict condition, larger Chinese switch costs than English switch costs, and larger language switch costs for negative over positive emotional words in the emotional congruent condition. In addition, high-IC participants showed larger English switch costs for negative emotional words compared with low-IC participants. These results indicated that hot EF and the embodiment of language had an impact on both language control and the modulation of cool EF on language control, and that the components of hot EFs interacted and jointly affected language control during language switching.

KEYWORDS

**EFs, language control, IC ability, emotional valence, emotional congruency, emotional word comprehension**

## Introduction

Code-switching (also called language switching) refers to the alternation of two languages, dialects or varieties within a single discourse, sentence or constituent (Poplack, 1980). When it occurs, bilingual speakers' non-target language is activated non-selectively and creates interference, thus they would rely on certain cognitive control mechanisms to select an appropriate language to communicate at a critical point and minimize the interference from the unintended language, which is known as "language control" (Abutalebi et al., 2008). Given the overlapping mechanisms (Declerck et al., 2017) and the common brain regions involved (Hernandez and Meschyan, 2006) in language control and executive functions (EF), the questions remain how bilinguals implement language control and whether EF, which refers to the psychological processes in the conscious control of thought and action and involves cool EF and hot EF[1] (Zelazo and Müller, 2002), plays a role in language control processes. Cool EF associated with the dorsolateral prefrontal cortex (DL-PFC) is more likely to be elicited by relatively abstract, emotionally neutral materials; hot EF associated with orbitofrontal cortex (OFC) is more likely to be involved when the stimuli are characterized by high affective involvement or demand flexible appraisals of the affective significance (Zelazo and Müller, 2002: 455).

Empirical evidence from most production-based language switching studies substantiates that IC of cool EFs is the primary mechanism used in language control (e.g., Linck et al., 2012; Babcock and Vallesi, 2015; Liu et al., 2019, but see Costa and Santesteban, 2004 for exceptional cases), which is supported by the inhibitory control model (IC model) proposed by Green (1998). IC is a basic cognitive depression that facilitates task execution by preventing unrelated information from entering into the task or remaining in working memory (Harnishfeger and Bjorklund, 1993). According to IC model, in order to switch to a word of a particular language, the new schema and language tag must be activated and the previously activated schema and language tag must be suppressed (Wang et al., 2009). The IC process through schema and language tag suppression takes time and thus yields language switch costs indexed by the reaction time (RT) difference between language switch (the languages of at least two consecutive trials are different) and repetition (the languages of at least two consecutive trials are the same) trials. The magnitude of language switch costs has been taken as the main indicator of the difficulty of language control (e.g., Guo et al., 2013; Prior and Gollan, 2013; Liu et al., 2019, 2020). In view of the important role of IC mechanism in language control, researchers initiated the research on the effects of participants' domain-general IC ability on language switch costs in bilingual language production (e.g., Linck et al., 2012; Liu et al., 2017; Chang et al., 2018; Liu et al., 2019). The results showed that participants with high-IC ability showed smaller language switch costs than those with low-IC ability, suggesting a nexus between participants' domain-general IC ability and language switch costs in particular, and between their EFs and language control in general.

To reveal the mechanisms of language control in bilinguals, researchers also focus their attention on language control in bilingual visual word recognition. Different from the mechanisms of language control in spoken word production, language control in visual word recognition refers to the ability to understand the meaning of written words pertaining to a given language while reducing interference from the unrelated language (Mosca and de Bot, 2017). It is a crucial point of controversy over whether IC of cool EF is applied to comprehension-based language switching. Thomas and Allport (2000) proposed that there were two types of inhibition in language recognition tasks. One was the inhibition of language representations within the bilingual lexico-semantic system and the other was the inhibition of language task schema outside the bilingual lexicon. However, Macizo et al. (2012), Reynolds et al. (2016), and Struys et al. (2019) have proposed that the stimuli in bilingual recognition tasks are univalent, meaning that they do not generate response competition, so bilinguals do not have to rely on IC to solve the competition like production-based language switching. Liu et al. (2013) explored the effects of cognitive flexibility on both comprehension- and production-based language switching. The results indirectly showed that bilinguals' IC ability played an important role in language switching of both speech production and visual word recognition. So far, the role of IC ability in comprehension-based language switching and the mechanisms of language control in bilingual language recognition remain unclear. Therefore, the first focus of this study is to explore the role of bilinguals' domain-general IC ability of cool EF in comprehension-based bilingual language switching.

Zelazo and Müller (2002) have proposed that it is probably impossible to design a task that is a pure measure of hot or cool EF, and DL-PFC and OFC which are, respectively, responsible for cool EF and hot EF are parts of a single coordinated system and work together in a normal case. This suggests that cool and hot EFs may work together in the same task. However, available evidence for the effects of EFs on language control in language switching tasks has traditionally been based on cool EFs, and thus another major concern for this study involves the relationship between hot EFs and language control in bilingual language switching. Bond and Lai (1986) found that Cantonese-English bilinguals would switch into their second language (L2) while answering embarrassing questions in their first language (L1), suggesting that code-switching may exert its effects on emotion processing to serve an emotionally distancing function. In contrast, through immigrant parent–child interactions, Williams et al. (2020) found that facial emotion behavior had an immediate impact on code-switching, i.e., negative facial emotion predicted a higher frequency of bilingual code-switching in two directions and positive facial emotion predicted a lower frequency of code-switching in L2-L1 direction. Zhang et al. (2020) found that bilinguals showed longer response latencies and lower accuracy for Chinese-English negative emotional words compared to positive ones during Chinese-English emotional word code-switching, suggesting the important role of emotional valence in code-switching. Based on the above results, it is reasonable to conclude that previous studies have reached opposite or contradictory conclusions concerning the relationship between hot EFs and code-switching.

In order to unveil the underlying mechanisms between hot EFs and code-switching, the present study attempted to employ two types of emotional salient materials (i.e., emotional faces and emotional words with two dimensions of valence and arousal[2]) to explore the role of emotional valence (positive and negative) and emotional congruency (congruent and conflict) on language control during bilingual language switching with the emotional priming paradigm proposed by Fazio et al. (1986). In the emotional priming paradigm, emotional priming stimuli are used to elicit participants' emotion to put them in a corresponding emotional state, then the emotional target stimuli are presented for them to finish a certain task. When the valences of emotional priming and target stimuli are different (emotional conflict condition), the RTs for the processing of emotional target stimuli are longer than those in the emotional congruent condition (the valences of emotional priming and target stimuli are the same), which is known as the emotional

1 Cool EF denotes the more purely cognitive skills like inhibitory control, working memory and cognitive flexibility. Take inhibitory control for example, this type of cool EF can be induced by the location conflict between squares and reaction keys in the Simon task of this study. In contrast, hot EF refers to the more affective aspects of EF, which can be elicited by emotional words like "happy"/"sad" and emotional faces with emotional expressions like "glad"/"sorrowful."

2 Valence is a bipolar dimension which classifies emotions into positive and negative, whereas arousal is a unipolar dimension that denotes the level of emotional activation in appetitive or aversive motivation system (Lang et al., 1997).

congruency effects or emotional priming effects (Haas et al., 2006; Yao and Wang, 2014; Başgöze et al., 2015). In our study, the emotional faces were used as emotional priming stimuli and the emotional words were used as emotional target stimuli. Participants were instructed to categorize the emotional valence of emotional words in both emotional congruent and conflict conditions. Their responses in the emotional conflict condition might be slower as compared with the emotional congruent condition in terms of the emotional congruency effects, resulting in larger language switch costs in the emotional conflict condition. Given the influence of language embodiment (due to language proficiency) on emotional word processing, this study would capitalize on positive and negative emotional words from two languages (i.e., L1 Chinese and L2 English) with different proficiency levels. For unbalanced late bilinguals, the less proficient L2 gets locked out of emotional contexts, thereby generating less embodied emotional words in the L2 (Sheikh and Titone, 2016). Conversely, the more proficient L1 can integrate the information from sensorimotor experience, emotional experiences and autobiographical memories, thus producing emotional words with higher embodiment in the L1 (Pavlenko, 2012). Based on the above embodiment difference between L1 and L2 emotional words, the dominant Chinese emotional words would have higher emotional activation than the weaker English emotional words. Therefore, participants need to allocate more resources to inhibit the higher activation of Chinese emotional words to facilitate the processing of English emotional words, and invest more cognitive processing resources to reactivate the previously suppressed Chinese than the previously suppressed English during language switching (Wang et al., 2009; Liu et al., 2019). According to these accounts, bilinguals might encounter larger difficulty in switching to L1 than to L2 and thus as a whole exhibit larger Chinese switch costs over English switch costs.

In addition to the respective impacts of hot EF and cool EF on language control during emotional word code-switching, this study also focused on the interactive effects of two EFs on language control. Zelazo and Müller (2002) proposed that OFC associated with hot EF typically developed earlier than DL-PFC associated with cool EF and came to be regulated by it, and they were parts of a single coordinated system and worked together in the normal case—even in a single situation, which indicates an intimate relationship between cool and hot EFs. According to Pessoa (2009), emotion has a great impact on human behavior and this impact crucially depends on how emotional stimuli affect the flow of EFs (the exact cool EF in Zelazo and Müller, 2002), such as directly convey emotional information to EF structures or direct prioritized attention toward strengthened sensory representations. The statements of Pessoa (2009) show the interplay between hot and cool EFs on human behavioral performance. The contribution of cool and hot EFs to decision-making (Séguin et al., 2007), academic achievement, learning related behaviors, and classroom behavior (O'Toole et al., 2020) can provide empirical evidence for the above indications. The findings of Başgöze et al. (2015) also lend support to the above indications. Employing an emotional word-face Stroop task to create emotional congruent and conflict trials with emotional words and faces, Başgöze et al. (2015) found interference related slowdown in emotional conflict trials for healthy participants and attributed it to the recruitment of inhibitory processes to remove the emotional conflict. Yet, how cool EF interacts with hot EF to affect bilinguals' language control behavior during language switching is less understood. Hence, the interaction between the two types of EFs is taken into account in the current study to better reveal the impacts of EFs on language control during language switching. Taken together, this study attempted to adopt the emotional priming paradigm to explore the effects of cool (e.g., IC ability) and hot (e.g., emotional valence and emotional congruency) EFs on the language switch costs of Chinese-English emotional word comprehension to reveal the role of EFs in language control during this process. Specifically, the current study addressed whether IC ability, emotional valence, emotional congruency and the embodiment of language could impose effects on the language switch costs of Chinese-English emotional word comprehension and whether these factors could interact with each other. According to the above review of prior studies, we hypothesized that larger language switch costs may be observed for participants with high-IC ability over their low counterparts, for negative emotional words over positive emotional words, for emotional conflict condition over emotional congruent condition, as well as for embodied language (Chinese) over less embodied language (English). Moreover, it was also hypothesized that emotional valence and emotional congruency might influence the effects of IC ability on language switch costs, and these variables might interact with each other to jointly affect the language switch costs.

## Materials and methods

### Participants

The participants were 85 late Chinese-English (Chinese L1, English L2) bilinguals from Ningbo University in China [44 males; mean (M) age = 20.1 years; standard deviation (SD) = 1.3 years; range: 18–24 years]. They were right-handed and had normal or corrected-to-normal vision. All had passed College English Test Band 4 (CET-4), an official and well-established English test implemented by the Ministry of Education of the People's Republic of China to measure Chinese non-English major college students' English proficiency in writing, listening, reading and translating. Each participant was required to finish an informed consent form and a revised language history questionnaire originally designed by Li et al. (2006). The results of their questionnaires showed that they began learning their L1 from early childhood in the natural environment and their L2 at the age ranging from 7 to 13 years in the context of classroom. According to the theory of language embodiment put forth by Pavlenko (2005), these participants' L1 Chinese are embodied due to the integration of phonological forms of words with the information from participants' multiple sensory modalities, autobiographical memories and emotion, whereas their L2 English are less embodied due to the decontextualized nature of L2 classroom. The results of paired-samples *t*-tests showed that the proficiency of their Chinese listening, speaking, reading and writing and overall Chinese proficiency were significantly higher than their English counterparts ($ps < 0.001$; see Table 1).

### Measure of IC ability and the grouping

The Simon task was administered to measure participants' IC ability. In this task, trials began with a red fixation cross "+" presented in the center of the screen for 500 ms, followed by a filled red or blue square (2° × 2°, 2.1 cm in edge length) displayed at fixation, on the left of fixation or on the right of fixation. The square remained on the screen for 1,500 ms if no response was given, then a blank of 500 ms appeared. Half of the participants were informed to press the "F" key if the square appeared in red and the "J" key if the square appeared in blue. The other half of the participants were instructed the opposite. This task consisted of a block of 12 practice trials for participants to familiarize themselves with the experimental procedure, and 3 blocks of 360 experimental trials with 60 red and 60 blue square trials in each block (20 trials per location). Also, each block consisted of 40 congruent, 40 conflict and 40 neutral trials. In the congruent trials, the squares were presented on the same side of the reaction keys. In the conflict trials, the squares were displayed on the opposite side of the reaction keys. In the neutral trials, the squares appeared at fixation.

According to the median of the Simon costs as indexed by the RT difference between congruent and conflict trials in Simon task, the valid participants were divided into high (with smaller Simon costs) and low (with larger Simon costs) IC ability groups. The results of paired-samples *t*-tests showed shorter RTs [$t$ (82) = −11.717, $p < 0.001$] and lower error rates (ERs) [$t$ (82) = −3.578, $p < 0.05$] for participants with high-IC ability than those with low-IC ability, suggesting that the grouping is effective. Further analysis revealed no significant differences between the high- and low-IC participants in the age of acquisition (AoA), CET-4 score, length for studying both L1 and L2, four skills of L1 and four skills of L2 (all $ps > 0.05$). Also, no significant differences were observed in the overall L1 proficiency (High: $M = 6.1$, $SD = 0.9$; Low: $M = 6.3$, $SD = 1.0$), $t$ (82) = −0.874, overall L2 proficiency (High: $M = 3.5$, $SD = 0.6$; Low: $M = 3.3$, $SD = 0.5$), $t$ (82) = 0.979, as well as the overall L1 and L2 language proficiency (High: $M = 4.8$, $SD = 0.6$; Low: $M = 4.8$, $SD = 0.6$) between the high- and low-IC participants, $t$ (82) = −0.203, $ps > 0.05$. Table 2 presents the two groups' descriptive statistics of Chinese and English proficiency.

## Materials

The materials included emotional primes and targets. The primes were 40 negative (20 males and 20 females; valence range: 2.1–3.3; arousal range: 4.3–7.7) and 40 positive (20 males and 20 females; valence range: 5.2–7.0; arousal range: 5.0–8.0) emotional faces rated with a 9-point Likert scale, which were selected from Chinese Facial Affective Picture System (CFAPS-P, Gong et al., 2011) and displayed in a height of 8.4 cm and a width of 6.8 cm. The results of independent-samples *t*-tests showed a significant difference between the valence of positive and negative faces ($p < 0.001$), but their arousal showed an insignificant difference ($p > 0.05$). Additionally, neither the valence nor the arousal showed significant differences between male and female faces ($ps > 0.05$).

The targets were 40 English emotional words and their Chinese translation equivalents (i.e., 40 Chinese emotional words), with the former taken from the appendices of previous studies (e.g., Harris et al., 2003; Scott et al., 2009; Kazanas and Altarriba, 2016), *Affective Norms for English Words* (ANEW, Bradley and Lang, 1999), *The Book of Human Emotions* (Smith, 2016) and *Pocket Oxford English-Chinese Dictionary* (Soanes, 2009). Each language included 20 positive (valence range: 4.8–6.6; arousal range: 3.8–5.4) and 20 negative (valence range: 1.3–3.4; arousal range: 3.7–5.3) emotional words rated with a 7-point Likert scale (see Supplementary material). The results of independent-samples *t*-tests revealed no significant differences in the familiarity, frequency, abstractness, arousal and valence between Chinese and English emotional words ($ps > 0.05$) and in the familiarity, frequency, abstractness and arousal between positive and negative emotional words ($ps > 0.05$), yet the valence showed a significant difference between positive and negative emotional words ($p < 0.001$; see Table 3). As shown in Table 4, Chinese positive and negative emotional words had no significant differences in their stroke number, frequency, familiarity, arousal and abstractness ($ps > 0.05$), but their valence showed an obvious difference ($p < 0.001$). As for English positive and negative emotional words, there were no significant differences in their syllable number, letter number, frequency, familiarity, arousal and abstractness ($ps > 0.05$), but their valence revealed a significant difference ($p < 0.05$). In addition, no significant differences were observed in the word frequency, familiarity, abstractness, arousal and valence between Chinese and English positive emotional words, as well as in those variables between Chinese and English negative emotional words ($ps > 0.05$).

TABLE 1 Means and SDs of the proficiency ratings for four skills of Chinese and English.

| Skills | L1 (Chinese) | L2 (English) | *t* | *p* |
|---|---|---|---|---|
| Listening | 6.6 (0.8) | 3.3 (0.9) | 27.014 | 0.000*** |
| Speaking | 6.4 (1.0) | 3.2 (0.9) | 25.375 | 0.000*** |
| Reading | 6.2 (1.2) | 3.8 (0.9) | 15.768 | 0.000*** |
| Writing | 5.7 (1.3) | 3.3 (0.7) | 15.932 | 0.000*** |
| Overall proficiency | 6.2 (0.9) | 3.4 (0.6) | 25.841 | 0.000*** |

***$p < 0.001$.

## Design

A 2 (IC ability: high and low) x2 (Language switch costs: Chinese and English) x2 (Emotional valence: positive and negative) x2 (Emotional congruency: congruent and conflict) analysis of variance (ANOVA) was employed, with IC ability as a between-subjects independent variable, language, emotional valence and emotional

TABLE 2 Means and SDs of the AoA, CET scores, learning time and proficiency ratings of four language skills for high- and low-IC ability groups' Chinese and English.

| Manipulation variables | L1 (Chinese) | | | | L2 (English) | | | |
|---|---|---|---|---|---|---|---|---|
| | High-IC | Low-IC | *t* | *p* | High-IC | Low-IC | *t* | *p* |
| AoA | – | – | – | – | 8.9 (1.4) | 9.2 (1.7) | −0.911 | 0.365 |
| CET | – | – | – | – | 504.5 (33.7) | 500.4 (36.5) | 0.541 | 0.590 |
| Length | 19.8 (1.1) | 20.2 (1.3) | −1.524 | 0.131 | 10.9 (1.6) | 11.0 (2.0) | −0.422 | 0.674 |
| Listening | 6.6 (0.7) | 6.6 (0.9) | −0.274 | 0.785 | 3.4 (0.9) | 3.2 (0.9) | 0.979 | 0.330 |
| Speaking | 6.4 (0.9) | 6.5 (1.0) | −0.574 | 0.568 | 3.4 (0.9) | 3.1 (0.8) | 1.436 | 0.155 |
| Reading | 6.0 (1.2) | 6.3 (1.1) | −1.411 | 0.162 | 3.9 (1.0) | 3.8 (0.8) | 0.376 | 0.708 |
| Writing | 5.6 (1.4) | 5.8 (1.3) | −0.654 | 0.515 | 3.2 (0.7) | 3.3 (0.7) | −0.157 | 0.876 |

TABLE 3 Means and SDs of stimulus attributes for Chinese, English, positive and negative emotional words.

| Manipulation variables | L1 (Chinese) | L2 (English) | *t* | Positive | Negative | *t* |
|---|---|---|---|---|---|---|
| Familiarity | 6.2 (0.2) | 6.2 (0.6) | 0.148 | 6.3 (0.5) | 6.1 (0.5) | 1.379 |
| Frequency | 27.0 (23.4) | 18.8 (15.7) | 1.831 | 25.9 (23.6) | 19.9 (15.8) | 1.328 |
| Abstractness | 3.6 (0.3) | 3.6 (0.3) | −0.235 | 3.6 (0.4) | 3.6 (0.3) | 0.364 |
| Arousal | 4.8 (0.4) | 4.7 (0.4) | 0.781 | 4.7 (0.4) | 4.7 (0.4) | −0.148 |
| Valence | 3.9 (1.8) | 4.0 (1.7) | −0.129 | 5.6 (0.5) | 2.3 (0.5) | 31.744 |

TABLE 4 Means and SDs of stimulus attributes for Chinese and English positive and negative emotional words.

| Manipulation variables | L1 (Chinese) | | | | L2 (English) | | | |
|---|---|---|---|---|---|---|---|---|
| | Positive | Negative | *t* | *p* | Positive | Negative | *t* | *p* |
| Syllables | – | – | – | – | 2.5 (0.9) | 2.1 (0.6) | 1.633 | 0.112 |
| Letters | – | – | – | – | 7.6 (1.9) | 7.0 (1.9) | 1.000 | 0.324 |
| Strokes | 18.8 (4.9) | 17.5 (3.8) | 0.940 | 0.353 | – | – | – | – |
| Frequency | 30.5 (28.0) | 23.5 (17.6) | 0.942 | 0.353 | 21.3 (17.7) | 16.3 (13.3) | 1.002 | 0.323 |
| Familiarity | 6.3 (0.2) | 6.1 (0.2) | 1.585 | 0.121 | 6.3 (0.6) | 6.1 (0.6) | 0.862 | 0.394 |
| Arousal | 4.8 (0.5) | 4.8 (0.4) | −0.287 | 0.776 | 4.7 (0.4) | 4.7 (0.4) | 0.091 | 0.928 |
| Abstractness | 3.6 (0.4) | 3.6 (0.2) | 0.363 | 0.719 | 3.6 (0.3) | 3.6 (0.4) | 0.152 | 0.880 |
| Valence | 5.7 (0.5) | 2.2 (0.5) | 21.977 | 0.000 | 5.6 (0.4) | 2.4 (0.5) | 22.977 | 0.000 |

congruency as within-subjects independent variables, and language switch costs of mean RTs and ERs as dependent variables.

## Procedures and tasks

The experiment employing an emotional priming paradigm was performed individually on a desktop computer with a 20-inch monitor in the laboratory of Ningbo University in China. In the experiment, E-prime 2.0 was used to present stimuli and collect data. Participants were seated in front of the screen at a distance of approximately 60 cm. They were instructed to categorize the valence of emotional words in the valence categorization task (*cf*., Houwer et al., 2001) including 12 practice trials and 4 blocks of 320 experimental trials. Each trial started with a red fixation cross (+) presented in the center of the screen for 500 ms, followed by a 200 ms emotional face as a prime to evoke participants' emotion and then a 100 ms blank screen. After that, a Chinese or English emotional word as a target appeared for 1,500 ms until a response was given or 1,500 ms had elapsed, then a blank screen of 500 ms appeared (see Figure 1). Participants were informed to press the F-key on the keyboard with the left index finger if the word was positive and press the J-key on the keyboard with the right index finger if the word was negative. The valence-response key association was counterbalanced across participants.

The experimental trials were divided into previous and current trials according to the sequence. In terms of this division and the valence of emotional words, the overall trials can be categorized into four types of 80 trials each: positive–positive, positive–negative, negative–negative and negative–positive. Based on the emotional congruency of priming and target stimuli, 4 sequence relation types of 80 trials each were also constructed: congruent-congruent, congruent-conflict, conflict-congruent, conflict-conflict. The repetition and switch of both language and emotional valence of emotional word were balanced. In all, there were 40 language repetition positive trials, language repetition negative trials, language switch positive trials, language switch negative trials in both L1 and L2. The experiment lasted approximately 20 min. Short breaks were given between blocks.

# Results

One participant's data was excluded due to accuracy rate lower than 80% in the valence categorization task. Data from the first three trials, trials with wrong responses (7.4%), RTs less than 200 ms (0.1%) and exceeding $M \pm 3SD$ (1.7%) in the valence categorization task were discarded. The remaining data were analyzed by SPSS 17.0. A repeated measure of $2 \times 2 \times 2 \times 2$ ANOVA with IC ability (high vs. low), language switch costs (Chinese vs. English), emotional valence (positive vs. negative) and emotional congruency (congruent vs. conflict) was performed. Due to space constraints, the results of insignificant interactions were not reported. Table 5 presented the descriptive statistics of the two groups' language switch costs in different emotional conditions.

The RT data analysis yielded significant main effects of emotional congruency, $F$ (1, 82) = 9.943, $p < 0.05$, $\eta_p^2 = 0.108$, and language, $F$ (1, 82) = 16.495, $p < 0.001$, $\eta_p^2 = 0.167$, with larger language switch costs in the emotional congruent condition relative to emotional conflict condition and larger Chinese switch costs than English switch costs. No significant main effects of IC ability and emotional valence were observed ($ps > 0.05$). The interaction between emotional congruency and emotional valence was significant, $F$ (1, 82) = 4.541, $p < 0.05$, $\eta_p^2 = 0.052$. Simple effect analysis revealed smaller language switch costs for negative emotional words in the emotional conflict condition as opposed to the emotional congruent condition ($p < 0.05$), and larger language switch costs for negative emotional words relative to positive ones in the emotional congruent condition ($p = 0.080$). Furthermore, there was an emotional valence by language interaction, $F$ (1, 82) = 24.361, $p < 0.001$,

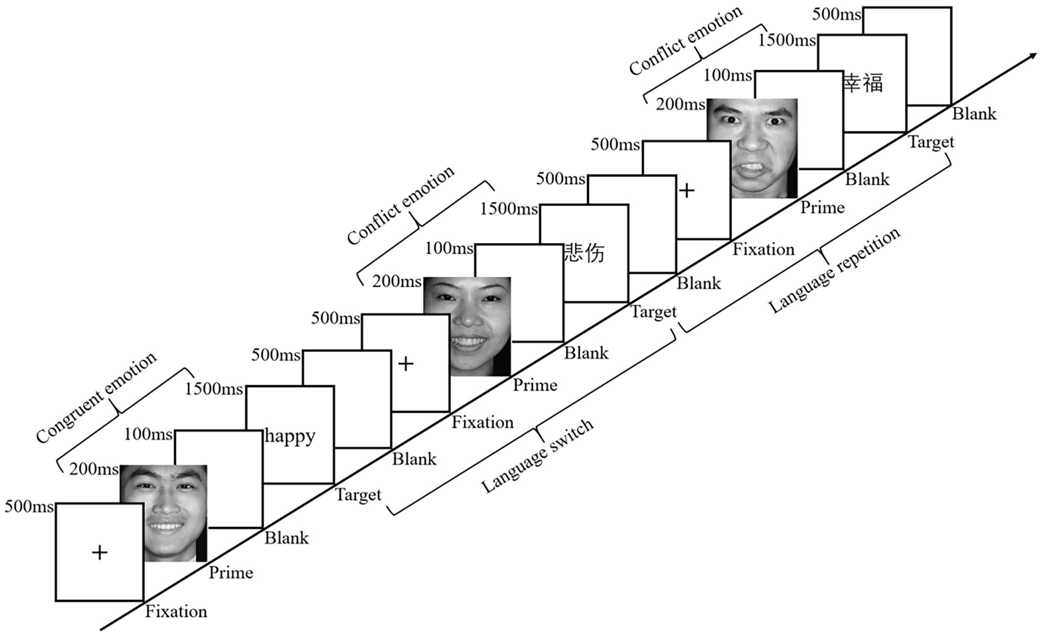


FIGURE 1
Flowchart of three experimental trials. Reproduced with permission from Yaojia Luo. Facial images reproduced with permission from Gong et al. (2011).

**TABLE 5** Descriptive statistics of high- and low-IC ability groups' language switch costs in different emotional conditions.

| Conditions | Switch costs | High-IC | | | | Low-IC | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | L1 (Chinese) | | L2 (English) | | L1 (Chinese) | | L2 (English) | |
| | | Positive | Negative | Positive | Negative | Positive | Negative | Positive | Negative |
| Congruent | RTs | 27.5 (59.0) | 27.7 (46.7) | 0.7 (37.8) | 34.4 (54.7) | 24.5 (38.9) | 19.4 (48.3) | −2.5 (46.9) | 8.3 (53.6) |
| | ERs | −1.0 (5.1) | 0.1 (8.5) | −0.8 (6.6) | −0.8 (10.5) | −2.4 (6.6) | −0.2 (7.2) | −0.6 (8.1) | −1.4 (10.4) |
| Conflict | RTs | 35.2 (33.0) | −10.1 (57.2) | −9.7 (41.2) | 12.8 (56.3) | 26.3 (31.4) | 8.2 (45.7) | −12.9 (57.3) | 2.1 (56.1) |
| | ERs | 0.2 (4.8) | −0.1 (7.2) | −1.4 (7.9) | −2.3 (10.1) | 0.5 (5.9) | −1.1 (7.7) | −3.5 (8.9) | −0.2 (10.8) |

$\eta_p^2 = 0.229$. Simple effect analysis showed larger Chinese switch costs for positive emotional words compared to negative ones and opposite English switch cost pattern for negative and positive emotional words ($ps < 0.05$). In addition, participants' Chinese switch costs were larger than their English switch costs for positive emotional words ($p < 0.001$).

The three-way interaction among emotional congruency, emotional valence and language reached significance, $F$ (1, 82) = 5.188, $p < 0.05$, $\eta_p^2 = 0.060$. Simple simple effect analysis revealed larger Chinese switch costs for negative emotional words in the emotional congruent condition relative to emotional conflict condition, and larger Chinese switch costs for positive relative to negative emotional words in the emotional conflict condition ($ps < 0.05$). Moreover, participants' English switch costs for negative emotional words were not only larger in the emotional congruent condition relative to emotional conflict condition ($p = 0.058$), but also larger than those for positive emotional words in both emotional congruent and conflict conditions ($ps < 0.05$), and their Chinese switch costs were larger than their English switch costs for positive emotional words in both emotional congruent and conflict conditions ($ps < 0.001$). Notably, the interaction among IC ability, emotional valence and language was marginally significant, $F$ (1, 82) = 2.940, $p = 0.090$, $\eta_p^2 = 0.035$. Simple simple effect analysis indicated that participants with high-IC ability displayed larger English switch costs for negative emotional words than those with low-IC ability ($p = 0.060$) and larger Chinese switch costs for positive relative to negative emotional words ($p < 0.05$). Additionally, high-IC participants displayed larger English switch costs for negative emotional words relative to positive ones ($p < 0.05$) and smaller Chinese switch costs relative to English switch costs for negative emotional words ($p = 0.085$). As for positive emotional words, the two groups' Chinese switch costs were significantly larger than their English switch costs ($ps < 0.001$).

The ER data analysis revealed that none of the main effects reached significance (all $ps > 0.05$). The three-way interaction among emotional congruency, emotional valence and language was marginally significant, $F$ (1, 82) = 3.306, $p = 0.073$, $\eta_p^2 = 0.039$. Simple simple effect analysis showed smaller Chinese switch costs for positive emotional words in the emotional congruent condition relative to emotional conflict condition and smaller English switch costs than Chinese switch costs for positive emotional words in the emotional conflict condition ($ps < 0.05$).

## Discussion

The current study aimed to explore the impacts of cool and hot EFs on language control during comprehension-based language switching between embodied Chinese emotional words and less embodied English emotional words. The results showed larger Chinese switch costs than English switch costs and larger language switch costs in the emotional congruent condition relative to the emotional conflict condition, indicating that the embodiment of language and the emotional congruency eliciting the involvement of hot EF can modulate the language control during Chinese-English emotional word code-switching. These findings are in line with our prediction for the role of the embodiment of language, but in contrast to our prediction for the role of emotional congruency. In the emotional conflict condition, the occurrence of conflict can not only trigger participants' adjustment mechanism and improve their cognitive control level in the same conflict task based on the emotion adaptation effect in conflict monitor theory proposed by Gratton et al. (1992), but also lead to the compensatory adjustments in perceptual selection, which in turn serves to alleviate conflict (Berlyne, 1960). Hence, participants' language switch costs in the emotional conflict condition were smaller. Another possible reason is that the emotional congruent and conflict conditions may trigger participants' appetitive and aversive motivational systems, respectively. Emotional conflict, as a kind of aversive signal (Dreisbach and Fischer, 2012; Fritz and Dreisbach, 2013), could trigger participants' aversive motivational system and capture their attention easily and automatically (Gawronski et al., 2005), resulting in less cognitive processing resources invested to avoid the cognitive loss in the emotional conflict condition. However, in the emotional congruent condition, driven by the appetitive motivational system, participants are more inclined to take a risk and invest more cognitive processing resources to achieve better performance. This observation in our study contrasts the finding of Liu et al. (2019), which reported larger language switch costs for the conflict processing context over the congruent processing context. These divergent research findings may be attributed to the different manipulation of the congruent and conflict conditions in the two studies. Specifically, compared to the non-emotional conditions in Liu et al. (2019), the congruent and conflict conditions in our study were emotional, and congruency and emotions could jointly affect the language switch costs, thus modulating the language switch cost pattern of non-emotional conditions.

However, the insignificant difference between the language switch costs of positive and negative emotional words in our study suggested that emotional valence which can induce the involvement of hot EF did not have a significant impact on language control during Chinese-English emotional word comprehension. This finding was inconsistent with that of the first experiment of Zhang (2020), which reported larger language switch costs for positive emotional words than negative emotional words. One possible explanation for the disparate findings is the cognitive task load elicited by the emotional priming stimuli (i.e., emotional faces). In the emotional priming paradigm, the emotions displayed by emotional faces can be recognized automatically (see Hanley et al., 1990), thus preferentially occupying participants' cognitive resources and leading to insufficient cognitive resources for the valence categorization task. Hence, no significant difference was observed between the language switch costs of positive and negative emotional words. This discrepancy may also be due to the modulating effects of emotional congruency on emotional valence in this study. Different from the processing in the first experiment of Zhang (2020), participants in our study should not only resort to IC ability of cool EFs for language switching, but also need to rely on hot EF to fulfill the valence categorization task and resolve the emotional conflict induced by the emotional priming paradigm. Therefore, part of the resources used for categorizing the valence of emotional words and switching languages in Zhang (2020), especially the resources in the hot emotional system, should be diverted to solve the emotional conflict, resulting in limited resources used for the valence categorization task and then insignificant difference between the language switch costs of positive and negative emotional words. This possible explanation was supported by the result of insignificant difference between the language switch costs of positive and negative emotional words in the emotional conflict condition.

Meanwhile, we also found smaller language switch costs for negative emotional words in the emotional conflict condition as opposed to the emotional congruent condition. van Steenbergen et al. (2009, 2010) found that emotions can regulate conflict-driven control. Specifically, positive emotion can offset the negative emotion elicited by conflict and reduce participants' conflict-driven cognitive control, thus lessening the conflict adaptation effect; whereas negative emotion can enhance participants' conflict-driven cognitive control, which in turn generates larger conflict adaptation effect, thus resulting in smaller language switch costs in the emotional conflict condition. This study also found larger language switch costs for negative over positive emotional words in the emotional congruent condition. A possible reason is that compared with conflict as an aversive signal (Dreisbach and Fischer, 2012; Fritz and Dreisbach, 2013), congruent emotion may be experienced as a pleasant signal which can enhance the emotional intensity of positive words and promote task switching (Wang and Guo, 2008), reducing the language switch costs. Another possible reason is that positive emotion can enhance cognitive flexibility (Isen and Daubman, 1984; Isen et al., 1992), which regulates the cognitive control by reducing the costs of information retention in task (Dreisbach, 2006), leading to smaller language switch costs for positive emotional words. The above results not only indicated that emotional congruency could modulate the effects of emotional valence on participants' language control, but also indicated that different emotional information of hot EFs could interact and jointly affect participants' language control during language switching.

Apart from the role of hot EFs, this study also concerned the impact of cool EF on language control. The insignificant main effect of IC ability in this study suggest that cool EF did not have a significant impact on language control during Chinese-English emotional word comprehension. This finding contrasts with that found in previous production-based language switching studies (Linck et al., 2012; Liu et al., 2014; Chang et al., 2018; Liu et al., 2019), reporting larger language switch costs for low-IC group over high-IC group. This discrepancy corroborated the different switching processes between comprehension- and production-based language switching proposed by other researchers (e.g., Qi et al., 2010; Reynolds et al., 2016; Struys et al., 2019). One possibility for this discrepancy lies in the distinct switching processes between language comprehension and production. In comprehension-based language switching, the stimuli are coded in a specific language (i.e., univalent), no response competition is generated, thus resorting to domain-specific control mechanism of language activation during language switching (Struys et al., 2019). In contrast, the stimuli in language production are bivalent which can elicit two responses, thus generating response competition. In this sense, participants should deploy domain-general IC mechanism to suppress the competition during language switching (Reynolds et al., 2016). Another plausible reason for this difference is whether the modulation of emotional information (hot EFs) occurs during language switching. Specifically, emotional stimuli were used in the current study and the conflict elicited in the language switching processes was emotional conflict, which may regulate participants' language control during language switching, thus affecting the relationship between their IC ability and language control. However, non-emotional stimuli were employed in previous studies, thus evoking cognitive conflict without emotional information. Therefore, it might have little regulatory effect on language control, nor did it affect the relationship between participants' IC ability and language control during the language switching processes.

However, it is worth noting that the interaction among IC ability, emotional valence and language was marginally significant. High-IC participants showed larger English switch costs for negative emotional words compared to low-IC participants. This finding can be attributed to high-IC participants' longer RTs for negative emotional words on English switch trials, which was derived from the data analysis of the two groups' RTs in English repetition and switch trials for negative emotional words. Pavlenko (2012) posited that the decreased automaticity of emotional processing in L2 on account of less embodied cognition can reduce interference effects and lower electrodermal reactivity to negative emotional stimuli, indicating the attenuated activation of L2 negative emotional words. With regard to English switch trials for negative emotional words, the attenuated activation of L2 negative emotional words may occupy less processing resources and retain more processing resources to switch languages for participants with both high- and low-IC ability. In addition, there was higher inhibition of English in the previous trials for high-IC participants over their low counterparts, thus it took longer for high-IC participants to overcome the inhibition. This result suggests that emotional valence can modulate the impact of IC ability on language control during language switching processes.

## Conclusion

This study adopted the emotional priming paradigm to explore the effects of both hot and cool EFs on language control during Chinese-English emotional word comprehension. The findings showed that (1) emotional congruency and the embodiment of language could modulate the language control; (2) emotional congruency and emotional valence interacted and jointly affected the language control; and (3) emotional valence could modulate the impact of IC ability on the language control. These results reveal for the first time that hot and cool EFs concurrently and interactively exert their influence on language control during Chinese-English emotional word comprehension. As mentioned previously, cool EFs include other cognitive skills besides IC ability, such as working memory and cognitive flexibility. Future studies exploring the effects of cool EFs on language control can involve more cognitive skills. Moreover, the primes and targets in the present study only include positively and negatively valenced stimuli, further studies on the effects of hot EFs on language control can use neutral faces and words to constitute a baseline condition, and better reveal the role of hot EFs through the comparative results between different valences.

## Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author.

## Ethics statement

The studies involving human participants were reviewed and approved by the Ethics Committee of Ningbo University. The participants provided their written informed consent to participate in this study.

## Author contributions

JZ: conceptualization, data collection, formal analysis, investigation, methodology, resources, visualization, and writing – original draft. LF: conceptualization, investigation, methodology, project administration, and supervision. All authors contributed to the article and approved the submitted version.

## Funding

This work was supported by the Fundamental Research Funds for the Provincial Universities of Zhejiang (SJWY2022010), the General Scientific Research Project of Zhejiang Provincial Education Department (Y202249103), and the Double First-Class Disciplines Major Project of Beijing Foreign Studies University (2022SYLZD008).

## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

## Publisher's note



## Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2023.1087513/full#supplementary-material

## References

Abutalebi, J., Annoni, J.-M., Zimine, I., Pegna, A. J., Seghier, M. L., Lee-Jahnke, H., et al. (2008). Language control and lexical competition in bilinguals: an event-related fMRI study. *Cereb. Cortex* 18, 1496–1505. doi: 10.1093/cercor/bhm182

Babcock, L., and Vallesi, A. (2015). Language control is not a one-size-fits-all languages process: evidence from simultaneous interpretation students and the n-2 repetition cost. *Front. Psychol.* 6:1622. doi: 10.3389/fpsyg.2015.01622

Başgöze, Z., Gönül, A. S., Baskak, B., and Gökçay, D. (2015). Valence-based word-face Stroop task reveals differential emotional interference in patients with major depression. *Psychiat. Res.* 229, 960–967. doi: 10.1016/j.psychres.2015.05.099

Berlyne, D. E. (1960). *Conflict, Arousal and Curiosity*. New York: McGraw-Hill.

Bond, M. H., and Lai, T.-m. (1986). Embarrassment and code-switching into a second language. *J. Soc. Psychol.* 126, 179–186.

Bradley, M. M., and Lang, P. J. (1999). *Affective Norms for English Words (ANEW): Instruction Manual and Affective Rating*. Gainesville: The NIMH Center for the Study of Emotion and Attention, University of Florida.

Chang, X., Bai, H., and Wang, P. (2018). The effect of inhibitory control ability training on bilinguals' language switching. *Foreign Lang. Teach. Res.* 50, 569–583.

Costa, A., and Santesteban, M. (2004). Lexical access in bilingual speech production: evidence from language switching in highly proficient bilinguals and L2 learners. *J. Mem. Lang.* 50, 491–511. doi: 10.1016/j.jml.2004.02.002

Declerck, M., Grainger, J., Koch, I., and Philipp, A. M. (2017). Is language control just a form of executive control? Evidence for overlapping processes in language switching and task switching. *J. Mem. Lang.* 95, 138–145. doi: 10.1016/j.jml.2017.03.005

Dreisbach, G. (2006). How positive affect modulates cognitive control: the costs and benefits of reduced maintenance capability. *Brain Cogn.* 60, 11–19. doi: 10.1016/j.bandc.2005.08.003

Dreisbach, G., and Fischer, R. (2012). Conflicts as aversive signals. *Brain Cogn.* 78, 94–98. doi: 10.1016/j.bandc.2011.12.003

Fazio, R. H., Sanbonmatsu, D. M., Powell, M. C., and Kardes, F. R. (1986). On the automatic activation of attitudes. *J. Pers. Soc. Psychol.* 50, 229–238. doi: 10.1037/0022-3514.50.2.229

Fritz, J., and Dreisbach, G. (2013). Conflicts as aversive signals: conflict priming increases negative judgments for neutral stimuli. *Cogn. Affect. Behav. Neurosci.* 13, 311–317. doi: 10.3758/s13415-012-0147-1

Gawronski, B., Deutsch, R., and Strack, F. (2005). Approach/avoidance-related motor actions and the processing of affective stimuli: incongruency effects in automatic attention allocation. *Soc. Cogn.* 23, 182–203. doi: 10.1521/soco.23.2.182.65627

Gong, X., Huang, Y. X., Wang, Y., and Luo, Y. J. (2011). Revision of the Chinese facial affective picture system. *Chin. Ment. Health J.* 25, 40–46. doi: 10.3969/j.issn.1000-6729.2011.01.011

Gratton, G., Coles, M. G., and Donchin, E. (1992). Optimizing the use of information: strategic control of activation of responses. *J. Exp. Psychol. Gen.* 121, 480–506. doi: 10.1037/0096-3445.121.4.480

Green, D. W. (1998). Mental control of the bilingual lexico-semantic system. *Biling. Lang. Cogn.* 1, 67–81. doi: 10.1017/S1366728998000133

Guo, T. M., Liu, F. Q., Chen, B., and Li, S. C. (2013). Inhibition of non-target languages in multilingual word production: evidence from Uighur-Chinese-English trilinguals. *Acta Psychol.* 143, 277–283. doi: 10.1016/j.actpsy.2013.04.002

Haas, B. W., Omura, K., Constable, R. T., and Canli, T. (2006). Interference produced by emotional conflict associated with anterior cingulate activation. *Cogn. Affect. Behav. Neurosci.* 6, 152–156. doi: 10.3758/cabn.6.2.152

Hanley, J. R., Pearson, N. A., and Young, A. W. (1990). Impaired memory for new visual forms. *Brain* 113, 1131–1148. doi: 10.1093/brain/113.4.1131

Harnishfeger, K. K., and Bjorklund, D. F. (1993). "The ontogeny of inhibition mechanisms: a renewed approach to cognitive development" in *Emerging Themes in Cognitive Development*. eds. M. L. Howe and R. Pasnak (New York: Springer-Verlag), 28–49.

Harris, C. L., Ayçiçeği, A., and Gleason, J. B. (2003). Taboo words and reprimands elicit greater autonomic reactivity in a first language than in a second language. *Appl. Psycholinguist.* 24, 561–579. doi: 10.1017/S0142716403000286

Hernandez, A. E., and Meschyan, G. (2006). Executive function is necessary to enhance lexical processing in a less proficient L2: evidence from fMRI during picture naming. *Biling. Lang. Cogn.* 9, 177–188. doi: 10.1017/S1366728906002525

Houwer, J. D., Hermans, D., and Spruyt, A. (2001). Affective priming of pronunciation responses: effects of target degradation. *J. Exp. Soc. Psychol.* 37, 85–91. doi: 10.1006/jesp.2000.1437

Isen, A. M., and Daubman, K. A. (1984). The influence of affect on categorization. *J. Pers. Soc. Psychol.* 47, 1206–1217. doi: 10.1037/0022-3514.47.6.1206

Isen, A. M., Niedenthal, P. M., and Cantor, N. (1992). An influence of positive affect on social categorization. *Motiv. Emotion* 16, 65–78. doi: 10.1007/BF00996487

Kazanas, S. A., and Altarriba, J. (2016). Emotion word type and affective valence priming at a long stimulus onset asynchrony. *Lang. Speech* 59, 339–352. doi: 10.1177/0023830915590

Lang, P. J., Bradley, M. M., and Cuthbert, B. N. (1997). "Motivated attention: affect, activation, and action" in *Attention and Orienting: Sensory and Motivational Processes*. eds. P. J. Lang, R. F. Simons and M. T. Balaban (Hillsdale, NJ: Erlbaum), 97–136.

Li, P., Sepanski, S., and Zhao, X. (2006). Language history questionnaire: a web-based interface for bilingual research. *Behav. Res. Methods* 38, 202–210. doi: 10.3758/BF03192770

Linck, J. A., Schwieter, J. W., and Sunderman, G. (2012). Inhibitory control predicts language switching performance in trilingual speech production. *Biling. Lang. Cogn.* 15, 651–662. doi: 10.1017/S136672891100054X

Liu, H. H., Fan, N., Shen, X. Y., and Ji, J. Y. (2013). Effect of cognitive flexibility on language switching in non-proficient bilinguals: an ERPs study. *Acta Psychol. Sin.* 45, 636–648. doi: 10.3724/SP.J.1041.2013.00636

Liu, C., Jiao, L., Wang, Z. Y., Wang, M. X., Wang, R. M., and Wu, Y. J. (2019). Symmetries of bilingual language switch costs in conflicting versus non-conflicting contexts. *Biling. Lang. Cogn.* 22, 624–636. doi: 10.1017/S1366728918000494

Liu, H. H., Liang, L. J., Zhang, L., Lu, Y., and Chen, B. G. (2017). Modulatory role of inhibition during language switching: evidence from evoked and induced oscillatory activity. *Int. J. Biling.* 21, 57–80. doi: 10.1177/1367006915600800

Liu, H. H., Rossi, S., Zhou, H. X., and Chen, B. G. (2014). Electrophysiological evidence for domain-general inhibitory control during bilingual language switching. *PLoS One* 9:e110887. doi: 10.1371/journal.pone.0110887

Liu, H. H., Zhang, Y. Y., Blanco-Elorrieta, E., He, Y. Y., and Chen, B. G. (2020). The role of proactive control on subcomponents of language control: evidence from trilinguals. *Cognition* 194, 1–12. doi: 10.1016/j.cognition.2019.104055

Macizo, P., Bajo, M. T., and Paolieri, D. (2012). Language switching and language competition. *Sec. Lang. Res.* 28, 131–149. doi: 10.1177/0267658311434893

Mosca, M., and de Bot, K. (2017). Bilingual language switching: production vs. recognition. *Front. Psychol.* 8:934. doi: 10.3389/fpsyg.2017.00934

O'Toole, S. E., Monks, C. P., Tsermentseli, S., and Rix, K. (2020). The contribution of cool and hot executive function to academic achievement, learning related behaviours, and classroom behaviour, early child dev. *Care* 190, 806–821. doi: 10.1080/03004430.2018.1494595

Pavlenko, A. (2005). *Emotions and Multilingualism*. Cambridge, UK: Cambridge University Press.

Pavlenko, A. (2012). Affective processing in bilingual speakers: disembodied cognition? *Int. J. Psychol.* 47, 405–428. doi: 10.1080/00207594.2012.743665

Pessoa, L. (2009). How do emotion and motivation direct executive control? *Trends Cogn. Sci.* 13, 160–166. doi: 10.1016/j.tics.2009.01.006

Poplack, S. (1980). Sometimes I'll start a sentence in Spanish Y TERMINO EN ESPAÑOL: toward a typology of code-switching. *Linguistics* 51, 11–14. doi: 10.1515/ling-2013-0039

Prior, A., and Gollan, T. H. (2013). The elusive link between language control and executive control: a case of limited transfer. *J. Cogn. Psychol.* 25, 622–645. doi: 10.1080/20445911.2013.821993

Qi, Z. Q., Peng, D. L., and Ding, G. S. (2010). A research on the language switching process of Chinese-English bilinguals under unpredictable conditions. *Psychol. Sci.* 33, 1051–1053.

Reynolds, M. G., Schlöffel, S., and Peressotti, F. (2016). Asymmetric switch costs in numeral naming and number word reading: implications for models of bilingual language production. *Front. Psychol.* 6:2011. doi: 10.3389/fpsyg.2015.02011

Scott, G. G., O'Donnell, P. J., Leuthold, H., and Sereno, S. C. (2009). Early emotion word processing: evidence from event-related potentials. *Biol. Psychol.* 80, 95–104. doi: 10.1016/j.biopsycho.2008.03.010

Séguin, J. R., Arseneault, L., and Tremblay, R. E. (2007). The contribution of "cool" and "hot" components of decision-making in adolescence: implications for developmental psychopathology. *Cogn. Dev.* 22, 530–543. doi: 10.1016/j.cogdev.2007.08.006

Sheikh, N. A., and Titone, D. (2016). The embodiment of emotional words in a second language: an eye-movement study. *Cogn. Emot.* 30, 488–500. doi: 10.1080/02699931.2015.1018144

Smith, T. W. (2016). *The Book of Human Emotions*. New York: Little, Brown and Company.

Soanes, C. (2009). *Pocket Oxford English-Chinese Dictionary*. Oxford: Oxford University Press.

Struys, E., Woumans, E., Nour, S., Kepinska, O., and Noort, M. V. D. (2019). A domain-general monitoring account of language switching in recognition tasks: evidence for adaptive control. *Biling. Lang. Cogn.* 22, 606–623. doi: 10.1017/S1366728918000342

Thomas, M. S. C., and Allport, A. (2000). Language switching costs in bilingual visual word recognition. *J. Mem. Lang.* 43, 44–66. doi: 10.1006/jmla.1999.2700

van Steenbergen, H., Band, G. P. H., and Hommel, B. (2009). Reward counteracts conflict adaptation: evidence for a role of affect in executive control. *Psychol. Sci.* 20, 1473–1477. doi: 10.1111/j.1467-9280.2009.02470.x

van Steenbergen, H., Band, G. P. H., and Hommel, B. (2010). In the mood for adaptation: how affect regulates conflict-driven control. *Psychol. Sci.* 21, 1629–1634. doi: 10.1177/0956797610385951

Wang, Y. M., and Guo, D. J. (2008). The effects of positive emotions on task switching. *Acta Psychol. Sin.* 40, 301–306. doi: 10.3724/SP.J.1041.2008.00301

Wang, H. L., Liu, W. Y., Sui, D. N., and Yu, Q. B. (2009). Asymmetric language switching costs in second language learners. *J. Dalian Univ. Technol.* 30, 121–125.

Williams, A., Srinivasan, M., Liu, C., Lee, P., and Zhou, Q. (2020). Why do bilinguals code-switch when emotional? Insights from immigrant parent-child interactions. *Emotion* 20, 830–841. doi: 10.1037/emo0000568

Yao, Z., and Wang, Z. H. (2014). Concreteness of positive word contributions to affective priming: an ERP study. *Int. J. Psychophysiol.* 93, 275–282. doi: 10.1016/j.ijpsycho.2014.06.005

Zelazo, P. D., and Müller, U. (2002). "Executive function in typical and atypical development" in *The Wiley-Blackwell Handbook of Childhood Cognitive Development*. ed. U. Goswami (London: Wiley-Blackwell), 445–469.

Zhang, J. (2020). *The Effects of Cool and Hot Executive Functions on Code-switching Costs of Chinese-English Emotion Words*. Doctoral Dissertation. Beijing, China: Beijing Foreign Studies University.

Zhang, J., Fan, L., and Wang, Z. (2020). A study on code-switching of Chinese-English bilinguals during emotion word comprehension. *Foreign Lang. Res.* 4, 66–71.

frontiers | Frontiers in Psychology

TYPE Original Research
PUBLISHED 27 January 2023
DOI 10.3389/fpsyg.2023.1127275



OPEN ACCESS

EDITED BY
Huili Wang,
Dalian University of Technology, China

REVIEWED BY
Degao Li,
Zhejiang International Studies University, China
Tongquan Zhou,
Southeast University, China

*CORRESPONDENCE
Xiaolu Wang
✉ lucywxl@zju.edu.cn

SPECIALTY SECTION
This article was submitted to Language Sciences, a section of the journal Frontiers in Psychology

RECEIVED 19 December 2022
ACCEPTED 09 January 2023
PUBLISHED 27 January 2023

CITATION
Zheng W and Wang X (2023) Humor experience facilitates ongoing cognitive tasks: Evidence from pun comprehension. *Front. Psychol.* 14:1127275.
doi: 10.3389/fpsyg.2023.1127275



# Humor experience facilitates ongoing cognitive tasks: Evidence from pun comprehension

Wei Zheng[1] and Xiaolu Wang[2,3,4]*

[1]School of Foreign Languages, China Three Gorges University, Yichang, China, [2]School of Foreign Languages, Hangzhou City University, Hangzhou, China, [3]School of International Studies, Zhejiang University, Hangzhou, China, [4]School of Humanities and Communication Arts, Western Sydney University, Kingswood, NSW, Australia

Empirical findings on embodied cognition have shown that bodily states (e.g., bodily postures and affective states) can influence how people appreciate humor. A case in point is that participants were reported to read pleasant sentences faster than the unpleasant controls when their muscles responsible for smiling were activated. However, little research has examined whether the feeling of amusement derived from humor processing like pun comprehension can exert a backward influence on ongoing cognitive tasks. In the present study, the participants' eye movements were tracked while they rated the comprehensibility of humorous sentences (homophone puns) and two types of unfunny control sentences (congruent and incongruent). Fixation measures showed an advantage in the critical homophone region for the congruent controls relative to the homophone puns; however, this pattern was reversed in terms of total sentence reading time. In addition, the humor rating scores acquired after the eye-tracking experiment were found negatively correlated to the overall sentence reading time, suggesting that the greater amusement the participant experienced the faster they would finish the rating task. Taken together, the current results indicate that the positive affect derived from humor can in turn provide immediate feedback to the cognitive system, which enhances text comprehension. As a result, the current finding provides more empirical evidence for the exploration of the interaction between the body and cognition.

KEYWORDS

**humor experience, homophone puns, facilitative effect, cognitive task, embodied cognition**

## Introduction

Humor is a crucial component of human social interaction and cognitive functioning (Vrticka et al., 2013). Although nearly all of us can easily detect humor when we experience it, we may still find it quite challenging to give a precise definition of humor. Indeed, the notion of humor is quite general and can vary from person to person. In this paper, we adopt the definition given by Martin and Ford (2018) that humor is a comprehensive term consisting of a verbal or non-verbal stimulus that people perceive as funny, the mental processes of generating or perceiving such an amusing stimulus, and as well as the emotional response of mirth. In particular, we focus on verbal humor, namely, humor expressed through language, rather than non-verbal ones such as comedy performances.

Previous research has shown that the positive emotion associated with humor can lead to cognitive benefits, especially in creativity and memory. Indeed, researchers have long noted the positive correlation between humor and creativity (Koestler, 1964), and have postulated at least two hypotheses on why humor may be beneficial for creativity. The Flexible Thought Hypothesis argues that the flexible cognitive processes involved in understanding humor can boost the divergent thinking necessary for creative tasks (Belanger et al., 1998). The Positive Emotion Hypothesis emphasizes that the positive emotion we experience in humor can reduce tension and anxiety, which in turn can promote our thinking and enhance our ability to integrate divergent materials (Isen et al., 1987). In addition, convincing evidence has also accumulated from empirical studies supporting the idea that humor can enhance memory. Specifically, researchers have found that humorous materials are recalled better when presented in educational settings (Ziv, 1988), advertising settings (Krishnan and Chakravarti, 2003), or research settings (Chambers and Payne, 2014).

Despite such cognitive benefits from a relatively long-term point of view, recent humor theories, especially cognitive-perceptual ones, predict a processing disadvantage for online humor comprehension. The Incongruity-Resolution Model, for example, argues that understanding a humorous text involves two separate stages (Suls, 1972; Attardo and Raskin, 1991). When reading humorous texts, such as a joke, the reader actively forms a discourse representation based on the input from the set-up sentences. However, this mental representation is then disconfirmed by the punchline, resulting in the detection of incongruity (the first stage). To get the joke, the reader has to search for the other plausible but less likely interpretation hinted by the punchline and resolve the semantic dilemma (the second stage). Take the following joke, for example.

> Son: *Daddy, what is an alcoholic?*
> Father: *Do you see those four trees, son? An alcoholic would see eight trees.*
> Son: *Um, Dad, there are only two trees.*

Before reading the last sentence of the dialog, one is likely to assume that it is a regular conversation about a sober father teaching his son something. However, the disparity between the number of trees reported by the father and son (four vs. two) leads to the incongruity, which triggers the reader to work out another interpretation to incorporate the new information. Once the reader realizes that it is not a sober but drunken father who is talking to his son, then the incongruity is resolved and the humor occurs. According to this theory, the incongruity-resolution process in a joke costs more cognitive resources than a straight ending (e.g., Son: "*Um, Dad, I understand it now*."), hence prolonged reading times for the punchline (See also the standard pragmatic view, Grice, 1975).

The Space Structuring Model also predicts a disadvantage for the processing of humorous materials (Coulson et al., 2006). Adopting the framework of cognitive linguistic theories, such as Mental Space Theory, Conceptual Blending, and Frame Semantics, this theory claims that background and contextual information plays an active and vital role in the meaning-construction process rather than just helping to disambiguate the meaning of ambiguous words. In the case of humor comprehension, the Space Structuring Model proposes "frame shifting" as the central process for getting the humor, in which a new frame is retrieved from the long-term memory when the incoming information is inconsistent with the currently-activated frame (Coulson, 2015). Due to this extra cognitive process, it also predicts extra processing efforts for reading humorous materials.

The predicted disadvantage of processing humorous materials has been demonstrated in several empirical studies. Coulson and Kutas (1998) employed the self-paced reading paradigm to investigate the processes of joke comprehension. In their experiment, the authors used one-line jokes and manipulated the relationship between preceding contexts and the sentence-final words so that the final words either trigger a frame-shifting process or remain consistent with the currently-activated frame (e.g., *I asked the woman at the party if she remembered me from last year and she said she never forgets a dress/face*). It was shown that the participants spent longer reading times on the final words in the humorous condition (e.g., *dress*) than in the non-funny control condition (e.g., *face*). Since the final words in both conditions were matched in cloze probability, these results were interpreted as reflecting the additional cognitive cost for the frame-shifting process. Coulson et al. (2006) replicated this processing disadvantage for jokes in an eye-tracking experiment using the same materials. In addition to longer reading times, the participants were also found to regress more into the previous context from the sentence-terminal position, indicating the readers needed to re-evaluate the relationship between the punchline and the discourse representation built upon the sentential context. In a recent ERP study, Mayerhofer and Schacht (2015) also reported increased reading times for the final words in the so-called garden-path jokes compared to those in sentences with coherent endings. Take one of their jokes for example. *Mummy, I just turned 14. May I please, finally, be allowed to wear a bra and makeup? –No, you are not. Eat up your soup, my son!* In this joke, the initial interpretation is disconfirmed by *my son* and readers have to reanalyze the speakers' relationship in order to form a new coherent representation. Additionally, joke endings also elicited enhanced N400 amplitudes, indicating greater integration difficulties (Kutas and Federmeier, 2011).

In contrast to the above-mentioned findings, results from other studies have suggested that humor facilitates online cognitive processing. Mitchell et al. (2010), for example, reported a humor facilitation effect when the participants were reading humorous jokes relative to non-humorous controls which differed only in the last sentence. It was found that jokes were not only rated as more humorous, recalled better, and more importantly read faster in the last sentence (the punchline). Since the participants were required to rate the funniness of the materials during the experiment, these authors attributed the longer reading times to the re-examination of possible humorous contents that may have been missed during the initial reading. Such a facilitative effect was also supported by Ferstl et al.'s (2017) eye-tracking study. To disentangle the cognitive and affective process involved in joke comprehension, Ferstl and colleagues compared jokes with texts involving revision of the situation model without being funny. According to their results, jokes were not only read faster than the revision texts but also induced fewer regressions back to the previous context. Therefore, these authors attributed these advantages to the positive affect elicited by jokes.

Besides the facilitative effect reported in jokes, Zheng and Wang (2022) also observed a similar effect using another important type of verbal humor, homophone puns. In this study, the participants were required to rate the funniness of three types of sentences: homophone puns (e.g., 陈氏男科医院, 您的男题我们解决。*Chen's Andrology Hospital, your male problems we solve*); unfunny congruent controls (e.g., 陈氏男科医院, 您的难题我们解决。*Chen's Andrology Hospital, your difficult problems we solve*) and unfunny incongruent controls (e.g., 陈氏牙科医院, 您的男题我们解。*Chen's Dental Hospital, your male problems we solve*). As they expected, these authors observed longer fixation times on the homophones in the pun condition (e.g., 男题, *male problem*) than in the congruent controls (e.g., 难题, *difficult problem*). However, since the homophones used in the congruent controls were more salient than those in the pun condition, it was difficult to decide whether the difficulty had arisen from the salience difference or from the extra effort needed for extra cognitive processes (e.g., frame shifting). Nevertheless, a reverse pattern was found regarding sentence reading times. Specifically, the authors found that the participants read the homophone puns faster than the two control conditions before moving on to the funniness rating task. Zheng and Wang (2022) argued that this finding could reflect a humor facilitation effect where the readers felt more confident to move on after they had gotten the pun.

Taken together, disputes still exist in the literature concerning whether humor comprehension can exert a facilitative effect on online cognitive processes. This inconsistency, firstly, could be partially due to the different materials used in the experiments. For example, the experimental materials used by Coulson et al. (2006) consisted of only one sentence, the final word of which could either turn the sentence into a joke or unfunny control (e.g., *She read so much about the bad effects of smoking; she decided to give up the reading/habit.*). While the jokes used by Mitchell et al. (2010) and Ferstl et al. (2017) were composed of several sentences. More importantly, the prolonged reading times for jokes reported by Coulson et al. (2006) were only reading times of these sentence-final words. In contrast, evidence supporting the humor facilitation effect was mainly based on reading times at the sentence level, usually those of the punchlines. Indeed, Zheng and Wang (2022) found prolonged reading times for the homophones in homophone puns, partly supporting the humor processing disadvantage predicted by the Space Structuring Model (Coulson et al., 2006); however, total reading times of the pun sentences were significantly shorter than their congruent controls differing only in the homophones, suggesting a humor facilitative effect could have occurred at a later stage. In addition, experimental tasks could have contributed to the above-mentioned discrepancies as well. So far, evidence supporting the humor facilitation effect is mainly from studies using funniness rating tasks (e.g., Mitchell et al., 2010; Zheng and Wang, 2022). As a result, more empirical data are needed to distinguish whether the facilitative effect is resulted from the positive feedback from humor *per se* or due to some specific strategies that readers formed during the funniness rating task, or both.

Answers to these questions may not only shed more light on the cognitive processing of humor but also provide new insights into the interaction between bodily status and cognition. Previous research on embodied cognition has demonstrated that certain bodily postures or status could influence how people perceive verbal humor (Strack et al., 1988; Kaspar et al., 2016). In a recent study exploring the humor-body association, Xu et al. (2022) abstracted the most frequent metaphors concerning humor and laughter based on a large-scale corpus investigation. They then primed the participants with some of these metaphors by asking them to perform related actions (e.g., "holding one's belly while bending forward and backward repeatedly," corresponding to the Chinese idiom "捧腹大笑") before they rated the materials containing jokes. Their results showed that the participants who were primed with these embodied humor metaphors reported higher funniness scores than the participants in the control group who were primed with non-metaphor actions. This finding provides more evidence that bodily posture or status can exert a feed-forward influence on how we perceive humor. However, it is still unclear whether particular bodily experiences (e.g., the feeling of amusement) can provide immediate feedback that can modulate cognition. As a result, this unanswered question has also motivated the present investigation.

To sum up, the present study attempts to answer the following research question: whether the facilitative effect in reading humorous texts reported in previous studies is due to positive feedback from the affect system or merely derived from task-related strategies? Since most of the studies that reported such a facilitative effect have employed a funniness rating task, it was possible that the task requirements rather than enhanced cognitive efforts have led participants to spend more time reading the unfunny text in case they would miss some potential funny contents, hence the shorter reading times for their humorous counterparts (e.g., Mitchell et al., 2010). To better compare with some of the previous research, the participants read one-line sentences adopted from Zheng and Wang's (2022) study while their eye movements were recorded. They needed to rate the comprehensibility of each sentence, which could be a homophone pun, an unfunny congruent control, or an unfunny incongruent control. If the participants would still exhibit a facilitative effect in reading the homophone puns, it would be more reasonable to claim that such an advantage may result from the humor experience itself rather than from task-based strategies. Besides, the participants were also asked to rate the same set of sentences after the eye-tracking experiment. If the facilitation effect for cognition was valid, it could be predicted that there should be a positive correlation between the facilitation and the amusement that readers received from humor.

# Methods

## Participants

A group of 32 native Chinese speakers (11 males and 21 females, mean age = 22.8, SD = 2.6) participated in the current study. The participants, recruited through the campus forum of a university in China, had normal or corrected-to-normal vision and were paid a small amount of money after the experiment. The study received approval from the research ethics board of the university.

## Materials

The experimental materials were adopted from the study of Zheng and Wang (2022) on homophone-pun comprehension, including a total of 72 one-line sentence triads falling into three conditions: homophone puns, congruent controls, and incongruent controls. The homophone puns were mostly collected from newspaper headlines, in which the less salient homophones were presented visually.[1] The congruent controls were the same as their homophone-pun counterparts except the salient homophones were used instead. The incongruent controls were also created from the homophone puns by just replacing the critical context nouns supporting the less salient homophones with unrelated ones, matched in both lexical frequencies and stroke numbers (*ps* > 0.10). See Table 1 for an example trial of the three conditions and Table 2 for the lexical properties of the critical noun.

Readability of the experimental sentences was pre-rated by 45 students through an online questionnaire, which showed that the congruent controls were as statistically understandable (*M* = 3.81,

1 A group of 30 judges was invited to write down the first word they can think of according to the homophonic sounds (expressed in Chinese *pingyin*). Homophones written down by more than 90% of the judges were defined as the salient homophones; the other homophonic alternatives were regarded as the less salient ones (Giora, 1997).

TABLE 1 Sample sentences and the setup for different region of interests (ROIs).

| Condition | Example sentences | $ROI_1$ (critical context noun) | $ROI_2$ (homophone) | $ROI_3$ (spill-over region) |
|---|---|---|---|---|
| Congruent control | 陈氏男科医院, 您的难题我们解决。 (Chen's Andrology Hospital, your difficulties we solve.) | 男科 (andrology) | 难题 (difficult problems) | 我们解决 (we solve) |
| Homophone pun | 陈氏男科医院, 您的男题我们解决。 (Chen's Andrology Hospital, your male problems we solve.) | 男科 (andrology) | 男题 (male problems) | 我们解决 (we solve) |
| Incongruent control | 陈氏牙科医院, 您的男题我们解决。 (Chen's Dental Hospital, your male problems we solve.) | 牙科 (dental) | 男题 (male problems) | 我们解决 (we solve) |

English translations were given in parentheses.

TABLE 2 Properties of context noun used in the three experimental conditions.

| Sentence type | Mean word frequency | Mean stroke number | Semantic relatedness |
|---|---|---|---|
| Congruent control | 20.54 | 16.93 | 2.35 |
| Homophone pun | 20.54 | 16.93 | 3.69 |
| Incongruent control | 22.03 | 17.18 | 1.95 |

"Semantic Relatedness" refers to the extent to which the critical context noun is semantically related to the presented homophone. Word frequency is measured in occurrences per million.

SD = 0.37) as the homophone puns ($M$ = 3.91, SD = 0.44, $p > 0.10$), while the incongruent controls ($M$ = 3.44, SD = 0.45) were more difficult to understand than the pun sentences ($p < 0.001$).

Using a Latin square design, the 72 sentence triads were divided into three counterbalanced lists, so that each participant would only see one sentence from any particular sentence triad. In addition, a total of 48 fillers (36 unfunny ones) from the same source as the homophone puns were added to further lower the participants' expectation of a humorous text. Therefore, the participants read 120 sentences during the eye-tracking experiment, including 24 homophone puns, 24 congruent controls, 24 incongruent controls, and 48 fillers. Among these sentences, humorous sentences accounted for about 30%.

## Apparatus

Eye movement data were collected from the right eye with the SR Research Eyelink 1000 plus system, at a sampling rate of 1,000 Hz. The text was displayed on a 19-inch monitor (Dell P1917S) with a refresh rate of 75 Hz and a screen resolution of 1024*768 pixels. A chin rest with forehead support was used for all participants to maximize the tracking accuracy throughout the experiment.

## Procedures

At the beginning of the eye-tracking experiment, the participants were briefly introduced to how the eye tracker works and were instructed to rate the readability of each sentence they read. The participants were seated 72 cm from the monitor. A three-point horizontal calibration was implemented and revalidation was carried out when necessary. The average validation error was within 0.5° of visual angle.

Each trial started with a cross sign displayed on the left side of the screen. Once a stable fixation at the cross sign was detected for 500 ms, a sentence would appear with its first character replacing the cross. Otherwise, the calibration procedure would be initiated in 5 s. The participants read in a normal manner and needed to press the space bar on the keyboard after they finished reading the sentence. Then, they rated the readability of the sentences on a 5-point Likert scale by mouse-clicking the corresponding number on the screen. To avoid superficial ratings, a yes/no comprehension question would follow in one-quarter of the sentences.

Each participant finished six practice trials to familiarize themselves with the experimental procedures and could try again if needed. The 120 experimental trials were pseudo-randomly assigned to four 30-trial blocks so that sentences from the same condition would not appear three times consecutively. The participants took a short break between each block. The whole eye-tracking experiment lasted for approximately 40 minutes. The procedures of the eye-tracking experiment are illustrated in Figure 1.

After the eye-tracking experiment, the participants took a rest for about 5 minutes and then were given a paper questionnaire to rate the funniness of the sentences they had previously read on a 5-point Likert scale.

# Results

The mean accuracy from the comprehension questions was 89.7% (SD = 6%), suggesting that the participants, in general, had understood the experimental sentences. Data from one participant was dropped from further data analysis due to low comprehension accuracy (66.7%). Moreover, trials indicating insufficient cognitive processing were eliminated (affecting around 2.6% of the data), including trials where less than two (out of the five) interest areas were visited, trials with more than two blinks, and trials with a total reading time less than 1,000 ms or greater than 2.5 standard deviations from their condition mean.

All statistical analyses were conducted using R (version 3.6.3, R Development Core Team, 2019). For analyses using continuous data (e.g., reading times) as the dependent variables, linear mixed-effect models (LMMs) were constructed using the *lmer* function from the lme4 package (Bates et al., 2015). Compared with traditional analyses, such as *t*-test or ANOVA, this method can disentangle fixed effects (experimental effect) from random effects (e.g., participant and item variations). In addition, the LMMs can produce robust results even when the sphericity and homoscedasticity assumptions are not met (Cunnings, 2012).

Following the recommendation of Barr et al. (2013), we started the model with a maximum random effect structure, including a random intercept and slope for each participant and trial item. In cases where

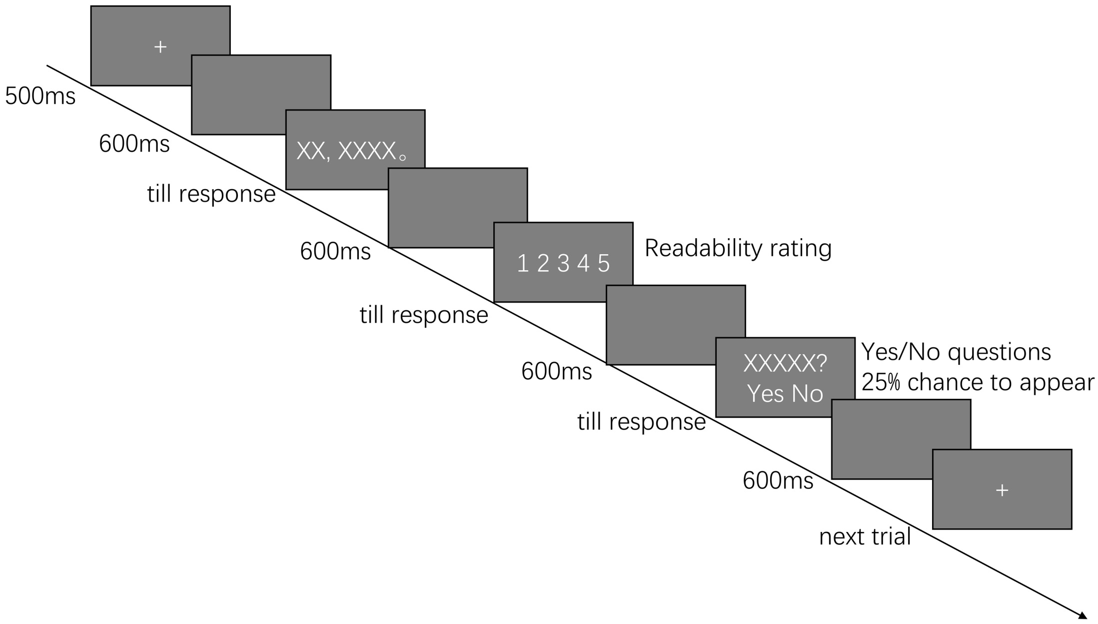


FIGURE 1
An illustration of the procedures of the eye-tracking experiment.

the model failed to converge or indicated a singularity issue, the by-item random slop was dropped, followed by the by-participant random slop if necessary. Model comparisons were conducted using the ANOVA function to select better models with lower AIC values. Besides, log-transformations were used on the time-related measures to better meet the assumption of normal distribution of the residuals. Considering the small number of fixed and random effects and the large number of observations estimated, effects with a *t* or *z* value greater than 2 were treated as significant.

## Sentence-level analysis

Sentence-level analyses were conducted on the reading times, readability rating scores, and funniness rating scores of the three different conditions. See Figure 2 for a summary of each measure.

### Sentence reading time

Sentence reading time (*RT*) was defined as the duration from the presentation of a sentence to the moment the participants pressed the space bar on the keyboard. The average sentence reading times of the three sentence types can be seen in Figure 2 (Panel A). LMMs were built to analyze the relationship between the sentence *RT* and the sentence *Type* controlling the factor of sentence *Length*. We started the model with a maximum random effect structure: lmer(log10(RT) ~ Type + Length + (1 + Type|Subject) + (1 + Type|Item), data = Data).

According to the analysis, the pun sentences ($M$ = 3,525 ms, SD = 1,481 ms, $t = -2.56$) were read significantly faster than both the congruent controls ($M$ = 3,754 ms, SD = 1786 ms), and the incongruent controls ($M$ = 4,147 ms, SD = 1745 ms, $t = 9.75$). This finding shows that even when the participants were required to read for comprehension, the homophone puns were still read faster than the congruent controls. As a result, this pattern is consistent with that reported by Zheng and Wang (2022), where the participants were required to focus on the affective side of the same set of materials by conducting a funniness rating task.

### Readability and funniness ratings

The average readability scores of the three conditions are shown in Figure 2 (Panel B). Consistent with the readability ratings acquired through the online questionnaire, the homophone puns ($M$ = 4.27, SD = 0.45) were rated as understandable as the congruent control sentences ($M$ = 4.14, SD = 0.45, $p > 0.10$), indicating that the observed difference in sentence reading time was unlikely due to readability differences in the two sentence conditions. On the other hand, incongruent controls ($M$ = 3.47, SD = 0.64, $p < 0.01$) were rated more difficult to understand than the other two conditions. Pairwise comparisons with Bonferroni correction showed that the homophone puns ($M$ = 3.63, SD = 0.62) were rated significantly funnier than both the congruent controls ($M$ = 2.53, SD = 0.67, $p < 0.01$) and the incongruous controls ($M$ = 3.08, SD = 0.54, $p < 0.01$).

The average funniness rating scores of the three conditions are illustrated in Figure 2 (Panel C). To examine whether the feeling of mirth can have a facilitative effect on cognitive decision latencies, we also analyzed the relationship between the *RT* and the funniness rating scores (*Fun*) controlling the factor of sentence *Length* with the following formula: lmer(log10(RT) ~ Fun + Length + (1 + Type|Subject) + (1 + Type|Item), data = Data). It was found that the sentence reading time was negatively related to the funniness rating scores ($\beta = -0.01$, SE = 0.00, $t = -2.35$), suggesting the funnier the participants rated the sentence the faster they would finish the rating task.

## Interest-area analysis

Prior to the analyses, fixations shorter than 80 ms or longer than 1,200 ms were excluded from further analysis (affecting around 4.6% of

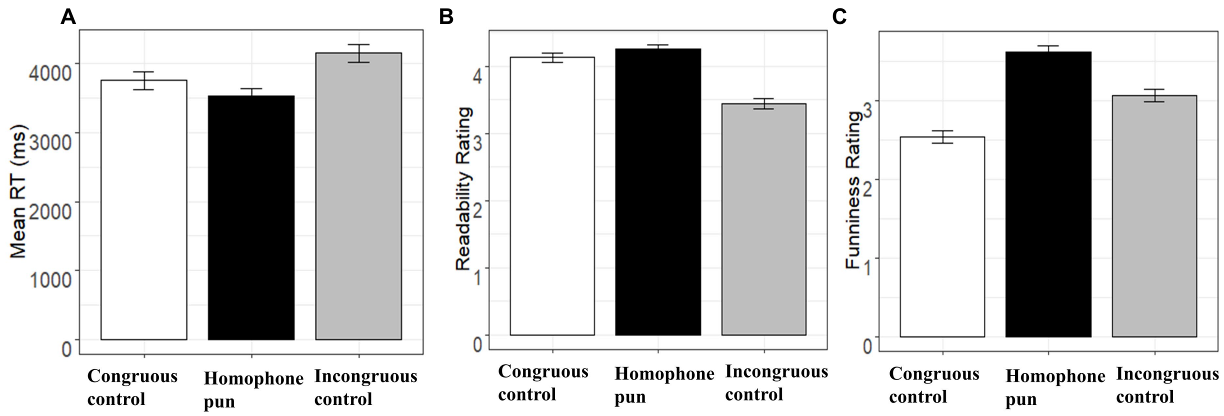


FIGURE 2
Summary statistics at the sentence level. Sentence reading time, readability rating, and funniness rating for the three sentence conditions are shown in panels **(A–C)**, respectively.

data). Three regions of interest (ROIs) were set up for eye movement analyses, including the critical context word area ($ROI_1$), the homophone area ($ROI_2$), and the spillover area ($ROI_3$). The $ROI_1$ was set up to examine the context effect, the $ROI_2$ to investigate the processing of the homophones, and the $ROI_3$ to capture possible spillover effects resulted from the homophones. See also Table 1 for an illustration of the setup for different ROIs.

The following eye-movement measures were analyzed. Gaze duration (GD, also called *first-pass time*) is the total duration of all fixations from entering a region until existing either to the right or to the left. Total duration (TD, also called *dwell time*) is the summed duration of all fixations in the region. Regression Path Duration (RPD) is the total duration of all fixations that occur from the first fixation on a region until the target region is exited to the right. Regression-In proportion (Reg_In) and Regression-Out proportion (Reg_Out) is defined as the probability that readers regress into or out of a certain region, respectively.

Among the fixation-based measures, GD is sensitive to early lexical processing, and TD can reflect both the early lexical processing and the semantic integration processes (Rayner et al., 2004). The regression-based measures, RPD, Reg_In, and Reg_Out, can index extra cognitive effort that readers have to make, especially when they experience difficulty in integrating the current input and have to search for more clues in previous regions.

Mean fixation times and the standard error for the eye movement measures are shown in Table 3. Eye movement measures were defined as dependent variables and subjected to a series of linear mixed-effect models using the homophone pun condition as the baseline for comparisons.

## The critical context noun region ($ROI_1$)

For $ROI_1$, early measures revealed no significant difference between the congruent control and the pun sentences in GD ($\beta = 0.01$, SE = 0.01, $t = 1.01$), which was as expected since the same critical context word was used. However, the critical context words were read significantly slower in the congruent controls than in the homophone puns in TD ($\beta = 0.04$, SE = 0.01, $t = 2.77$). Regression-In data showed that the participants were more likely to regress to the context noun region in the congruent control condition ($\beta = 0.38$, SE = 0.13, $z = 2.83$, $p < 0.01$).

Gaze-duration analyses revealed no significant difference between the pun sentences and the incongruent controls in $ROI_1$ ($\beta = 0.01$, SE = 0.01, $t = 0.98$), indicating that the lexical properties of the critical context nouns were well-matched. As in the congruent control condition, the participants also spent longer times in $ROI_1$ in the incongruent control condition in terms of TD ($\beta = 0.07$, SE = 0.01, $t = 4.93$) and were more likely to regress into this region ($\beta = 0.33$, SE = 0.13, $z = 2.46$, $p < 0.05$).

## The homophone region ($ROI_2$)

For the homophone region, fixation-based measures revealed that the less salient homophone in the homophone pun condition was read significantly slower than its salient homophone mate in the congruent condition (GD, $\beta = -0.07$, SE = 0.01, $t = -6.09$; TD, $\beta = -0.08$, SE = 0.01, $t = -6.18$). However, regression-based measures showed another pattern: the participants were less likely to reexamine this region in the former condition (Reg_In, $\beta = -0.33$, SE = 0.13, $t = -2.51$, $p < 0.05$) and there was no significant difference between the two conditions in terms of RPD ($\beta = 0.00$, SE = 0.03, $t = 0.06$).

Fixation analyses showed that the less salient homophone in homophone puns was read as fast as in the incongruent condition in terms of GD ($\beta = 0.01$, SE = 0.01, $t = 0.73$), but faster in terms of TD ($\beta = 0.07$, SE = 0.01, $t = 5.25$), indicating that the homophones were easier to be integrated in the homophone-pun condition. This pattern was further supported by the longer RPD in the incongruent condition ($\beta = 0.10$, SE = 0.03, $t = 3.95$).

## The spill-over region ($ROI_3$)

In $ROI_3$, analyses suggested no difference between the congruent control sentences and the homophone puns in GD ($\beta = -0.01$, SE = 0.01, $t = -0.60$) and in TD ($\beta = -0.02$, SE = 0.02, $t = -1.06$) and in RPD ($\beta = 0.00$, SE = 0.02, $t = 0.27$). However, the participants regressed significantly more in the congruent control condition ($\beta = 0.39$, SE = 0.17, $z = 2.33$, $p < 0.05$), consistent with the finding that the participants were more likely to re-examine $ROI_1$ in this condition.

Analyses of gaze duration show no significant difference between the pun sentences and the incongruent sentences ($\beta = 0.02$, SE = 0.01, $t = 1.09$). In contrast, analyses on other measures revealed significant differences in TD ($\beta = 0.04$, SE = 0.02, $t = 2.98$), RPD ($\beta = 0.09$, SE = 0.02,

TABLE 3 Fixation data of different regions of interest (ROIs) in the three experimental conditions.

| | $ROI_1$ (critical context noun) | | | $ROI_2$ (homophone) | | | $ROI_3$ (spill-over region) | | |
|---|---|---|---|---|---|---|---|---|---|
| | CC | HP | IC | CC | HP | IC | CC | HP | IC |
| GD (ms) | 271(6) | 260(6) | 272(6) | 324(8) | 390(9) | 397(9) | 373(11) | 382(11) | 408(13) |
| TD (ms) | 431(12) | 392(11) | 480(14) | 545(14) | 633(14) | 753(18) | 642(23) | 643(20) | 724(23) |
| RPD (ms) | 726(30) | 729(28) | 709(26) | 1,136(55) | 1,124(55) | 1,428(62) | 1,672(56) | 1,630(50) | 1991(60) |
| Reg_In (%) | 36.9(2) | 29.5(2) | 36.0(2) | 27.1(2) | 32.7(2) | 35.5(2) | NA | NA | NA |
| Reg_Out (%) | 21.3(2) | 20.5(2) | 20.4(2) | 27.3(2) | 22.8(2) | 25.6(2) | 82.8(2) | 77.3(2) | 84.4(2) |

CC, congruent control; HP, homophone pun; IC, incongruent control. Standard errors are reported in parentheses.

$t = 5.81$), and Reg_Out ($\beta = 0.50$, SE = 0.17, $z = 2.96$, $p < 0.05$), suggesting it was more difficult to make sense of the incongruent sentences.

## Discussion

The current eye-tracking study has investigated whether humor experience (i.e., the feeling of amusement or mirth) can give immediate feedback to the brain and facilitate ongoing cognitive tasks. In the experiment, the participants read homophone-pun sentences and two comparison controls (congruous and incongruous). It is found that though the salient homophones in the congruent control sentences were read significantly faster than their less salient homophone mates in the homophone puns, this lexical-level advantage was overridden when regression-based measures were examined. Specifically, the participants were more likely to make regressions from both the homophone region and the following sentential-final region in the congruous control condition. In addition, sentence-level analyses have exhibited a negative correlation between sentence reading time and the funniness rating score. Since the participants were required to rate the comprehensibility instead of the funniness of the sentences during the eye-tracking experiment, it was unlikely that the participants had strategically regressed more in the unfunny control conditions to double-check for potential humorous contents. Instead, we argue that the positive feeling of mirth when getting the pun facilitated the cognitive processes of the readability rating task, hence the fewer regressions and faster sentence reading times.

### Facilitative effect in reading humorous texts

The facilitative effect in reading puns observed in the present study is consistent with previous research reporting a similar effect in reading jokes (Mitchell et al., 2010; Ferstl et al., 2017). However, unlike previous studies where the participants were usually required to rate the funniness of the materials, we required the participants to rate the readability of the sentences. Compared with a funniness rating task, this task can lead the participants to focus more on the cognitive aspects of the reading materials instead of the affective ones. Indeed, Mitchell et al. (2010) contributed the facilitative effect of jokes, at least partly, to the funniness rating task, which could have led the participants to regress more to recheck humorous contents that could have been missed. As a result, it is more conclusive for the current study to claim that reading humorous materials can facilitate online cognitive processing.

The shorter reading times for pun sentences than both the congruent and incongruent controls lend further support to Ferstl et al.'s (2017) explanation. According to these authors, such a facilitative effect in reading humorous materials (e.g., jokes) could be attributed to the instantaneous feedback about the correctness of the interpretation. Although homophone puns are used in the current study instead of jokes, puns are also an important type of verbal humor, which has been widely used in the research of humor (e.g., Goel and Dolan, 2001). As a result, we believe that it is the same mechanism that underlies the facilitative effects in both studies. In addition to reading times, Ferstl et al. (2017) also found that the regression rate from the punchline to the context region was negatively correlated with the funniness rating score in the jokes. And in the current study, we have found a negative correlation between the sentence reading time and the funniness rating score. Although the funniness rating scores were acquired after the participants finished the eye-tracking experiment, this general trend can also support this cognitive feedback account.

The faster sentence reading time for humorous materials (i.e., homophone puns), however, does not contrast with the study of Coulson et al. (2006). Ferstl et al. (2017) also compared their results with this earlier study and attributed the differences to task requirements and experimental materials. Specifically, their joke materials were dialogs consisting of several sentences, and the participants were required to finish either a funniness rating task or revision judgment, while in Coulson et al.'s (2006) study the participants only read one-line jokes and answered comprehension questions. Of course, these differences could account for some of the variations in the reading times. However, the total reading times reported in Coulson et al.'s (2006) study were the total reading times of the sentence-final words, which should not be compared directly with the sentence reading times reported in Ferstl et al.'s (2017) study. Comparatively speaking, the materials and tasks used in the current study are more comparable to those of Coulson et al. (2006). In the present study, we also used one-line sentences which can either turn into a homophone pun or a non-humorous control by the critical homophone. And the readability rating task was also supposed to focus the participants' attention on the cognitive aspects of the text.

Indeed, the longer fixations (GD and TD) at the critical homophone regions for the homophone puns compared with the congruent controls are consistent with the findings of Coulson et al. (2006), supportive of their Space Structure Model. According to this theory, understanding homophone puns involves a frame-shifting process (retrieving a new frame from the long-term memory), which is cognitively more effortful and increases the reading times for words that trigger this process (namely, the less salient homophones). Of course, the difference in GD can at least partially be resulted from the lexical properties of the homophones since less salient homophones are used in the homophone pun condition. However, the differences in TD indicate more difficulty in integrating the less salient homophones into the context, presumably indicating the extra effort involved in the process of frame-shifting. In addition, this difficulty seemed quite local and we did not observe a significant spill-over effect in the following region. It is worth noting that this local (lexical) processing difficulty in reading homophone puns is not necessarily in conflict with the global (sentential) advantage of this type of humorous material. On the contrary, this reverse pattern highlighted the positive feedback of humor was derived after the participants had gotten the pun.

In addition, the significantly longer fixations for both the $ROI_2$ and $ROI_3$ in the incongruent condition relative to the pun condition indicate that the incongruity caused by the less salient homophone was detected. Note that the incongruent condition was created from the homophone pun condition by replacing the critical context noun with an unrelated noun. Although this manipulation made the less salient homophone difficult to process, the participants could still make some sense out of the sentence with the meaning of the unpresented salient homophones, as in the homophone pun condition. According to the Incongruity-Resolution Model, the resolution of incongruity should elicit the feeling of amusement in humorous texts (Suls, 1972). However, funniness rating scores for the incongruous condition ($M = 3.08$) indicate more uncertainty rather than amusement. As a result, this discrepancy indicates the other important prerequisite of humor experience, namely a nonserious playful mindset (Wyer and Collins, 1992). In the homophone pun condition, the participants were more likely to treat the less salient homophones as "a play on words" in the pun condition while as "spelling mistakes" in the incongruent condition. In fact, some of the participants did express their doubt about potential misspellings in the incongruent condition after finishing the experiment.

## Interaction between the body and cognition

The current findings can shed new light on the embodied cognition approach to humor studies. One of the central claims of the embodied cognition theories is that our knowledge or cognition is derived from our interaction with the outside world through our bodied experience, and therefore is fundamentally anchored in multiple bodily ways such as simulations, situated actions, and bodily states (Barsalou, 2008). An increasing literature has accumulated supporting this embodied view of language (See Barsalou, 2010 for a review). One of the most extensively used paradigms in this line of research is to prime participants with certain sensorimotor experiences that are associated with abstract concepts and then evaluate the influence they may have on the ensuing processing of the corresponding concepts. For example, Kaspar et al. (2016) asked some of their participants to pull a manikin leg or yank a chain before they added captions for cartoons. According to the funniness ratings of independent judges, these participants generated funnier captions than the control group who received no such action primes, suggesting that these bodied actions (connected with metaphorical expressions, i.e., *pulling one's leg* and *yank one's chain*) may have a "feed-forward" impact on the ongoing language tasks. In contrast, the participants in the current study were faster in finishing rating the more humorous homophone-pun sentences without any bodily prime before the task, indicating the bodily state of feeling mirth can also exert a "feed-backward" influence on ongoing cognitive tasks. As a result, the current study lends more support to the embodied cognition view of language processing.

The interaction between cognition and affect observed in the current study can be better explained by models that implicitly distinguish the cognitive and affective aspects of verbal humor. Chan et al. (2013), for example, proposed a three-staged model of verbal humor processing based on their fMRI study, including incongruity detection, incongruity resolution, and humor elaboration (See also Wyer and Collins, 1992). According to their findings, these three stages have their specific neural signatures in the brain: the incongruity-detection stage is characterized by greater activation in the right middle temporal gyrus and right medial frontal gyrus, the incongruity-resolution stage is associated with greater activation in the left superior frontal gyrus and left inferior parietal lobule, and the feeling of mirth activates rewarding areas such as the subcortical bilateral amygdalae and bilateral parahippocampal gyri. These findings have provided convincing evidence that the cognitive and affective aspects associated with humor are underpinned by discrete neural networks. As a result, this cognitive-affective model can delineate a more complete picture of humor processing than the classic cognitive-perceptual models, such as the incongruity-resolution model (Suls, 1972).

One limitation of the current study needs to be noted. Namely, the funniness rating scores obtained in this study could be affected by the experimental procedures. Since our first concern is to disentangle the positive feedback triggered by the humor experience from the potential strategic influence formed by the funniness rating task, the funniness rating scores were collected after the eye-tracking experiment. Although the general patterns in the ratings of the three sentence types were consistent with that of Zheng and Wang's (2022) study, some of these scores could suffer from the fatigue or practice effect.

# Conclusion

In conclusion, the current study provides new evidence that the feeling of mirth that we experience from reading humorous texts can send instantaneous feedback to our cognitive system and facilitate ongoing cognitive tasks. This finding is consistent with the embodied cognition view of language, which emphasizes the essential role of bodily experience in shaping our cognition. In addition, this interaction between body and cognition also suggests humor theories should incorporate both the cognitive and affective components to better account for our humor experience.

# Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

# Ethics statement

The studies involving human participants were reviewed and approved by Research Ethics Board of Zhejiang University. The patients/participants provided their written informed consent to participate in this study.

# Author contributions

WZ and XW conceived and designed the experiments and revised the manuscript. WZ performed the experiments and analyzed the data and wrote the manuscript. All authors contributed to the article and approved the submitted version.

# Funding

This study is supported by the Major Project of National Social Science Foundation of China (14ZDB155).

## Acknowledgments

The study was carried out in partial fulfillment of the requirements for WZ's doctoral dissertation at Zhejiang University. We would like to thank Professor Kevin Tang for his help in data analysis.

## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

## Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

## Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2023.1127275/full#supplementary-material

## References

Attardo, S., and Raskin, V. (1991). Script theory revis(it)ed: joke similarity and joke representation model. *Humor* 4, 293–348. doi: 10.1515/humr.1991.4.3-4.293

Barr, D. J., Levy, R., Scheepers, C., and Tily, H. J. (2013). Random effects structure for confirmatory hypothesis testing: keep it maximal. *J. Mem. Lang.* 68, 255–278. doi: 10.1016/j.jml.2012.11.001

Barsalou, L. W. (2008). Grounded cognition. *Annu. Rev. Psychol.* 59, 617–645. doi: 10.1146/annurev.psych.59.103006.093639

Barsalou, L. W. (2010). Grounded cognition: past, present, and future. *Top. Cogn. Sci.* 2, 716–724. doi: 10.1111/j.1756-8765.2010.01115.x

Bates, D., Machler, M., Bolker, B. M., and Walker, S. C. (2015). Fitting linear mixed-effects models using lme 4. *J. Stat. Softw.* 67, 1–48. doi: 10.18637/jss.v067.i01

Belanger, H. G., Kirkpatrick, L. A., and Derks, P. (1998). The effects of humor on verbal and imaginal problem solving. *Humor* 11, 21–31. doi: 10.1515/humr.1998.11.1.21

Chambers, A. M., and Payne, J. D. (2014). Laugh yourself to sleep: memory consolidation for humorous information. *Exp. Brain Res.* 232, 1415–1427. doi: 10.1007/s00221-013-3779-7

Chan, Y. C., Chou, T. L., Chen, H. C., Yeh, Y. C., Lavallee, J. P., Liang, K. C., et al. (2013). Towards a neural circuit model of verbal humor processing: an fMRI study of the neural substrates of incongruity detection and resolution. *NeuroImage* 66, 169–176. doi: 10.1016/j.neuroimage.2012.10.019

Coulson, S. (2015). "Frame-shifting and frame semantics: joke comprehension on the space structuring model" in *Cognitive Linguistics and Humor Research*. eds. G. Brône, K. Feyaerts and T. Veale (Berlin: Mouton de Gruyter).

Coulson, S., and Kutas, M. (1998). Frame-shifting and sentential integration. Technical Report Cog Sci., UCSD-98.03. UCSD: San Diego.

Coulson, S., Urbach, T. P., and Kutas, M. (2006). Looking back: joke comprehension and the space structuring model. *Humor* 19, 229–250. doi: 10.1515/humor.2006.013

Cunnings, I. (2012). An overview of mixed-effects statistical models for second language researchers. *Second. Lang. Res.* 28, 369–382. doi: 10.1177/0267658312443651

Ferstl, E. C., Israel, L., and Putzar, L. (2017). Humor facilitates text comprehension: evidence from eye movements. *Discourse Process.* 54, 259–284. doi: 10.1080/0163853x.2015.1131583

Giora, R. (1997). Understanding figurative and literal language: the graded salience hypothesis. *Cogn. Linguist.* 8, 183–206. doi: 10.1515/cogl.1997.8.3.183

Goel, V., and Dolan, R. J. (2001). The functional anatomy of humor: segregating cognitive and affective components. *Nat. Neurosci.* 4, 237–238. doi: 10.1038/85076

Grice, P. H. (1975). "'Logic and conversation' in syntax and semantics" in *Speech Acts*. eds. P. Cole and J. Morgan (New York, NY: Academic Press).

Isen, A. M., Daubman, K. A., and Nowicki, G. P. (1987). Positive affect facilitates creative problem solving. *J. Pers. Soc. Psychol.* 52, 1122–1131. doi: 10.1037/0022-3514.52.6.1122

Kaspar, K., Jurisch, A., and Schneider, M. (2016). Embodied cognition and humor: the impact of weight sensations on humor experience and the moderating role of gender. *Curr. Psychol.* 35, 377–385. doi: 10.1007/s12144-015-9304-3

Koestler, A. (1964). *The Act of Creation*. London: Hutchinson.

Krishnan, H. S., and Chakravarti, D. (2003). A process analysis of the effects of humorous advertising executions on brand claims memory. *J. Consum. Psychol.* 13, 230–245. doi: 10.1207/S15327663JCP1303_05

Kutas, M., and Federmeier, K. D. (2011). Thirty years and counting: finding meaning in the N400 component of the event-related brain potential (ERP). *Annu. Rev. Psychol.* 62, 621–647. doi: 10.1146/annurev.psych.093008.131123

Martin, R. A., and Ford, T. E. (2018). *The Psychology of Humor: An Integrative Approach* (*2nd*). Elsevier: Academic Press.

Mayerhofer, B., and Schacht, A. (2015). From incoherence to mirth: neuro-cognitive processing of garden-path jokes. *Front. Psychol.* 6:550. doi: 10.3389/fpsyg.2015.00550

Mitchell, H. H., Graesser, A. C., and Louwerse, M. M. (2010). The effect of context on humor: a constraint-based model of comprehending verbal jokes. *Discourse Process.* 47, 104–129. doi: 10.1080/01638530902959893

R Development Core Team. (2019). *R: A Language and Environment For Statistical Computing (Version 3.6.1)*. Vienna: R Foundation for Statistical Computing.

Rayner, K., Warren, T., Juhasz, B. J., and Liversedge, S. P. (2004). The effect of plausibility on eye movements in reading. *J. Exp. Psychol. Learn. Mem. Cogn.* 30, 1290–1301. doi: 10.1037/0278-7393.30.6.1290

Strack, F., Martin, L. L., and Stepper, S. (1988). Inhibiting and facilitating conditions of the human smile: a nonobtrusive test of the facial feedback hypothesis. *J. Pers. Soc. Psychol.* 54, 768–777. doi: 10.1037/0022-3514.54.5.768

Suls, J. M. (1972). "A two-stage model for the appreciation of jokes and cartoons: an information-processing analysis" in *The Psychology of Humor*. eds. J. H. Goldstein and P. E. McGhee (San Diego, CA: Academic Press)

Vrticka, P., Black, J. M., and Reiss, A. L. (2013). The neural basis of humor processing. *Nat. Rev. Neurosci.* 14, 860–868. doi: 10.1038/nrn3566

Wyer, R. S., and Collins, J. E. (1992). A theory of humor elicitation. *Psychol. Rev.* 99, 663–688. doi: 10.1037/0033-295x.99.4.663

Xu, T. T., Liu, M. C., and Wang, X. L. (2022). How humor is experienced: an embodied metaphor account. *Curr. Psychol.* 1–13. doi: 10.1007/s12144-022-02918-1

Zheng, W., and Wang, X. (2022). Contextual support for less salient homophones and pun humor appreciation: evidence from eye movements in reading Chinese homophone puns. *Front. Psychol.* 13:875479. doi: 10.3389/fpsyg.2022.875479

Ziv, A. (1988). Teaching and learning with humor: experiment and replication. *J. Exp. Educ.* 57, 4–15. doi: 10.1080/00220973.1988.10806492

frontiers | Frontiers in Psychology

TYPE Original Research
PUBLISHED 09 February 2023
DOI 10.3389/fpsyg.2023.1128340

Check for updates

OPEN ACCESS

EDITED BY
Huili Wang,
Dalian University of Technology, China

REVIEWED BY
Chuanbin Ni,
Nanjing Normal University,
China
Hang Su,
Sichuan International Studies University,
China

*CORRESPONDENCE
Xin Weng
✉ weng_xin@shisu.edu.cn
Chao Dong
✉ dc1193632716@163.com

†These authors have contributed equally to this work

SPECIALTY SECTION
This article was submitted to
Language Sciences,
a section of the journal
Frontiers in Psychology

RECEIVED 20 December 2022
ACCEPTED 18 January 2023
PUBLISHED 09 February 2023

CITATION
Liao Q, Weng X, Dong C and Zhang Y (2023)
The facilitation of constructional meaning in the processing of Mandarin innovative *Bei* construction.
*Front. Psychol.* 14:1128340.
doi: 10.3389/fpsyg.2023.1128340



# The facilitation of constructional meaning in the processing of Mandarin innovative *Bei* construction

Qiaoyun Liao[1], Xin Weng[1*†], Chao Dong[2*†] and Yuxin Zhang[1]

[1]Institute of Linguistics, Shanghai International Studies University, Shanghai, China, [2]School of English Studies, Shanghai International Studies University, Shanghai, China

The processing of Mandarin innovative *Bei* construction in the form of "*Bei* + X" is different from that of the traditional *Bei* construction in that the former activates the constructional meaning which is intrinsically negative. This study thus investigates whether the processing of Mandarin innovative *Bei* construction is facilitated by the access of such emergent negative associations in a self-paced reading experiment with a priming paradigm. In this study, participants firstly read lexical primes in three conditions including construction-related phrases (i.e. phrases expressing the negative constructional meaning of the innovative *Bei* construction), component-related phrases (i.e. phrases expressing the partial literal meaning of the innovative *Bei* construction), and unrelated phrases (i.e. phrases expressing unrelated meaning to the innovative *Bei* construction). They then read sentences where the innovative *Bei* construction was fitted into and finally answered questions. Results showed that the lexical primes conveying the constructional meaning of the innovative *Bei* construction significantly shortened participants' reading time duration as compared with another two priming conditions. To conclude, the processing of Mandarin innovative *Bei* construction is facilitated by the priming of its constructional meaning, which provides some psychological evidence for the construction-based processing of Mandarin innovative *Bei* construction.

KEYWORDS

**Mandarin innovative *Bei* construction, facilitation, constructional meaning, processing, priming**

## 1. Introduction

Canonical passive construction expresses the force of an action, typically featured by the passive marker "被 (*bei*)" followed by a transitive verb in Mandarin. However, other words such as nouns, adjective, and intransitive verbs can also follow the passive marker *Bei*, such as "被和谐 ("be harmonied," a person's opinions that are at odds with prevalent views held in society are either silenced or edited), "被自杀 ("be suicided," be mistakenly reported to have taken one's own life)" and "被小三 ("be mistressed," be rumored to be a mistress of someone)." This innovative usage is proliferating and gaining acceptance in modern Chinese (Chen, 2010; Qiu, 2017; Chen and Hu, 2020). The above novel constructions are named as Mandarin innovative *Bei* construction with the form of "*Bei*+X" where the X can be filled with nouns, adjectives, and intransitive verbs, which is interpreted as "The subject of the construction involuntarily experiences Event X that brings negative or even detrimental consequences" (Chen and Hu, 2020, p. 91).

Since construction is a form-meaning correspondence, including morphemes, idioms, and words which are partially filled lexis and fully general linguistic patterns (Goldberg, 1995, 1996, 2006, 2019), most studies on the Mandarin innovative *Bei* construction focus on its novel properties, as many researchers have demonstrated that this construction is unique in its syntactic and semantic-pragmatic features. For example, the Mandarin innovative *Bei* construction is considered as an indirect passive structure (Yao et al., 2013), a double violation of form and meaning (Shi, 2013), a light verb structure (Huang and Liu, 2014), and a non-autonomous syntactic structure with semantic changes (Ye, 2019). More importantly, studies compare the innovative *Bei* construction with the canonical passive structure in order to examine its properties. Studies reveal that in terms of syntactic structure, the innovative *Bei* construction is more flexible than the canonical passive structure in that the parts of speech of the lexical item "X" following "*Bei*" can be adjectives, nouns, intransitive verbs as well as transitive verbs (Wang, 2011; Chen, 2017; Chen and Hu, 2020). In terms of semantics, the innovative *Bei* construction expresses various meanings including humor (Yao et al., 2013), mocking (Wang, 2019), sarcasm, and criticism (Wang, 2011; Yao and Song, 2012; Wang, 2019). Among all these associations, one of the most significant aspects is its negative, undesirable, and even detrimental meanings of the subject's participation in the event X, while the canonical passive structure conveys all positive, neutral, and negative meanings (Chen, 2017; Ye, 2019; Chen and Hu, 2020, p. 96). For example, in the example of "被自杀 ('be suicided')" mentioned above, its extra negative association is "be mistakenly reported to." By referring to Chen and Hu (2020), these negative associations are defined as the "involuntariness" of the subjects when they are experiencing event X, which mainly refers to three types including "be forced into doing," "be falsely/mistakenly portrayed as," and "be thought of/treated as" (p. 85). Taken together, these studies indicate that the "abnormal" form of the innovative *Bei* construction is especially related to its extra negative associations, constructing a form-meaning correspondence.

In addition, other researchers further relate the abovementioned negative associations with certain socio-pragmatic aspects reflected in the construction. For example, Chen (2017) considered that this construction was especially appropriate for the Chinese sociocultural context, as it expresses negative feelings toward the society in a euphemistic way. Similarly, Ye (2019) regarded the innovative *Bei* construction as the dissent against a higher authority in the society. More directly, Chen and Hu (2020) claimed that the innovative *Bei* construction is a "parody of the social reality" (p. 83) associated with ridiculousness, which demonstrates an intrinsic relationship between the negative aspects of this construction and society. Furthermore, what intrinsically relates to this sociality of the innovative *Bei* construction is people's embodied construal of the society and their interpretation of daily life (Wang, 2011). That is to say, similar to the generation of other constructions such as the causative construction (Liu, 2019) and fictive motion construction (Zhang and Zhang, 2020), the "*Bei* +X" construction also has its embodied base rooted in reality. Specifically, as for the "*Bei* +X" construction, based on the social events (i.e., Event "X") that are often ridiculous and absurd, it emerges and reflects people's observation, experience, and cognitive operation of the real world. From this perspective, it can be inferred that Mandarin innovative *Bei* construction has its embodied social ground from which the construction gains its emergent negative meanings.

Finally, some researchers go deeper into the cognitive mechanism of the innovative *Bei* construction. Generally, scholars have taken different perspectives, including the Conceptual Integration Theory (Chen, 2010; Yuan and Liang, 2016), Meme Theory (Chen, 2017), Philosophy of Mind (Qiu, 2017), and generative grammar (Han and Han, 2019), to explain how the innovative *Bei* construction is generated and comprehended. Among these perspectives, here we intend to put a special focus on Construction Grammar (CxG; Goldberg, 1995, 1996, 2006, 2019), whose key assumption is that the meaning of construction cannot be simply inferred from its components, to explore the novelty of the innovative *Bei* construction. It is because this proposal accords with the essential syntactic and semantic feature of the innovative *Bei* construction as a potential form-meaning pairing as discussed before. From this viewpoint, researchers have explored the innovative *Bei* construction by assuming that the cognitive operations underlying the comprehension of this construction are construction coercion (Wang, 2011) and/or reverse construction coercion (Chen and Hu, 2020). Specifically, it is proposed that the "*Bei* + X" structure is coerced into an entirety and should be treated and processed by regarding "*Bei* + X" as a whole instead of two separate components, which hence offers a perspective to explain how the negative associations of this construction emerge.

Taken together, previous studies have provided much interpretation of the novel syntactic-semantic features, social aspects, as well as cognitive mechanisms of Mandarin innovative *Bei* construction, especially focusing on its negative associations. Yet with regard to the exact cognitive processing of this construction, though some studies have tried to clarify that the meaning accessing process of the innovative *Bei* construction is unique from different perspectives, they have not explained whether and how people actually derive the meaning of the innovative *Bei* construction. Given this map and based on the syntactic-semantic novelty of the innovative *Bei* construction, here this study considers CxG as an appropriate perspective to explore the processing of this construction.

According to Goldberg (1995, 1996, 2006, 2019), construction is a form-meaning correspondence. When interpreting constructions, its meaning cannot be strictly predicted from its components (Goldberg, 1996) as the direct combination of meaning components might be unacceptable. For instance, in example (1) (adapted from Chen and Hu, 2020), the Chinese character "被 (*bei*)" is a marker of passive voice, which should be followed by a transitive verb as required by prescriptive rules, while the following word "旅游 (travel)" is an intransitive verb in Chinese. Hence the combination of "被 (*bei*)" and "旅游 (travel)" is ungrammatical according to the syntactic rules of canonical passive structure in Chinese.

(1) 他被旅游了。.

"He was traveled (was forced to travel away from home or was mistakenly reported to be traveling)."

However, this contradiction is reconciled by the construction coercion (Goldberg, 1995; Michaelis, 2004) of "被 (*bei*)" which coerces "旅游 (travel)" into behaving like a transitive verb and imposes itself onto other parts of the sentence (Wang, 2011; Chen and Hu, 2020). The context then helps to shade the meaning of this construction by defining "*bei*" as "be forced to travel away or be mistakenly reported to be traveling." In this way, even when the "X" slot (i.e., "travel") of this construction is a neutral word, there generate extra negative associations of "be forced to" or "be mistakenly reported to." In other words, this emergent and typical negative meaning possessed by Mandarin innovative *Bei* construction cannot be derived by simply regarding "被 (*bei*)" and "旅游 (travel)" separately, as in this case, the coercion process could not occur. Only by regarding "被旅游 ('be traveled')" as a whole can the negative associations be generated and accessed. In this way, it is reasonable to infer that the final interpretation of the innovative *Bei* construction is achieved based on a holistic processing of the "*Bei* + X" combination instead of the independent meanings of "*Bei*" or "X," which accords with the kernel assumptions of Construction Grammar.

Given the reasonability of investigating the innovative *Bei* construction from the perspective of Construction Grammar, though there is no direct empirical evidence with regard to the processing of Mandarin innovative *Bei* construction, there are some experiments demonstrating the role of the holistic processing of other constructions. For example, Bencini and Goldberg (2000) used a sorting paradigm to investigate whether readers comprehended a sentence's meaning *via* constructions. Participants were required to sort 16 types of sentences according to their understanding of the overall meanings of the sentences. These sentences varied in their verbs (i.e., throw, slice, get, take) and constructions (i.e., di-transitive, caused-motion, resultative, transitive). Results showed that native speakers favored constructions over verbs as the major classification criteria during the experiment. That is to say, constructions are better predictors of overall sentence meaning than simple verbs.

More importantly, some studies provided evidence more directly for the existence of constructions or constructional meanings. For example, Kaschak and Glenberg (2000)'s first two experiments explored the processing of "denominal verb" construction (e.g., "crutch"). In pairs of di-transitive and transitive sentences containing those denominal verbs followed by a statement of inference (transfer inference or act-on inference), participants were required to choose one sentence that fit more with the statement (Experiment One) or finish a sentence-paraphrase task and a verb-definition task (Experiment Two). Results of Experiment One revealed that when the inference implied transfer, participants were more likely to choose di-transitive sentences, indicating that the meaning of the construction is not purely tied to the semantics of the verb components, showing that constructions are more likely to be regarded as a whole. Results of Experiment Two showed that participants manifested sensitivity to the holistic constructional meaning in their paraphrases and such constructional meaning shaped the definition imposed on the innovative verbs. These two experiments provide complementary evidence for the existence of constructions and the access of constructional meaning in the comprehension of "denominal verb" construction.

Furthermore, several studies also used the priming paradigm to investigate the processing of constructional meaning. For instance, Eddington and Ruiz de Mendoza (2010) investigated the priming effects of two conditions (same-constructional vs. similar-syntactical) when participants were required to judge whether the argument constructions were correct or not. This experiment showed that when the primes had the same-constructional template with the target, as compared with primes having only similar syntactic structures, participants spent significantly shorter reaction times on the judgment task, which provides evidence for the existence of construction as the psychological entities in language processing. Also, in order to explore how the constructional meaning is accessed, Johnson and Goldberg (2013) used a lexical decision task that created target words with regard to some preceding abstract skeletal constructions (e.g., *He daxed her the norp*), including transitive, di-transitive, caused-motion, and resultative constructions. Three types of target words were created, including high frequency associated words (e.g., Gave), low frequency associated words (e.g., Handed) and semantically related non-associated words (e.g., Transferred) with regard to the construction, resulting in either congruent (e.g., when the skeletal construction and the target word were both di-transitive) or incongruent (e.g., when the skeletal construction was resultative structure but the target word was di-transitive) priming conditions. Results showed significant priming effects for congruent over incongruent target words, both for the associated words with low and high frequency, and even for those semantically related words. The findings lead support for the idea that constructions, as an entirety, convey constructional meanings that are accessed quickly and automatically without explicit instruction. More straightforwardly, in order to investigate the interaction of lexical and constructional meaning in valency coercion processing, Busso et al. (2021) used three types of Italian targets (i.e., construction-associated verbs, lexical-associated verbs, and unrelated verbs as control) primed by coercion instances of Italian argument structure constructions in a lexical decision task. Results revealed that the construction-associated and lexical-associated targets both lead to shorter reaction duration as compared with unrelated targets, which indicates that both construction- or lexical-related meanings can facilitate construction processing. In addition, participants were significantly faster in recognizing construction-associated verbs than lexical-associated ones, further indicating that constructional meaning seems to be more primary than lexical meaning. Therefore, it provides evidence for the function of constructions as a unity instead of separate components in language processing.

Taken together, these studies have provided evidence for the assumption that constructional meaning is derived by processing the construction as a whole, which more or less supports the hypotheses of Construction Grammar. However, regarding the processing of Mandarin innovative *Bei* construction, whether or not it also involves the access to its constructional meaning by regarding "*Bei* + X" as an entirety still lacks empirical investigation. Therefore, in light of the hypothesis of CxG as a possible theoretical account for the processing of the innovative *Bei* construction, this study, based on previous studies, intends to further examine how it is processed by employing a self-paced reading experiment in a priming paradigm. In particular, based on and through the novelty of the negative associations of the Mandarin innovative *Bei* construction, we aim to address the following questions:

(i) Are constructional meanings, which are reflected in the negative associations of Mandarin innovative *Bei* construction, activated in the processing of the construction?

(ii) If yes, how do the constructional meanings influence the processing procedure?

Specifically, we assume that if the negative associations of the constructions are activated and achieved, significant priming effects can be found as the reading time duration of the innovative *Bei* construction will be shorter in the construction-related condition than the other two conditions. It denotes the case that readers treat the "*Bei* + X" construction as a unity, since these negative associations could only be derived by combing "*Bei* + X" as a whole in the construction coercion process as discussed before.

# 2. Method

## 2.1. Participants

Thirty-nine native Chinese speakers (20 females, average age = 24.3, SD = 2.78) participated in this experiment and received financial rewards for their participation. Participants, who were undergraduate university students recruited at Shanghai International Studies University, all had normal or corrected to normal vision. All were right-handed and had no speech-hearing, neurological, or motor disorders.

**TABLE 1** An experimental stimuli sample.

| Priming conditions | | Context | | | | |
|---|---|---|---|---|---|---|
| | | Clause 1 | | Clause 2 | Clause 3 | |
| | | Person | The innovative *Bei* construction | Post-*Bei* region | Phrase | Phrase |
| Construction-related | 曲解 misunderstanding | 李明 Li Ming | 被贪污 is mistakenly indicted on corruption | 清正廉洁 while he is actually clean and honest | 反而 yet | 遭受冤枉 he is treated unjustly |
| Component-related | 贿赂 bribing | 李明 Li Ming | 被贪污 is mistakenly indicted on corruption | 清正廉洁 while he is actually clean and honest | 反而 yet | 遭受冤枉 he is treated unjustly |
| Unrelated | 生病 being sick | 李明 Li Ming | 被贪污 is mistakenly indicted on corruption | 清正廉洁 while he is actually clean and honest | 反而 yet | 遭受冤枉 he is treated unjustly |

## 2.2. Materials

Ninety frequently used Mandarin innovative *Bei* constructions were selected from BLCU Corpus Center[1], in order to ensure that participants were familiar with these expressions. These constructions all consisted of three Chinese characters in the form of "*Bei*+X" in which the "X" is a two-character Chinese word including nouns, verbs, and adjectives. Then these innovative *Bei* expressions were adapted into contexts with the same sentence pattern that included three short clauses (see Table 1).

For the first clause, it included a two-character noun and an innovative *Bei* construction, with the former referring to a person such as "Li Ming" who underwent the *Bei* construction, and the latter referring to the "*Bei*+X" construction as the target of this experiment. The second clause (i.e., the post-*Bei* region) was a four-character phrase, conveying information that echoed the context. This position was added to allow for the measurement of possible spill-over effects of processing as the faster or easier processing of the targets may also show in the reading time duration of their following words (Wang et al., 2006; Roberts and Liszka, 2013; Jegerski, 2014). The third clause consisted of a two-character phrase followed by a four-character phrase, which served to complete the context. In this way, all materials had the same sentence length and sentence structure. In each context, the reading time duration of the innovative *Bei* construction and the post-*Bei* region was measured and analyzed.

In addition, three types of primes were created (Priming Condition: construction-related vs. component-related vs. unrelated) with regard to each innovative *Bei* construction based on their semantic relatedness with the emergent negative associations of the innovative *Bei* construction (i.e., "*Bei*+X") as well as the partial lexical meaning of the construction (i.e., "X"). Specifically, the construction-related primes were highly related to the negative meaning of "*Bei*+X" in order to ensure that the construction-related primes reflected the emergent negative associations of the construction. In turn, the component-related primes were highly related to the "X" in order to ensure that the component-related primes reflected the partial lexical meaning of the componential item "X." Also, the unrelated primes were of very low relatedness with both "*Bei*+X" and "X," in order to ensure that they did not provide useful semantic activation of the construction.

A group of 18 native Chinese students from Shanghai International Studies University (nine females, average age = 21.83, SD = 1.51) were recruited to rate these priming words based on their semantic relatedness with either the negative associations of "*Bei*+X" or the lexical meaning of "X" in the context on a seven-point scale (1 = extremely unrelated, 7 = extremely related) as well as the plausibility of the context (1 = extremely not plausible, 7 = extremely plausible). Instructions were provided for each participant at the beginning of the test.

As for the construction-related priming condition, priming words with higher ratings with the negative associations of "*Bei*+X" and lower ratings with "X" were selected, in order to ensure that these priming words reflected the negative associations of the construction instead of the lexical meaning of "X." As for the component-related priming condition, priming words with higher ratings with "X" and lower ratings with the negative associations of "*Bei*+X" were selected, in order to ensure that these priming words reflected the lexical meaning of "X" instead of the negative associations of the construction. As for the unrelated priming condition, priming words with lower ratings with either the negative associations of "*Bei*+X" or "X" were selected, in order to ensure that these priming words did not relate to the meaning of the construction.

Finally, based on the above criteria as well as a high plausibility of context, a total of 60 sets of priming words together with their contexts were selected as the experimental materials. As for the final 60 sets of materials, analyses showed that Priming Condition and Rating Type interacted significantly [$F(2,929.18) = 14.768$, $p < 0.001$]. Further analyses revealed that the construction-related priming words ($M = 5.07$) were significantly more related to the negative associations of "*Bei*+X" than the component-related [$M = 4.44$; $\beta = -0.628$, SE = 0.155, t(924) = −4.056, $p < 0.001$] and the unrelated ($M = 2.68$) priming words [$\beta = 2.389$, SE = 0.155, $t(924) = 15.433$, $p < 0.001$], and that the component-related priming words ($M = 5.20$) were significantly more related to the "X" slot than the construction-related [$M = 4.68$; $\beta = 0.522$, SE = 0.155, $t(924) = 3.374$, $p = 0.002$] and the unrelated ($M = 2.60$) priming words [$\beta = 2.600$, SE = 0.155, $t(924) = 16.797$, $p < 0.001$]. Also, these three types of priming words did not differ in their strokes and frequency ($ps > 0.05$), and the average plausibility of the entire context was relatively high ($M = 5.22$, $SD = 3.91$). In addition, at the end of the context in each set, one follow-up balanced yes/no question about the innovative *Bei* construction was created in order to detect whether the participants have concentrated on comprehending the materials. For example, in the example provided in Table 1, the question could be "Does Li Ming take a bribe?" and the answer was "No."

In addition, a total of 90 fillers in the same sentence pattern with the experimental materials were created. The plausibility of these filler sentences was rated by another group of 20 native Chinese students from Shanghai International Studies University (10 females, average age = 21.6, SD = 1.56); and finally, 60 filler sentences were selected based on their relatively high plausibility ($M = 6.29$, SD = 0.91). For each filler sentence, a two-character priming word was created referring to the

1 http://bcc.blcu.edu.cn/

details of the context. The follow-up questions for fillers were targeted at different segments of the filler sentences, aiming to ensure that participants read every part of the sentence carefully. For example, for this filler sentence "Zhang Liang/is always late for work/without punching in, /which makes the leader annoyed" with the prime "sign in," the judging task could be "Did you see 'sign in' at first?"

The experimental stimuli were divided into three lists based on a Latin-square design and each list was received randomly by one participant. Thus each participant read 120 sentences with primes including 60 experimental sentences and 60 filler sentences. These materials were pseudo-randomized per list in a way that sentences of the same condition would not appear three times consecutively. For each participant, the same target innovative *Bei* construction could appear once in only one context.

## 2.3. Procedure

The experiment was conducted in a quiet room where participants were comfortably seated, approximately 70 cm away from the screen. All materials were presented visually in black on a white background at the center of the computer screen. After instructions were provided, participants pressed the "space" key to move on to the practice block containing four trails.

Each experimental trial started with a "+" of 500 ms followed by a blank screen of 200 ms. Then the priming word appeared and participants read the priming word in a self-paced way by pressing the "space" key, after which a blank screen of 200 ms appeared. After that, participants pressed the "space" key to read the context sentence including three clauses in a self-paced manner. The first clause was presented in two screens including the person's name and the innovative *Bei* construction; the second clause was presented as a whole; and the third one was presented in two screens including a noun and a phrase. After reading the context sentence, a blank screen of 200 ms appeared, and then the yes/no probing question was presented and lasted until participants made responses ("J" for Yes, "F" for No). After a delay of 800 ms, the next trial was presented. Breaks were allowed during the experiment.

## 2.4. Data collection and analysis

The reading time duration and the accuracy were recorded in E-prime 2.0. Only correctly answered trials were included and analyzed. Reading time duration and accuracy rates that were more than 2.5 standard deviations above and below each group's means were replaced by that group's means. As for the reading time duration of the innovative *Bei* construction and the post-*Bei* region as well as accuracy rates, analyses were carried out in the Linear Mixed Model (LMM) with the lme4 (Bates et al., 2015) and lmerTest (Kuznetsova et al., 2017) packages in R (R Core Team, 2022). Priming Condition (construction-related vs. component-related vs. unrelated) was included as the fixed factor, with subject as the random factor.

# 3. Results

Three participants' data were excluded due to low accuracy rate (<80%). Thus 36 participants' data were included in the analyses. Results of the accuracy rates, the reading time duration of the innovative *Bei* construction, and post-*Bei* region were presented as follows.

Participants reached generally high accuracy rates (92.67%), with no significant main effect ($p > 0.05$), showing that they had paid equal attention to each condition.

## 3.1. The innovative *Bei* construction

LMM showed significant effects of Priming Condition [$F(2,2,124) = 44.537$, $p < 0.001$]. Further analyses showed significantly shorter reading time duration for the construction-related condition ($M = 555.774$ ms) than the component-related condition [$M = 597.243$ ms; $\beta = 41.5$, SE = 6.13, $t(2126) = 6.769$, $p < 0.001$] as well as the unrelated condition [$M = 611.368$ ms; $\beta = -55.6$, SE = 6.13, $t(2126) = -9.075$, $p < 0.001$]. Besides, the reading time duration for the component-related condition was also slightly shorter than the unrelated condition [$\beta = -14.1$, SE = 6.13, $t(2126) = -2.306$, $p = 0.055$; see Figure 1].

## 3.2. The post-*Bei* region

Linear Mixed Model also showed a significant effect of Priming Condition [$F(2,2,124) = 9.528$, $p < 0.001$] at the post-*Bei* region. Further analyses also showed significantly shorter reading time duration for the construction-related condition ($M = 577.939$ ms) than the component-related condition [$M = 611.874$ ms; $\beta = 33.93$, SE = 10.5, $t(2126) = 3.238$, $p = 0.004$] as well as the unrelated condition [$M = 621.454$ ms; $\beta = -43.52$, SE = 10.5, $t(2126) = -4.152$, $p < 0.001$; see Figure 1].

Taken together, the current experiment revealed significant priming effects of the construction-related primes as contrasted with the unrelated primes both at the reading locations of the innovation *Bei* construction and the post-*Bei* region. In addition, the reading time duration of these two locations was also significantly shorter when primed by construction-related primes than component-related primes.

# 4. Discussion

As hypothesized by Construction Grammer (Goldberg, 1996, 2006), processing Mandarin innovative *Bei* construction involves a holistic storage and processing (Siyanova-Chanturia, 2015) by regarding "*Bei* + X" as a unity. Based on the novelty of this construction that its negative associations are generated by considering this construction as a whole in the construction coercion process, this study explored whether and how such negative associations were activated and achieved in the processing of this construction in a self-paced reading experiment with three types of priming words. Results showed that priming words conveying the negative associations of the innovative *Bei* construction significantly shortened the reading time duration of the "*Bei* + X" construction and the post-*Bei* region than priming words conveying partial componential meaning and unrelated meaning of the construction. These findings indicate that negative associations are activated and achieved in the processing of Mandarin innovative *Bei* construction.

## 4.1. Priming effects of the negative associations of "*Bei*+X" on the processing of innovative *Bei* construction

### 4.1.1. The facilitation of the negative associations of "*Bei*+X"

As for the target innovative *Bei* construction, analyses revealed a significant priming effect that the negative associations of the construction

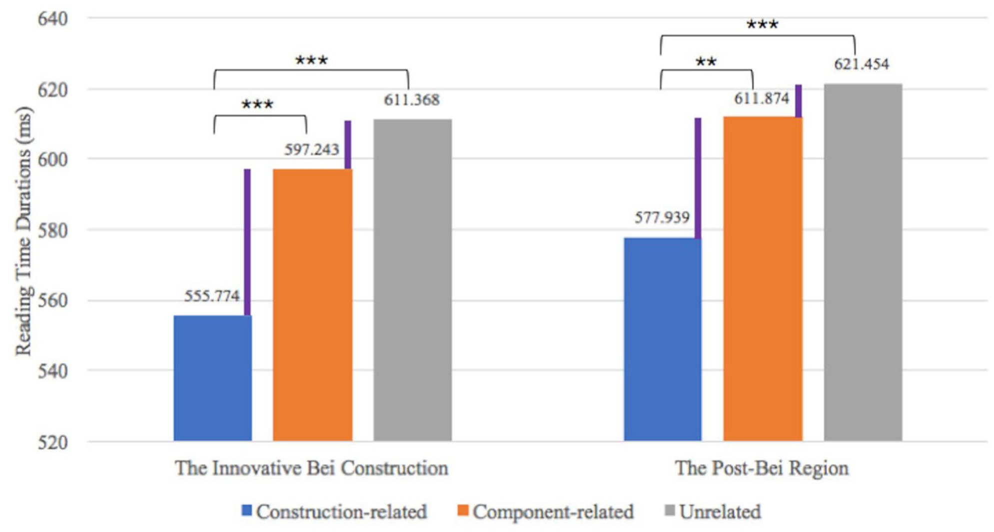


FIGURE 1
The reading time duration of the innovative *Bei* construction and the post-*Bei* region. The symbols ** and *** refer to the statistical significance of the comparisons. ** refers to the situation when $p < 0.01$; *** refers to the situation when $p < 0.001$.

facilitate participants' processing of the targeted *Bei* construction as compared with the unrelated condition. Such a priming effect is similar to previous studies of constructions (e.g., Eddington and Ruiz de Mendoza, 2010; Busso et al., 2021) that also report significant priming effects of constructional meaning in the processing of other types of constructions. It indicates that the construction-related primes, which convey the emergent negative associations of the Mandarin innovative *Bei* construction, provide an access to the inference of its constructional meaning before the actual appearance of "*Bei*+X" in the context. It consequently reduces the cognitive efforts required to comprehend the innovative *Bei* construction. Such a facilitative function can be ascribed to the possibility that the nature of the innovative *Bei* construction has more or less been triggered and achieved in advance when participants read the construction-related primes. However, as for the unrelated condition, primes did not provide useful or associative meanings for participants to get access to the constructional meaning of the "*Bei*+X" construction. In this way, in the construction-related condition, when the innovative *Bei* construction appeared again in the context, it is possible and much easier for participants to retrieve the negative associations of the construction from their working memory and apply it to fit in the context where the novel "ungrammatical" *Bei* construction emerges, resulting in shortened processing duration. In addition, the current experiment revealed that this priming effect of the construction-related primes spills over into the reading location of the post-*Bei* region that serves as a buffer to resolve the integration of the innovative *Bei* construction. This downstream effect may further manifest that the facilitative function of the negative associations on the processing of innovative *Bei* construction is relatively stable and consistent.

Furthermore, in the current experiment, the priming effect elicited by the construction-related primes started at the location where participants just read the key "*Bei*+X" construction instead of showing a delayed effect (e.g., starting from the post-*Bei* region). Thus we intend to assume that the activation of the constructional meaning is relatively fast in the processing of Mandarin innovative *Bei* construction. In other words, participants have retrieved and integrated the negative associations into the innovative *Bei* construction before finishing reading the construction itself, further supporting the idea that the accessing of constructional meaning might be quick and autonomous (Johnson and Goldberg, 2013). However, the above inference requires further straightforward experimental evidence and validation.

To conclude, less reading time duration in the construction-related priming condition than the unrelated condition provides evidence that negative associations facilitate the processing of Mandarin innovative *Bei* construction in a relatively instant way.

### 4.1.2. More contributions of the negative associations of "*Bei*+X" than the lexical meaning of "X"

In the current study, apart from the priming effect of negative associations of "*Bei*+X," the reading time duration of the "*Bei*+X" region is also shorter when it is primed by the component-related meaning than by the unrelated meaning. Though this is only a marginally significant effect, it still reveals the possibility that partial meaning of the "*Bei*+X" construction (i.e., the lexical meaning of "X") may also facilitate the processing to some extent. It can be interpreted in terms of the fact that the component-related primes activate part of the meaning of the "*Bei*+X" construction, that is, the meaning of the lexical item "X" as a part of the innovative *Bei* construction (Wang, 2011; Chi and Zhou, 2012). This accords with Busso et al. (2021)'s results that participants spent less reaction time when the targets were lexically associated to the primes than when the targets were unrelated to the primes.

However, as similarly discovered by Busso et al. (2021), this priming effect of the component-related primes was not so stable or strong as these construction-related primes, because the former was only marginally significant and disappeared at the post-*Bei* region in the current experiment. Also, the reading time duration in the construction-related condition was significantly shorter than that in the component-related condition, further indicating that the emergent negative associations contribute more to the processing of innovative *Bei* construction than the partial lexical meaning of "X." It is because the activation of the meaning of the lexical item "X" is only an intermediate part in the process of comprehending the innovative *Bei* construction, while the negative associations activated by the construction-related primes represent the final rhetorical meaning of the whole "*Bei*+X" construction. In this way, contrasted to the construction-related primes, component-related primes provide inadequate facilitation to the processing procedure and thus require more cognitive efforts from participants to extract coherent meanings in the comprehension. In this case, the above asymmetry indicates that the processing of the innovative *Bei* construction is influenced by both negative associations of "*Bei* + X" and componential meanings of "X," but the former seems to be primary as it contributes more to the comprehension, which further emphasizes the importance of negative associations in Mandarin innovative *Bei* construction comprehension.

## 4.2. Evidence for the assumptions of construction grammar

With regard to the processing of constructions, the current study also provides implication for the hypotheses of Construction Grammar as the innovative *Bei* construction display the essential properties of a construction.

Firstly, the innovative *Bei* construction is a unified form-meaning pairing. As mentioned before, the "X" slot in the innovative *Bei* construction can be filled with lexemes of other parts of speech besides the transitive verb, which deviates from the canonical passive structure in Chinese. Hence such a deviation in structure and form occurs together with the emergence of negative associations, constructing a form-meaning correspondence. In the current experiment, the stable facilitation of construction-related primes reveals that participants process "*Bei* + X" as a unified construction. It is because when processing "*Bei* + X," participants could obtain the negative associations of the construction only by regarding it as a whole. In other words, if participants process "*Bei*" and "X" separately, they could not yield the negative meanings of the construction but only get the lexical meanings of the passive marker and the "X" slot. In a holistic way, these accessed emergent meanings could then be primed by these construction-related primes that convey similar negative associations. Given this map, the current priming effect of the negative associations of "*Bei* + X" provides evidence for the assumption that construction is comprehended as a form-meaning unity.

Secondly, as a construction, the meaning of the innovative *Bei* construction is based on but goes beyond the combination of the meanings of its parts (Goldberg, 1995; Chen and Hu, 2020). Specifically, the current results show that it is the negative associations of the construction instead of the componential lexical meaning that serves as the key through which the innovative *Bei* construction is processed. It indicates that although the piratical lexical meaning of "X" may provide some facilitation to the processing procedure, it does not represent the nature of the construction, for the negative associations of the Mandarin innovative *Bei* construction cannot be strictly predicted from its component parts (Goldberg, 2006). Thus from the aspect of Mandarin innovative *Bei* expressions, this study provides evidence that constructions contain its holistic meaning which cannot be obtained from the components (Goldberg, 2019, pp. 28–42). In addition, this stronger priming effect of construction-related primes than component-related primes may further indicate that the components of the architecture must fit into the designated slots and behave accordingly through coercion (Goldberg, 1995; Chen and Hu, 2020). In the current experiment, the lexical meaning of the component "X" cannot function independently to facilitate construction processing, but is coerced into the passive marker "*Bei*" to produce new meanings (i.e., negative associations). In this way, the combination of "*Bei* + X" can coerce the lexical items "X" into producing systematically related negative meanings, such as "be forced to/be mistakenly reported to," and can impose constraints on the creation of new constructions (Goldberg, 2006; Wang, 2011). This is also why the component-related primes could only provide limited facilitation to the comprehension of Mandarin innovative *Bei* construction.

Thirdly, as indicated by other studies, the constructional meaning and the componential meaning of constructions may interact with each other through the function of other factors such as "compatibility" (Busso et al., 2021). Though the current study could not address how these two types of meaning indeed interact with each other, the findings of the asymmetric facilitative functions of the negative associations and the componential meanings may at least show that extra negative meanings and partial lexical meanings play different roles in the comprehension of Mandarin innovative *Bei* construction.

## 4.3. The embodied nature of the innovative *Bei* construction

From previous discussions, it is revealed that the processing of the innovative *Bei* construction is facilitated by the negative associations, and thus supports the hypotheses of Construction Grammar. What intrinsically underlies such access and usage of negative associations is an experiential basis grounded in the social reality (Wang, 2011), based on which the cognitive operations of the construction could be carried out and extra meanings could be accessed.

As contrasted with the canonical passive structure that can be interpreted directly, the innovative *Bei* construction is highly reality- and context-based, which requires a clear physical basis. Specifically, the innovative *Bei* construction is interpreted as "The subject of the construction involuntarily experiences Event X" and the "X" denotes an event instead of a state or motion in the canonical passive structure (Chen and Hu, 2020). This event "differs from a verbal process (action or state) in that it is often a specific incident, a real-life story that occurs at a specific time and in a specific place" (Chen and Hu, 2020, p. 92), and is what the subject experiences. For instance, in Example (2) as follows (adapted from Chen and Hu, 2020), the incident is "The registration of a household was outrageously wrong but the local officials refused to correct it."

(2) 某家人的户口信息错得离谱，当地部门硬是不给改。*13*岁的女孩于是被长大*10*岁。.

"The registration of a household was outrageously wrong but the local officials refused to correct it. Therefore, the 13-year-old girl was grown-up by 10 years (was registered 10 years older than she actually was)."

Through the experience of "X" (e.g., the wrong registration), the subject (e.g., the 13-year-old girl) was mistakenly portrayed as a 23-year-old girl. In this way, the use of the construction "被长大 ('be grown-up')" could be reasonable and understandable. Given this map, we assume that only based on the knowledge that the subject has involuntarily experienced the event denoted by "X," could the interpretation of the innovative *Bei* construction be successfully achieved. In other words, event "X" is the physical basis of the coherent interpretation of this construction. In addition, these events manifested in the "X" slot are closely related to the social reality from which the innovative construction has emerged. In Example (2), the social reality refers to the dereliction of local officials; and many other innovative *Bei* constructions (e.g., "被自杀 ('be suicided')," "被和谐 ('be harmonied')," etc.) are reflections of the social events occurring at a certain time in

China (Chen, 2017; Ye, 2019; Chen and Hu, 2020). This sociality further enhances our assumption that the innovative *Bei* construction requires embodied experience and is grounded in these social realities.

Moreover, based on the experience of event "X," further cognitive operations are carried out to generate extra negative feelings possessed by the innovative *Bei* construction. Specifically, through a constructional coercion or a reverse constructional coercion (Chen and Hu, 2020), the combination of "*Bei*" and "X" particularly exerts negative impacts and emotions (Wang, 2011; Yao et al., 2013; Huang and Liu, 2014; Chen and Hu, 2020). Specifically, these negative feelings are associated with ridiculousness and absurdity of the social reality, as the subject involved in the event should have avoided such incidents. However, due to many factors, these incidents occur out of control, which subsequently leads to the negative associations of the construction. At the same time, the readers of the construction were "invited to see and experience the specifics of event 'X'" (Chen and Hu, 2020, p. 103), which further arouses their senses of indignation and helplessness. As revealed in the current experiment, the carrier of these negative associations is the construction-related priming words that convey similar negative feelings aroused by their corresponding innovative *Bei* construction. Hence when reading the construction, participants were virtually experiencing the event "X" and producing negative emotions.

In this way, we regard the processing of the innovative *Bei* construction as an embodied cognitive processing, as it is reality-based and involves participants' experience of event "X" and their generation of negative emotions.

## 5. Conclusion

This study extends the literature on the comprehension of Mandarin innovative *Bei* constructions by providing psychological evidence of the facilitation of negative associations in its processing. Specifically, priming words conveying the negative associations significantly shortened the reading time duration of the "*Bei* + X" construction and the post-*Bei* region as contrasted with the priming words conveying lexical meanings of "X" and unrelated meanings. These findings indicate that constructional meanings, which are reflected in the negative associations, are activated and achieved to facilitate the processing of Mandarin innovative *Bei* construction in a relatively instant way.

In addition, we should acknowledge that there were several limitations in the current experiment, which may be improved upon in future studies. Regarding this self-paced reading study, it was not able to detect the time course of Mandarin innovative *Bei* construction processing, for example, whether the activation of the constructional meaning is exactly an early and instant process or not. In order to capture more sensitive procedures and provide more fine-grained evidence in Mandarin innovative *Bei* construction processing, eye-tracking and time-locked techniques such as EEG can be used in future studies. In addition, future studies may also improve the experimental materials. Though the materials used in the current study were adapted from corpus and were validated, they were compiled into a fixed sentence pattern for the sake of recording and measuring. Hence future studies should adapt materials of Mandarin innovative *Bei* construction into more natural and daily contexts. Also, it should be noted that other factors that may influence the comprehension of Mandarin innovative *Bei* construction should be included in future studies, such as the degree of familiarity of the construction, the social experiences, and individual differences of participants. Finally, since some of the innovative *Bei* construction may also produce other subtypes of associations such as humor and sarcasm, further studies may also focus on more specific aspects of the emergent associations of this construction.

To conclude, based on current evidence, our data reveal that there is a holistic process in comprehending Mandarin innovative *Bei* construction, as the negative associations of the construction manifest a more stable and strong facilitative function to fit the construction into the contexts. These results provide some new psychological evidence to support the observations of Construction Grammar that the innovative *Bei* construction is a form-meaning pairing whose processing is based on its constructional meaning.

## Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding authors.

## Ethics statement

The studies involving human participants were reviewed and approved by the Institute of Linguistics, Shanghai International Studies University. The patients/participants provided their written informed consent to participate in this study.

## Author contributions

CD prepared the materials and collected the data. XW performed all data analyses and wrote the manuscript. All authors contributed to the study conception and design, commented on previous versions of the manuscript, read and approved the final manuscript.

## Funding

This work was supported by the Key Program of the National Social Science Fund of China (grant no. 19AYY011), the Major Scientific Program of Shanghai International Studies University (grant no. 2018114027), and the 5th Tutor Guidance Program of Shanghai International Studies University (grant no. 2022113002).

## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

## Publisher's note

# References


Bates, D., Machler, M., Bolker, B. M., and Walker, S. C. (2015). Fitting linear mixed-effects models using lme4. *J. Stat. Softw.* 67, 1–48. doi: 10.18637/jss.v067.i01

Bencini, G. M., and Goldberg, A. E. (2000). The contribution of argument structure constructions to sentence meaning. *J. Mem. Lang.* 43, 640–651. doi: 10.1006/jmla.2000.2757

Busso, L., Perek, F., and Lenci, A. (2021). Constructional associations trump lexical associations in processing valency coercion. *Cogn. Linguist.* 32, 287–318. doi: 10.1515/cog-2020-0050

Chen, W. B. (2010). A semantic-cognitive investigation of the construction "X is Y": an exploration of the interface from grammar construction to rhetoric construction. *Contemp. Rhetor.* 160, 19–26. doi: 10.16027/j.cnki.cn31-2043/h.2012.02.006

Chen, X. (2017). Extensions of the mandarin passive construction: a memetic account. *Pragmatics* 2, 59–74. doi: 10.1558/eap.32412

Chen, R., and Hu, X. (2020). "Be suicided": a construction grammar analysis of the innovative bèi construction in mandarin. *Cogn. Semant.* 6, 83–106. doi: 10.1163/23526416-00502004

Chi, C. H., and Zhou, X. J. (2012). The generating mechanism and rhetorical intention of new "bei + X" structure. *J. Fujian Norm. Univ.* 175, 53–61.

Eddington, D., and Ruiz de Mendoza, F. J. (2010). "Argument constructions and language processing: evidence from a priming experiment and pedagogical implications," in *Fostering Language Teaching Efficiency Through Cognitive Linguistics*. eds. S. De Knop, F. Boers and A. De Rycker, vol. *17* (Berlin: Mouton de Gruyter), 213.

Goldberg, A. E. (1995). *Constructions: A Construction Grammar Approach to Argument Structure*. Chicago, IL: University of Chicago Press.

Goldberg, A. E. (1996). Words by default: optimizing constraints and the Persian complex predicate. In Annual meeting of the Berkeley linguistics society 22, 132–146). Berkeley: Berkeley Linguistics Society.

Goldberg, A. E. (2006). *Constructions at Work: The Nature of Generalization in Language*. Oxford: Oxford University Press.

Goldberg, A. E. (2019). *Explain Me This: Creativity, Competition, and the Partial Productivity of Constructions*. Princeton: Princeton University Press.

Han, Y., and Han, J. (2019). The syntactic derivation of non-canonical Bei -sentences in mandarin. *Foreign Lang. China* 16, 39–47. doi: 10.13564/j.cnki.issn.1672-9382.2019.02.007

Huang, Z. D., and Liu, N. (2014). The syntax and semantics of the new non-canonical Bei XX construction. *Lang. Sci.* 70, 225–241.

Jegerski, J. (2014). "Self-paced reading," in *Research Methods in Second Language Psycholinguistics*. eds. J. Jegerski and B. Van Patten (New York: Routledge), 36–65.

Johnson, M. A., and Goldberg, A. E. (2013). Evidence for automatic accessing of constructional meaning: jabberwocky sentences prime associated verbs. *Lang. Cogn. Process.* 28, 1439–1452. doi: 10.1080/01690965.2012.717632

Kaschak, M. P., and Glenberg, A. M. (2000). Constructing meaning: the role of affordances and grammatical constructions in sentence comprehension. *J. Mem. Lang.* 43, 508–529. doi: 10.1006/jmla.2000.2705

Kuznetsova, A., Brockhoff, P. B., and Christensen, R. H. B. (2017). lmerTest package: tests in linear mixed effects models. *J. Stat. Softw.* 82, 1–26. doi: 10.18637/jss. v082.i13

Liu, Y. F. (2019). A study of conceptual overlap of causative Jianyu construction from the perspective of embodied-cognitive linguistics. *Foreign Lang. Lit.* 5, 15–21. doi: 10.3969/j.issn.1674-6414.2019.05.003

Michaelis, L. A. (2004). Type shifting in construction grammar: an integrated approach to aspectual coercion. *Cogn. Linguist.* 15, 1–67. doi: 10.1515/cogl.2004.001

Qiu, J. (2017). Mind-philosophical approach to new mandarin passive construction and its English translation. *J. Sichuan Int. Stud. Univ.* 33, 90–96. doi: 10.3969/j.issn.1674-6414.2017.05.016

R Core Team. (2022). R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing. Vienna, Austria. Available at: https://www.R-project.org/.

Roberts, L., and Liszka, S. (2013). Processing tense/aspect agreement violations online in the second language: a self-paced reading study with French and German L2 learners of English. *Second Lang. Res.* 29, 413–439. doi: 10.1177/0267658313503171

Shi, C. H. (2013). The generation mechanism, semantic interpretation and pragmatic effects of the new "Bei" construction. *Contemp. Rhetor.* 1:12-28. doi: 10.16027/j.cnki.cn31-2043/h.2013.01.003

Siyanova-Chanturia, A. (2015). On the 'holistic' nature of formulaic language. *Corpus Linguist. Linguist. Theory* 11, 285–301. doi: 10.1515/cllt-2014-0016

Wang, Y. (2011). Analysis of "new construction with *Bei*" via lexical coercion: a research on "*Bei Ziyuan*" in cognitive construction grammar. *J. Foreign Lang.* 34, 13–20.

Wang, Y. G. (2019). "*Bei* X" Snowclones in speech-act/epistemic domains and constructional coercion. *J. Foreign Lang.* 2, 34–44. doi: 10.3969/j.issn.1004-5139.2019.02.004

Wang, S. P., Chen, H. Z., Yang, J. M., Wu, Y., and Wang, R. M. (2006). Immediacy of integration in reading Chinese. *Acta Psychol. Sin.* 5, 645–653.

Yao, J., and Song, J. (2012). The identification and interpretation of ironical Chinese *Bei*-passives. *Foreign Lang. Res.* 1, 55–58. doi: 10.16263/j.cnki.23-1071/h.2012.01.014

Yao, J., Song, J., and Singh, M. (2013). The ironical Chinese Bei-construction and its accessibility to English speakers. *J. Pragmat.* 55, 195–209. doi: 10.1016/j.pragma.2013.06.003

Ye, Z. D. (2019). The emergence of expressible agency and irony in Today's China: a semantic explanation of the new Bèi -construction. *Aust. J. Linguist.* 39, 57–78. doi: 10.1080/07268602.2019.1542933

Yuan, H. M., and Liang, J. Y. (2016). An analysis of the conceptual integration of the constructional meaning of "*Bei* + X". *Foreign Lang. Res.* 33, 33–39. doi: 10.13978/j.cnki.wyyj.2016.01.026

Zhang, K. D., and Zhang, X. (2020). The embodiment-cognition and interactivity of fictive motion construction. *Foreign Lang. Educ.* 5, 6–10. doi: 10.16362/j.cnki.cn61-1023/h.2020.05.002

frontiers | Frontiers in Psychology

TYPE Original Research
PUBLISHED 21 February 2023
DOI 10.3389/fpsyg.2023.1120140

Check for updates

OPEN ACCESS

EDITED BY
Huili Wang,
Dalian University of Technology,
China

REVIEWED BY
Luming Wang,
Zhejiang University of Technology,
China
Zhi Lu,
Guangdong University of Foreign Studies,
China

*CORRESPONDENCE
Xiaolu Wang
✉ lucywxl@zju.edu.cn

SPECIALTY SECTION
This article was submitted to
Language Sciences,
a section of the journal
Frontiers in Psychology

RECEIVED 09 December 2022
ACCEPTED 16 January 2023
PUBLISHED 21 February 2023

CITATION
Jia J, Wei Z, Cheng H and Wang X (2023) Translation directionality and translator anxiety: Evidence from eye movements in L1-L2 translation.
*Front. Psychol.* 14:1120140.
doi: 10.3389/fpsyg.2023.1120140



# Translation directionality and translator anxiety: Evidence from eye movements in L1-L2 translation

Juan Jia[1], Ziyu Wei[2], Heben Cheng[3] and Xiaolu Wang[1,3,4]*

[1]School of Foreign Languages, Hangzhou City University, Hangzhou, China, [2]Hangzhou Guancheng Wulin Middle School, Hangzhou, China, [3]School of International Studies, Zhejiang University, Hangzhou, China, [4]School of Humanities and Communication Arts, Western Sydney University, Penrith, NSW, Australia

While considerable research on the impact of anxiety on second language learning has been carried out in international contexts, the impact of anxiety on the translator's undertaking L2 translation, a sort of anxiety arising from the translation directionality, as well as the structure of cognitive mechanism for translational anxiety, remain under-explored. Adopting the eye-tracking and key-logging approach to data collection, this study implemented an eye-tracking experiment with EFL learners at a Chinese university to probe into how the participants responded to L1 and L2 translation-tasks and the mechanism involved in these processes. It is found that translation directionality does have a great impact on the processing of translation, which causes the change of cognitive load and then leads to the change of levels in translator anxiety. The finding further confirms the key premises of the Processing Proficiency Model and the Revised Hierarchical Model with attendant implications for translation processes.

KEYWORDS

**translation directionality, translator anxiety, cognitive load, beck anxiety inventory, eye-tracking**

## Introduction

Second or foreign language learning is affected by a wide range of factors, including 'cognitive factors (language aptitude, learning strategies), affective factors (attitudes, motivation, and anxiety), metacognitive factors, and demographic factors (Henter, 2014, p. 373). Amongst these factors, anxiety is one of the most notable variables of influence since researchers such as Horwitz et al. (1986) and MacIntyre and Gardner (1994) demonstrated that the anxiety experienced by foreign language learners is distinctive in nature. MacIntyre and Gardner (1994, p. 284) defined anxiety as "a feeling of tension and apprehension specifically associated with second language contexts, including speaking, listening, and learning." Multiple studies (e.g., Horwitz et al., 1986; Phillips, 1992; Woodrow, 2006) investigating the phenomenon of language learning anxiety suggested that anxiety and foreign language performance are negatively related. While many studies have examined the effect of L2 anxiety on L2 learners' performance or achievement in class, there is limited research on the impact of anxiety on learners within translation-training settings (Yan and Wang, 2012) and even less so on the cognitive mechanism whereby anxiety influences cognitive operations within the process of translation. Therefore, the relationship between translation directionality and translator anxiety and its cognitive mechanism become the key foci of the current paper.

With reference to the cognitive mechanism involved in translation, the general theory of anxiety efficacy processing efficiency theory (PET) advanced by Eysenck and Calvo (1992) is of considerable importance as it helps to explore the influence of anxiety on cognitive process which in turn affects individual's task performance. Earlier studies on translation direction have tended to focus on output quality in different translation directions. Kroll and Stewart (1994) revised hierarchical model (RHM) is of great help for a better understanding of the process of translation from the perspective of cognition as the model describes the bilinguals' dynamic development of the conceptual representation of second language vocabulary along with the improvement in second language proficiency. The value of this model is that it provides a basis for the study of translation from a cognitive perspective. Research on translation process tends to focus on the influence of anxiety level on cognitive load, the influence of translation direction on cognitive load, and the influence of translation direction, anxiety, and cognitive load on translation performance. However, the correlation between cognitive load and anxiety related to translation direction is under-explored, particularly in relation to the possible differences of cognitive load in the source text (ST) and the target text (TT) mediating different translation directions. Thus the present study is hypothesized that L2 translation direction is likely to arouse more translation anxiety than L1 translation as anxiety tends to weaken the individual's processing efficiency with more cognitive efforts used, and while cognitive efforts can be measured by the translator's outward performance with the tools of key logging and eye movements, anxiety can be measured by the beck anxiety inventory (BAI) after the immediate task performance. Our study, in this way, was designed not only to address the gaps highlighted in the following research questions but also to examine the cognitive mechanism of translation anxiety in different translation directions.

1. In the process of translation, what relationship can be found between the translators' foreign language anxiety (FLA) and their cognitive load?
2. In L1 translation and L2 translation, which translation direction is likely to arouse more translation anxiety, and why?
3. In what way is the cognitive mechanism of translation anxiety distinguishable between L1 and L2 translations?

# Key terms and previous studies

## Foreign language anxiety

Synchronically, studies on language acquisition, especially second or foreign language learning, were conducted from cognitive factors to affective factors. Among them, the affective filter hypothesis (Krashen, 1985) is of pivotal importance to the present study as it relates to the role of affective variables (e.g., anxiety). According to Krashen (1985), the affective filter is a mental block which obstructs language learners from fully utilizing the comprehensible input they receive in the process of acquiring a language. The affective filter does not restrain acquisition directly, but it can prevent input from reaching the part of the brain responsible for language acquisition. Drawing upon Krashen (1982) and Hammond (1990, p. 65), observed that "the affective variables of motivation, self-confidence and anxiety" exercise a deep influence on the acquisition of language. Oxford (1999) contended that "anxiety" is the first and most factor of the affective variables affecting language acquisition.

As translation activities must be generated in a foreign language environment, foreign language anxiety produced in such environment affects translation behavior. With reference to the cognitive mechanism involved in translation, PET, the general theory of anxiety efficacy suggests that individuals with high anxiety tend to pay more attention to their performance and evaluation by others, which gives rise to their negative thoughts in mind. Given that these negative thoughts occupy large parts of the working memory resources in central executive system and/or the auditory rehearsal loop, their effect on performance in the form of anxiety are very significant. Task difficulty also impacts the performance of individuals experiencing anxiety. As the level of task difficulty is determined by the resource requirements of central execution system and auditory rehearsal loop, the higher the requirements, the more difficult the task is. Multiple task completion/experiment-based studies have provided support for the credibility of this theory (Dornic, 1977, 1980; Weinberg, 1978; Eysenck, 1985, etc). In the Chinese context, anxiety has been accepted as a negative correlation with translation (Zheng, 2003). Research in the Chinese context has also examined the influence of anxiety on language cognitive processing, focusing on the negative effect of trait anxiety on emotional word processing by eye-tracking (Xu, 2014), and offering evidence in support of PET assumptions (Lin, 2004; Yu, 2019).

## Translation directionality

An important factor affecting FLA is translation directionality. Translation directionality had long been completely rejected or neglected in traditional translation studies until the call appeared by various scholars in 1990s. Pavlović (2007, p. 80) described "directionality" as whether the translation is done into individuals' mother tongue/language of habitual use, or into their second language/foreign language. The traditional view regarded translation directionality as a combination of dismissing L2 translation and taking LI translation as "the unwritten rule" (Pokorn, 2000). Now the consensus has been reached that "directionality" can be done from a foreign language to a mother tongue or vice versa in the translation process (Beeby, 2009). As terms "mother tongue" and "foreign language" are seen as problematic due to feeling or ideology "colored" (Pedersen, 2000), the neutral description "first language -L1" and "the second language-L2" are adopted for this work. Thus, translation directionality refers to the direction of translation from L2 to L1 (L1 translation) or from L1 to L2 (L2 translation).

Previous studies on translation directionality have been limited to theoretical discussions on the quality of products in two opposite translation directions (Kroll and Stewart, 1994). They showed that translators encounter similar problems in the process of translation while the quality of the final products of translation depends on the direction of translation. To be specific, the quality of L1 translation turned out to be much higher than that of L2 translation. The aspects which contributed to the direction difference can be assigned as translators' translation competence, personal preferences, text types, environmental conditions, etc (Pavlović, 2007). Actually, it is the translator's cognitive processes and affective factors (anxiety) in different translation directions determine the quality of the final products of translation.

## Empirical studies on translation directionality

Most previous studies on the relationship between cognitive load of translation and translation directionality have been premised on behavioral evidence (Harley, 2001). The proposed model, RHM, specifically figures out "translation asymmetry" in translation activities, which means translating/interpreting a word into a second language requires more cognitive effort than undertaking this in the first language (Kroll and Stewart, 1994). Since the mid-to-late 1980s, evolving science, technology and methodological innovation have opened up avenues for the generation and use of objective data to describe translation phenomena and demonstrate theoretical hypotheses. A breakthrough in this field was the introduction of the Think-aloud Protocols (TAPs) in the field of psychology. Inspired by this, researchers concerning translation process began to draw upon other disciplinary methods, such as key-logging, screen recording, webcam recording, eye-tracking and neuroscience methods which effectively supplemented or replaced the traditional TAPs. However, the application of key-logging and/or eye-tracking technology to research on directionality has still been limited in translation (Ferreira, 2014; de Lima Fonseca, 2015) and interpreting research.

The traditional view of directionality which is based on assumptions rather than on empirical data has been challenged by international research. Investigating cognitive effort in translation processes by deploying the eye-tracking experiment with student and professional subjects in translation tasks, Jensen and Pavlović (2009) found that the cognitive effort required in the TT processing is significantly higher than in the ST processing in both translation directions. Chinese scholars have also explored the correlation between translation directionality and cognitive load by key-logging and/or eye-tracking. Deploying eye-tracking and fMRI, Chang (2009) explored the validity of RHM at textual level with physiological and neurological data on cognitive loading of 16 participants (Chinese as their first language and English as their foreign language). Based on Chang's work, Feng (2017) sought to verify three hypotheses by collecting eye-tracking data pertaining to task time, pupil diameter, average fixation time, total fixation time and fixation frequency of 20 student translators, concluding that while the cognitive load in L2 translation is higher than that in L1 translation, the relationship between cognitive load and text type (ST and TT) cannot be conclusively established. Wang (2019) also explored the effects of translation directionality and text difficulty on cognitive load and translation performance of 16 Chinese students majoring in translation and interpretation by means of key-logging, eye-tracking and questionnaires and found that with STs of low difficulty, cognitive load in Chinese-English translation is higher than English-Chinese translation; with STs of high difficulty, the cognitive load in Chinese-English translation is not necessarily higher than English-Chinese translation.

To sum up, the above discussion shows that the proposed PET offers a new perspective in translation process research (TPR) and that the hypothesized effects of anxiety on cognitive load and performance have been well-tested. However, the relationship between anxiety and cognitive load has only been confirmed in one direction, while the effects of cognitive load level on anxiety level remain under-researched. Further, while most studies have confirmed the relationship between translation direction and cognitive load, research questions related to translation direction, such as whether there is a significant difference of cognitive load in the ST and the TT between different translation directions, still remain to be investigated.

# Methods

## Translation anxiety experiment

In order to explore the correlations and differences of the following factors, i.e., EFL learners' cognitive load, translation directionality and anxiety between L1 translation and L2 translation, first, participants were selected randomly to two groups. Then, they were required to complete a pre-test to ensure similar level of English proficiency. Next, as they performed E-C and C-E translation tasks, their anxiety was compared by means of their eye-movement and keystroke data.

## Eye-tracking

Eye-tracking technology which is the measurement of eye activities is widely used in TPR, especially in cognitive translation research (CTS). Eye-tracking collects eye data by using a computer-connected device called "eye-tracker" which could either be remote or head-mounted. In the present study, we tracked the eye movement data only from the participant's right eye by the SR Research Eyelink 1,000 plus system at a sampling rate of 1,000 Hz. The experiment was carried out on Dell P1917S with a 19-inch monitor, which has a refresh rate of 75 Hz and a screen resolution of 1024*768 pixels. A chin rest with forehead support was used in the experiment in order to minimize the interference caused by participants' head movements.

## Translog II

In the present study, Translog II is used to record the user activity data including all the gaze movements and keystrokes which is connected to an SR Research Eyelink 1,000 plus system and a specific key-logging software. Translog II collects eye movements data in the form of gaze-sample points and fixations. In order to track gaze-sample points and fixations of the participants effectively, STs were set on the left window and TTs were on the right window in "Configure Experiment" step in Translog II Supervisor. It also collects keystroke data through the specific key-logging software installed on the subject's computer by recording his/her keyboard activities. Information includes keystroke and mouse movements data such as deletions, insertions, corrections, editorial changes together with total task duration and time intervals between keystrokes. According to the distribution of keyboard activities, the translation process consists of initial orientation phase, middle drafting phase and revision and monitoring phase (Feng and Wang, 2016). Translog II finally creates a log files which contains all the data mentioned above when the user finishes their tasks of reading, writing and translating a text.

## Beck anxiety inventory

In this study, the beck anxiety inventory (BAI) was used to test the anxiety level of participants during L2-L1 (English-Chinese, E-C) or L1-L2 (Chinese-English, C-E) translation. Beck anxiety inventory was created by Aaron T. Beck et al., and it comprises a self-report inventory consisting of 21 multiple-choice items describing emotional, physiological, and cognitive symptoms of anxiety.

## Participants

A total of 78 undergraduate and postgraduate students [55 females, 23 males; mean age = 22.1, standard deviation (SD) = 2.58] from a top university in China, participated in the experiment. To maintain the integrity of the experiment, appropriate selection was ensured to exclude the participants with prior translation experience and English-major background. All of the participants were right-handed and had Mandarin Chinese as their L1 and English as their L2. They also had normal or correct-to-normal vision. None of them had any history of neurological or psychiatric disorders. Before the experiment, all the participants signed an ethical statement describing the ethical guidelines under which this research was carried out and were paid a small amount after the experiment.

## Materials

In the pre-test, translation texts were carefully selected from CET-4 simulation test in order to suit subjects' language ability and avoid accidentally translating before (see Supplementary Appendix S1). During the preparation for the experimental materials, the difficulty of formal texts were carefully controlled to correspond to the learners' level of knowledge. The texts of the formal experiment are also divided into Chinese text and English text. Different from the pre-test texts, the formal texts were a Chinese-English translation test and its reference answer selected from CET-4 simulation test. The Chinese text was used as the experimental material of C-E translation, and the English version of the reference answer was used as the experimental materials of E-C translation (see Supplementary Appendix S2). Time for the translation task was limited within 30 min adhering to the CET-4 rules.

## Procedures

At the recruitment stage, the participants completed the questionnaires on their personal background and their score of CET-4[1] as well as their score of translation in CET-4. In order to ensure the participants with similar English proficiency level, a pre-test was conducted with suitable translation tasks and the participants with total scores above 18 points were enrolled. In the formal experiment, after each participant was informed of the test steps, the subjects were positioned at their stations in accordance with the necessary guidelines to ensure that the experiment was not adversely impacted by the physical movement of the participants. During the experiment, the participants did the translation task and output the translation in the right window of Translog II User. And the monocular mode of the SR Research Eyelink 1,000 plus system was used in this study, so only the right eye of each participants was tracked. After completing the translation task, the participants immediately filled out a BAI scale based on their personal physiological symptoms and evaluations. During the experiment, the participants were not aware that anxiety evaluation would be provided after the translation tasks, otherwise, they would not totally focus their attention on the translation task. Moreover, if they had known that they would evaluate their anxiety after the translation task, they might think of some strategy to show their confidence. If that happened, we would never collect the true data for their anxiety.

1 CET-4 refers to the Chinese College English Test Band 4, which is an important benchmark to test the college students' English proficiency in China.

## Results and analysis

The data collected from Translog II software and SR Research Eyelink 1,000 plus system mainly include the task duration, fixation count (displayed, respectively, on ST and TT), fixation duration, pause count, and pause duration of the 68 participants from the two groups. The anxiety level was obtained from their BAI scores. All of the data were analyzed in SPSS 20.0. In this study, most of the key-logging and eye-tracking data in this experiment were coded and could not be analyzed directly. Therefore, data analyzing tools adopted for this study included CRITT TPR-DB and SPSS 20.0. CRITT is the abbreviation of Center for Research and Innovation in Translation and Translation Technology. The tables selected for the follow-up data processing in this study include the session summary table, the fixation data summary table and the keystroke data summary table.

## Anxiety difference analysis

In this part, the difference between the cognitive load and the BAI scores of E-C and C-E tasks was tested by independent-samples *t*-test. What is more, as the variables of fixation count and reading time were displayed, respectively, in ST and TT in the tables generated from CRITT TPR-DB, the difference of cognitive load between ST and TT processings was also tested by independent-samples *t*-test.

## Descriptive results

Figures 1–5 display the descriptive results of key-logging and eye-tracking data of the two groups (E-C group and C-E group) respectively. And Figure 6 displays the descriptive results of BAI scores of the two groups.

### Task duration

TD refers to the production duration of a final TT per session. It starts from the beginning of the session recording until it is stopped. Estimating how long a task will take to complete (i.e., the task duration) is important for our research, for the data regarding TD indicate that the more time used for a task completion, the more cognitive efforts are used in the performance. As we can see from Figure 1, all the descriptive results of TD in E-C translation ($M_{E\text{-}C}$ = 1013315.58 ms, $SD_{E\text{-}C}$ = 233305.78 ms) are lower than those in C-E translation ($M_{C\text{-}E}$ = 1429555.71 ms, $SD_{C\text{-}E}$ = 331444.94 ms).

### Fixation count

Fixation count refers to the total number of fixations on the source and TTs during the presentation of stimulus materials. The cumulative result of each saccade is the total number of fixations. In general, the more times the subjects focus on a certain area, the greater attention of this area is paid by the translator. Figure 2 shows that all the descriptive results of FC in E-C translation ($M_{E\text{-}C}$ = 1651.85 times, $SD_{E\text{-}C}$ = 525.02 times) are lower than those in C-E translation ($M_{C\text{-}E}$ = 2279.63 times, $SD_{C\text{-}E}$ = 603.07 times).

### Fixation duration

Fixation duration stands for the duration of each fixation. Generally speaking, the longer the subject looks at a certain area, the more interested he/she is in the area. In translation process, it may also

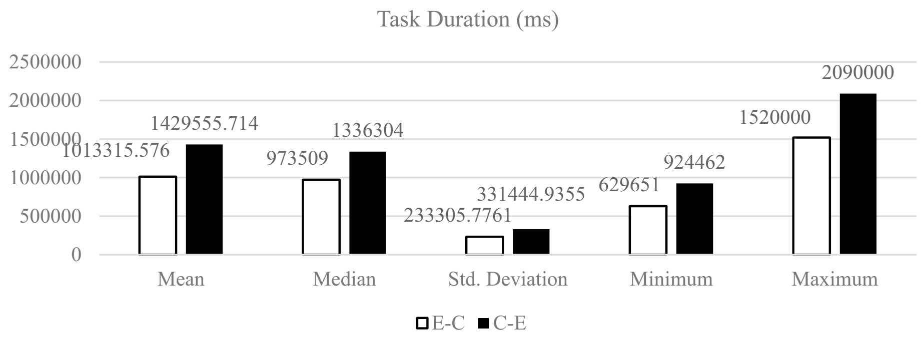


FIGURE 1
Descriptive results of TD in L1 and L2 translations.

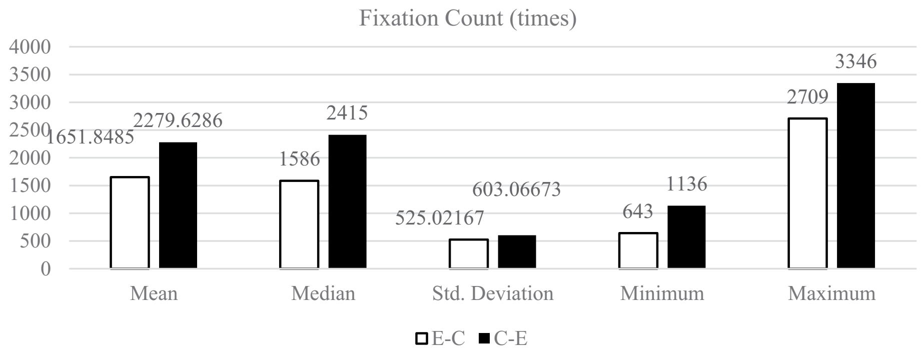


FIGURE 2
Descriptive results of FC in L1 and L2 translations.

indicate that the participant is more confused about the contents of the materials, and vice versa. Figure 3 shows that all the descriptive results of FD in E-C translation ($M_{E-C} = 744742.30$ ms, $SD_{E-C} = 207773.54$ ms) are lower than those in C-E translation ($M_{C-E} = 1034171.43$ ms, $SD_{C-E} = 286826.32$ ms).

## Pause count

Pause count refers to the total number of pauses when the participants produce their TTs. It is agreed that the more pause count, the more cognitive load and less cognitive resources in the translation process, and vice versa. All the descriptive results of PC in E-C translation ($M_{E-C} = 425.76$ times, $SD_{E-C} = 66.82$ times) are much lower than those in C-E translation ($M_{C-E} = 1538.34$ times, $SD_{C-E} = 301.51$ times).

## Pause duration

Pause duration refers to typing pause duration prior to a keystroke. According to Muñoz Martín and Apfelthaler (2021), 200 ms can capture"all translators' disfluencies; typing goal breaks and changes; reactions to visual stimuli; and the interaction of cognitive, perceptual, and action operations (i.e., embodiment) (p. 24)." The average fixation duration and planning of motor saccades in the present study is 200 ms. In our research the pause duration is longer, the more cognitive load is carried by the participant, and vice versa. Based on the results of Figure 5, all the descriptive results of PD in E-C translation ($M_{E-C} = 931902.18$ ms, $SD_{E-C} = 264124.01$ ms) are lower than those in C-E translation ($M_{C-E} = 1320882.83$ ms, $SD_{C-E} = 307353.95$ ms).

The descriptive results of BAI score are the same with those of the five variables mentioned above. All the descriptive results of BAI score in E-C translation ($M_{E-C} = 5.61$ points, $SD_{E-C} = 2.83$ points) are lower than those in C-E translation ($M_{C-E} = 7.8$ points, $SD_{C-E} = 3.30$ points).

# Test of normality

Before independent-samples *t*-test, it is necessary to make sure whether the data is normal distribution. Therefore, the tests of normality for five variables are examined. Tables 1, 2 are the tests of normality about the key-logging, eye-tracking and BAI score data.

Tables 1, 2 show the tests of normality for the results of the task duration (TD), fixation count (FC), fixation duration (FD), pause count (PC), pause duration (PD), and BAI scores, which help determine exactly whether the distribution is normal or not. In these tables, the significant values of both Kolmogorov–Smirnov and Shapiro–Wilk are displayed. According to the results of the tables, the significant values of the five variables of key-logging and eye-tracking and BAI scores from both groups are larger than 0.05, which means that the key-logging and eye-tracking data and BAI scores of the two groups are in accordance with normal distribution, so significant difference analysis can be conducted in the next step.

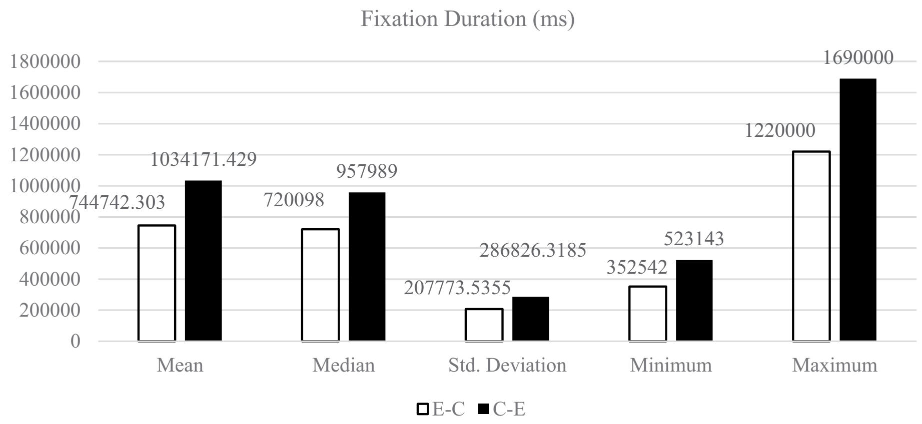


FIGURE 3
Descriptive results of FD in L1 and L2 translations.

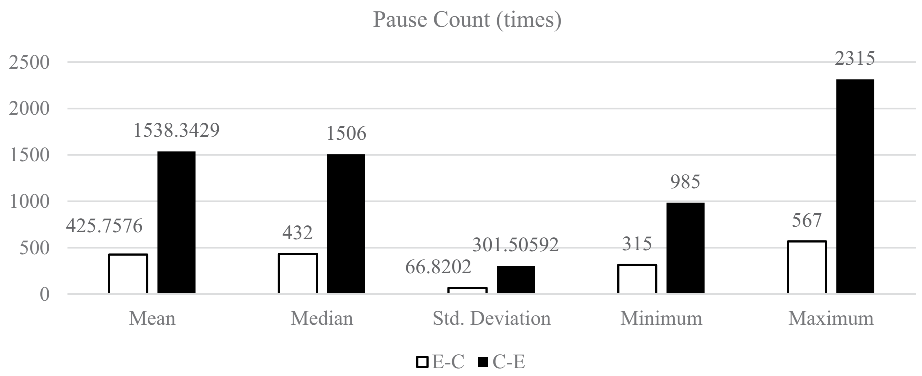


FIGURE 4
Descriptive results of PC in L1 and L2 translations.

## Difference of cognitive load between L1 and L2 translations

After the tests of normality, the difference between key-logging and eye-tracking data of the two groups is tested by independent-samples $t$-test. The results are presented in Table 3.

The results of Table 3 shows that there is a significant difference of task duration between E-C task (1013315.58 ± 233305.78) and C-E task (1429555.71 ± 331444.94), $t(61.174) = -6.015$, $p < 0.001$. As for fixation count, according to the above data, there is a significant difference of fixation count between E-C task (1651.85 ± 525.02) and C-E task (2279.63 ± 603.07), $t(66) = -4.567$, $p < 0.001$. Significant difference of fixation duration between E-C task (744742.30 ± 207773.54) and C-E task (1034171.43 ± 286826.32) is detected in the tables, $t(61.979) = -4.785$, $p < 0.001$. There also exits a significant difference of pause count between E-C task (425.76 ± 66.82) and C-E task (1538.34 ± 301.51), $t(37.526) = -21.284$, $p < 0.001$, and the pause duration in E-C task (931902.18 ± 264124.01) is significantly lower than that in C-E task (1320882.83 ± 307353.95), $t(66) = -5.582$, $p < 0.001$.

In order to explore the reason of significantly higher cognitive load in L2 translation, this part mainly displays the results of the difference of cognitive load in ST and TT between two translation directions. Independent-samples $t$-test is used to analyze the fixation count on source text (FCS), fixation count on target test (FCT), reading time on source text (RTS) and reading time on target text (RTT) in both L1 and L2 translations, aiming to explore whether there is a significant difference of cognitive load in the ST and the TT between different translation directions. The results are presented in Tables 4, 5.

TABLE 1 Tests of normality of key-logging and eye-tracking data in L1 and L2 translation.

| L1 and L2 | Kolmogorov-Smirnov | | | Shapiro–Wilk | | |
|---|---|---|---|---|---|---|
| | Statistic | df | Sig. | Statistic | df | Sig. |
| Dur | 0.100 | 33 | 0.200 | 0.974 | 33 | 0.600 |
| | 0.138 | 35 | 0.089 | 0.944 | 35 | 0.076 |
| FC | 0.123 | 33 | 0.200 | 0.966 | 33 | 0.367 |
| | 0.114 | 35 | 0.200 | 0.959 | 35 | 0.216 |
| FD | 0.130 | 33 | 0.171 | 0.948 | 33 | 0.115 |
| | 0.146 | 35 | 0.058 | 0.958 | 35 | 0.198 |
| PC | 0.103 | 33 | 0.200 | 0.963 | 33 | 0.318 |
| | 0.101 | 35 | 0.200 | 0.962 | 35 | 0.260 |
| PD | 0.117 | 33 | 0.200 | 0.946 | 33 | 0.099 |
| | 0.154 | 35 | 0.034 | 0.948 | 35 | 0.102 |

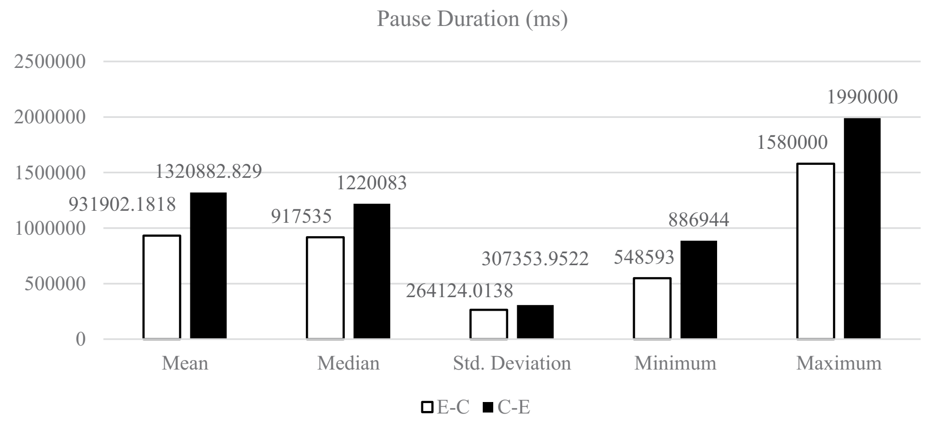


FIGURE 5
Descriptive results of PD in L1 and L2 translations.

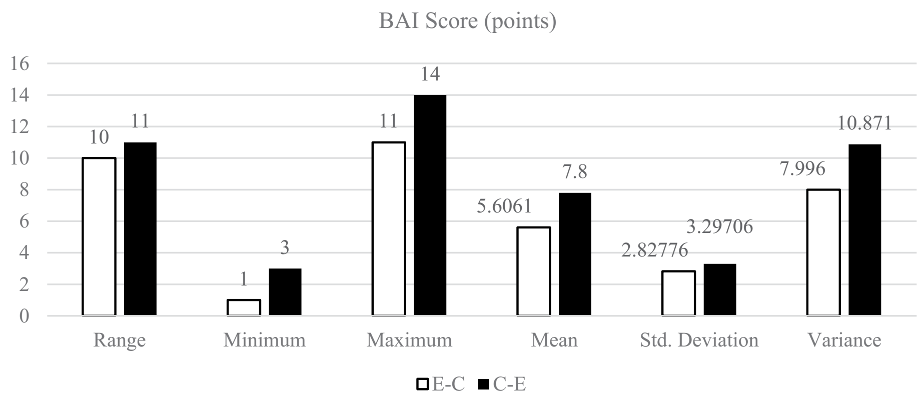


FIGURE 6
Descriptive results of BAI score in L1 and L2 translations.

TABLE 2 Tests of normality of BAI scores in L1 and L2 translations.

| BAI | Kolmogorov-Smirnov | | | Shapiro–Wilk | | |
|---|---|---|---|---|---|---|
| | Statistic | df | Sig. | Statistic | df | Sig. |
| E-C | 0.135 | 33 | 0.135 | 0.943 | 33 | 0.083 |
| C-E | 0.128 | 33 | 0.185 | 0.939 | 33 | 0.062 |

The results of Tables 4, 5 show that there exists a difference of fixation count on the ST between E-C translation (926.27 ± 319.31) and C-E translation (813.57 ± 271.86), but such difference is not significant, $t(66) = 1.57$, $p = 0.121$.

Also, no significant difference of reading time on the ST between E-C translation (396157.03 ± 111004.94) and C-E translation (348357.37 ± 108085.30) is detected in this study, $t(66) = 1.799$, $p = 0.077$. However, there is a significant difference of fixation count on the TT between E-C translation (725.58 ± 292.64) and C-E translation (1153.00 ± 434.97), $t(59.83) = -4.779$, $p < 0.001$. Also, there is a significant difference of reading time on the TT between E-C translation (330100.42 ± 154493.80) and C-E translation (641242.63 ± 233606.79), $t(59.302) = -6.513$, $p < 0.001$.

## Difference of beck anxiety inventory score between L1 and L2 translations

The results of BAI scores are presented in Table 6.

The results of independent-samples *t*-test in the table above show that there is a significant difference of BAI scores between E-C task (5.61 ± 2.83) and C-E task (7.80 ± 3.30), $t(66) = -2.937$, $p < 0.05$.

## Correlation analysis between cognitive load and anxiety

This part focuses on the correlation between key-logging and eye-tracking data and BAI scores of the two groups. As the normal distribution of the data of the study has been verified in the part of difference analysis, the results of Pearson Product–Moment correlation are displayed in Table 7.

The results of Pearson Product–Moment correlation test in the tables above show that there is a significant and positive correlation between BAI scores and task duration in both E-C ($r = 0.928$, $p < 0.01$) and C-E tasks ($r = 0.962$, $p < 0.01$) and also between BAI scores and fixation count in both E-C ($r = 0.611$, $p < 0.01$) and C-E tasks ($r = 0.807$, $p < 0.01$). As for the relationship between BAI scores and fixation

TABLE 3 Independent sample test of key-logging and eye-tracking data in L1 and L2 translations.

| | Levene's test for equality of variances | | *t*-test for equality of means | | | | |
|---|---|---|---|---|---|---|---|
| | *F* | Sig. | *t* | df | Sig. (two-tailed) | Mean difference | Standard error difference |
| Dur. | 8.592 | 0.005 | −5.955 | 66 | 0.000 | −416240.1 | 69897.1 |
| | | | −6.015 | 61.174 | 0.000 | −416240.1 | 69196.66 |
| FC | 1.046 | 0.31 | −4.567 | 66 | 0.000 | −627.7801 | 137.4731 |
| | | | −4.585 | 65.596 | 0.000 | −627.7801 | 136.9091 |
| FD | 7.619 | 0.007 | −4.741 | 66 | 0.000 | −289429.1 | 61052.93 |
| | | | −4.785 | 61.979 | 0.000 | −289429.1 | 60487.43 |
| PC | 33.306 | 0.000 | −20.715 | 66 | 0.000 | −1112.585 | 53.70809 |
| | | | −21.284 | 37.526 | 0.000 | −1112.585 | 52.27438 |
| PD | 2.283 | 0.136 | −5.582 | 66 | 0.000 | −388980.6 | 69688.26 |
| | | | −5.607 | 65.454 | 0.000 | −388980.6 | 69375.98 |

TABLE 4 Group statistics of key-logging and eye-tracking data in ST and TT processings.

| | Direction | *N* | Mean | Standard deviation | Standard error mean |
|---|---|---|---|---|---|
| FCS | E-C | 33 | 926.2727 | 319.30582 | 55.58401 |
| | C-E | 35 | 813.5714 | 271.86332 | 45.95329 |
| RTS | E-C | 33 | 396157.0303 | 111004.93957 | 19323.47968 |
| | C-E | 35 | 348357.3714 | 108085.29645 | 18269.74963 |
| FCT | E-C | 33 | 725.5758 | 292.63939 | 50.94198 |
| | C-E | 35 | 1153.0000 | 434.97153 | 73.52361 |
| RTT | E-C | 33 | 330100.4242 | 154493.79791 | 26893.91820 |
| | C-E | 35 | 641242.6286 | 233606.78691 | 39486.75398 |

duration, there is a significant and positive correlation in both E-C ($r = 0.814$, $p < 0.01$) and C-E tasks ($r = 0.916$, $p < 0.01$). A positive correlation between BAI scores and pause count in both E-C ($r = 0.481$, $p < 0.01$) and C-E tasks ($r = 0.329$, $p = 0.053$) is also detected in the experiment, but the correlation in the C-E task is less significant than that in the E-C task. Besides, there is a significant and positive correlation between BAI scores and pause duration in both E-C ($r = 0.926$, $p < 0.01$) and C-E tasks ($r = 0.951$, $p < 0.01$).

# Discussion

## Translation anxiety and cognitive load

As language is of embodiment in nature and to a great extent, translation can be regarded as a kind of embodied-cognitive activity (Wang, 2021). That is why translation process is a sort of cognitive process, which takes cognitive load (total amount of cognitive resources consumed by human information processing) as an index to explain the cognitive processing of translators. To accomplish a task, an individual uses the limited cognitive-psychological resources in working memory at which point cognitive load transpires (Sweller, 1988).

The results of the present study suggest that the FLA in translation correlates positively with the cognitive load. The students performing both E-C and C-E translation tasks with higher cognitive load attained higher BAI scores. The findings offer support for Eysenck and Calvo (1992) PET theory which argues that cognitive efficiency is likely to suffer as stress or anxiety increases. As highlighted by Eysenck and Calvo (1992), intrusive thoughts irrelevant to tasks engage working memory capacity and hinder the efficiency of the cognitive process. The divided attention is likely to cause the decrease of the capacity demanded by information processing. As a result of the decrease in cognitive efficiency, it is likely to take longer to achieve good performance, otherwise, the performance is likely to become worse. The effect is noticed more easily when tasks are challenging or carried out under a high cognitive load (Baddeley and Hitch, 1974; Osborne, 2006; Derakshan and Eysenck, 2009). The findings also provide some support for Arnold and Brown (1999) claims that learners' cognitive activities are likely to stop automatically when they are in a negative emotional state, and that only by using emotion and cognition at the same time can the learning process be built on a firmer foundation.

Furthermore, the results align with the findings of the study carried out by Chen et al. (2009). Chen reported some evidence in support of the existence of a relationship between FLA and cognitive load in the context of English listening comprehension. The current study contributes more empirically-substantiated findings in relation to the link between FLA and cognitive load, and offers some evidence for the existence of positive relationship between cognitive load and FLA in the context of L1 and L2 translations.

The results of this experiment not only provide stronger substantiation of the PET model which depicts the relationship between anxiety and cognitive load uni-directionally without depicting the effects of cognitive load on anxiety, i.e., it only examined the influence of anxiety on cognitive load, but also set up the relationship between anxiety and cognitive load bi-directionally. In other words, the results indicate that cognitive load is positively correlated with anxiety and that the increase of cognitive load is likely to lead to an increase in anxiety.

Compared with the previous studies that they only investigated the relationship between anxiety and cognitive load by grouping subjects according to anxiety evaluation prior to experimentation, the present study was designed to solve the limitations of previous studies. To ensure

TABLE 5 Independent sample test of key-logging and eye-tracking data in ST and TT processings.

| | Levene's test for equality of variances | | *t*-test for equality of means | | | | |
|---|---|---|---|---|---|---|---|
| | *F* | Sig. | *t* | df | Sig. (two-tailed) | Mean difference | Standard error difference |
| FCS | 0.165 | 0.686 | 1.57 | 66 | 0.121 | 112.7013 | 71.77733 |
| | | | 1.563 | 62.995 | 0.123 | 112.7013 | 72.11995 |
| RTS | 0.043 | 0.837 | 1.799 | 66 | 0.077 | 47799.66 | 26571.72 |
| | | | 1.797 | 65.511 | 0.077 | 47799.66 | 26592.87 |
| FCT | 5.215 | 0.026 | −4.725 | 66 | 0.000 | −427.4242 | 90.45912 |
| | | | −4.779 | 59.83 | 0.000 | −427.4242 | 89.44723 |
| RTT | 6.684 | 0.012 | −6.437 | 66 | 0.000 | −311142.2 | 48336.93 |
| | | | −6.513 | 59.302 | 0.000 | −311142.2 | 47775.38 |

TABLE 6 Independent sample test of BAI scores.

| | Levene's test for equality of variances | | *t*-test for equality of means | | | | |
|---|---|---|---|---|---|---|---|
| | *F* | Sig. | *t* | df | Sig. (two-tailed) | Mean difference | Standard error difference |
| | | | | | | | |
| BAI | 0.462 | 0.499 | −2.937 | 66 | 0.005 | −2.19394 | 0.74696 |
| | | | −2.951 | 65.431 | 0.004 | −2.19394 | 0.74357 |

that any anxiety identified in the participants could be clearly linked to the cognitive load of the directionality of the translation tasks rather than pre-existing affective states, the experiment in the present study assigned participants to two groups randomly, set them up to complete two translation tasks and then evaluated their levels of anxiety. Such a structuring of design allowed a clearer understanding of the antecedents of the participants' anxiety. The findings of this study can be clearly observed in Figure 7.

As Figure 7 shows, the level of anxiety is determined by the degree of cognitive effort involved which in turn produces a corresponding level of cognitive load in cognitive activities. This implies that the attendant anxiety will attenuate the individual's processing efficiency and lead to a low cognitive performance.

## More anxiety in L2 translation than in L1 translation

The results show that the BAI scores of the participants undertaking the L1 translation are significantly lower than those identifiable in the L2 translation task. This establishes that more anxiety is experienced in the process of L2 translation. In L1 translation, the participants' BAI scores range from 1 to 11 with an average of 5.61 points, while the participants' BAI scores in L2 translation range from 3 to 14 with an average of 7.80 points. With reference to the relationship between anxiety and translation direction, there is a significant difference of BAI scores between L1 and L2 translation tasks, i.e., the BAI scores of the participants in L1 translation is significantly lower than that in L2 translation. The difference can be explained by the correlation between cognitive load and anxiety.

For assessing cognitive load in L1 and L2 translations, variables such as task duration, fixation count, fixation duration, pause count and pause duration collected in the E-C and C-E translation tasks were compared in this study. Based on the results, the study has found that the value of these five variables of the participants in L2 translation are significantly higher than those in L1 translation, suggesting higher cognitive load and processing difficulty in L2 translation. This finding is congruent with the results reported in some previous studies. Feng (2017) compared the cognitive load of 20 student translators in L1 and L2 translations based on their eye-tracking data during translation processes and found that the cognitive load during L2 translation was higher than the cognitive load experienced during L1 translation.

In order to explore the reason of such a difference, a comparison between fixation time and reading time on the ST and TT in both translation directions was conducted in this study. According to the results and analysis, both fixation count and reading time on the ST in L1 translation is higher than that in L2 translation, though the difference is not significant. In the case of cognitive load in the target-text processing, both fixation count and reading time on the TT in L1 translation is lower than that in L2 translation, which means that the cognitive load placed on the TT (Chinese) in L1 translation is lower than that on the TT (English) in L2 translation. It can be found from the results presented above that the participant's cognitive load in English processing is higher than that in Chinese processing in the process of translation. We may find some support from previous studies. Jensen and Pavlović (2009) used eye-tracking technology to investigate the distribution of translators' cognitive load in L1 and L2 translations. They tried to test whether the cognitive effort invested in the processing of the ST was higher in L1 translation than that in L2 translation, and whether the cognitive effort invested in the processing of the TT was higher in L2 translation than that in L1 translation. Their results only confirmed their expectation that the TT processing requires more cognitive effort than the ST processing in both directions of translation. However, the results of the present study suggest that there may exist a "L2 effect" in translation, in which the second or foreign language usually receives more attention than the native language irrespective of translation direction.

Furthermore, owing to the less significant difference of cognitive load in the ST processing than that in the TT processing between L1 and L2 translations, the language type of the TT tends to have a greater impact on the translator's cognitive load in the process of translation. The translation process can be seen as the combination of language comprehension and language output. The translator needs to get access to the concepts of ST and then output it with another language. High-level language learners do not need too much cognitive load for both first language comprehension and second language comprehension since they have already achieved high English proficiency. Therefore, certain second language words are directly linked to the concepts in a person's mind instead of associating to the first language words.

The findings above also offer support for the RHM model. According to this model, high-level learners can directly access the conceptual system from second language vocabulary, while low-level learners access the conceptual information of second language vocabulary depending more on the first language translation, which indicates that it takes more cognitive load to understand the concepts of second language for low-level learners. In the present study, all the participants have passed CET-4 with the average score of 572.1, and based on their English proficiency, they can be regarded as medium- or high-level learners. Therefore, it was not very difficult for them to directly get access to the concepts of ST no matter it is L1 or L2, which helps to explain the insignificant difference of cognitive load between L1 and L2 in the source-text processing.

In the light of the above analysis, it is clear that the level of anxiety is closely related to the task difficulty, which is in turn reflected by cognitive load. For translators, L2 translation is more difficult than L1 translation due to the higher cognitive load involved in the former. The translators' understanding and output of their mother tongue is a natural process, while the understanding and output of the second or foreign language is affected by many other external factors, such as social culture and language environment which leads to an increasing complexity for L2 translation.

TABLE 7 Correlations between variables in L1 and L2 translation.

| | Dur. | FC | FD | PC | PD | BAI | |
|---|---|---|---|---|---|---|---|
| L1—BAI | Pearson correlation | 0.928 | 0.611 | 0.814 | 0.481 | 0.926 | 1 |
| | Sig. (two-tailed) | 0.000 | 0.000 | 0.000 | 0.005 | 0.000 | |
| | *N* | 33 | 33 | 33 | 33 | 33 | 33 |
| L2—BAI | Pearson correlation | 0.962 | 0.807 | 0.916 | 0.329 | 0.951 | 1 |
| | Sig. (two-tailed) | 0.000 | 0.000 | 0.000 | 0.053 | 0.000 | |
| | *N* | 35 | 35 | 35 | 35 | 35 | 35 |

## Cognitive mechanism of anxiety in L1 and L2 translations

Based on the data we collected from the translation anxiety experiment and the above discussion, a general cognitive mechanism model of translation anxiety under the influence of translation direction is presented in Figure 8. It delineates the timeline from the time of the translators' first encounter with the translation task to the time of their translation production. From this model, we can see the different anxiety levels of translators instantiating between L1 translation and L2 translation.

The reason why the translator feels anxious when a L2 translation is provided can be explained with reference to the complexity of translation task (Wang and Wang, 2018). L2 translation is more difficult than L1 translation, because it requires more efforts for processing (e.g., monitoring and revision) which generates greater cognitive load and gives rise to higher anxiety. As the model shows, when a medium or high-level proficiency translator receives a translation task, he/she initially processes the ST in L1 or in L2 translation from the early period to the intermediate period in a nearly similar way. A high-level language learner is able to get access to the concepts directly no matter the ST is given in the first language or second language. During the early period, if the ST is presented in the first language, it is easy for the translator to understand his/her mother tongue and get the concepts. If the translator encounters the ST in the second language, due to his/her solid grasp of the second language knowledge, he/she does not need much cognitive efforts in the process of language comprehension.

After the concepts are obtained, the language type of TT determines the level of cognitive load in the processing which follows. In the stage of language output, L2 translation requires more cognitive efforts compared to L1 translation as the translator needs to do drafting, monitoring and revision before producing the TT. Such extensive cognitive efforts may result in a higher level of cognitive load due to the

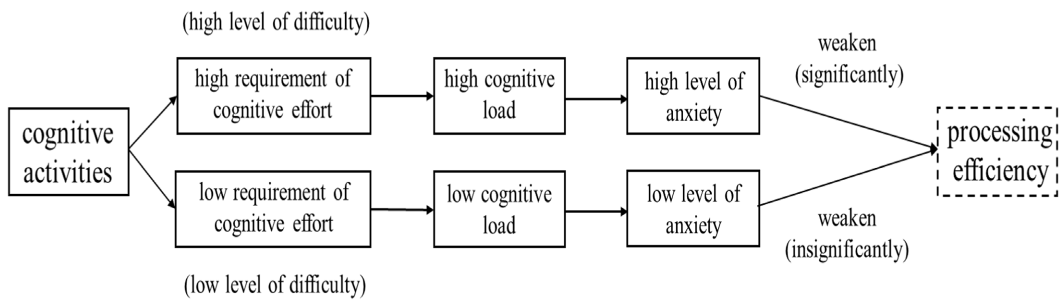


FIGURE 7
The correlation between cognitive load and anxiety.

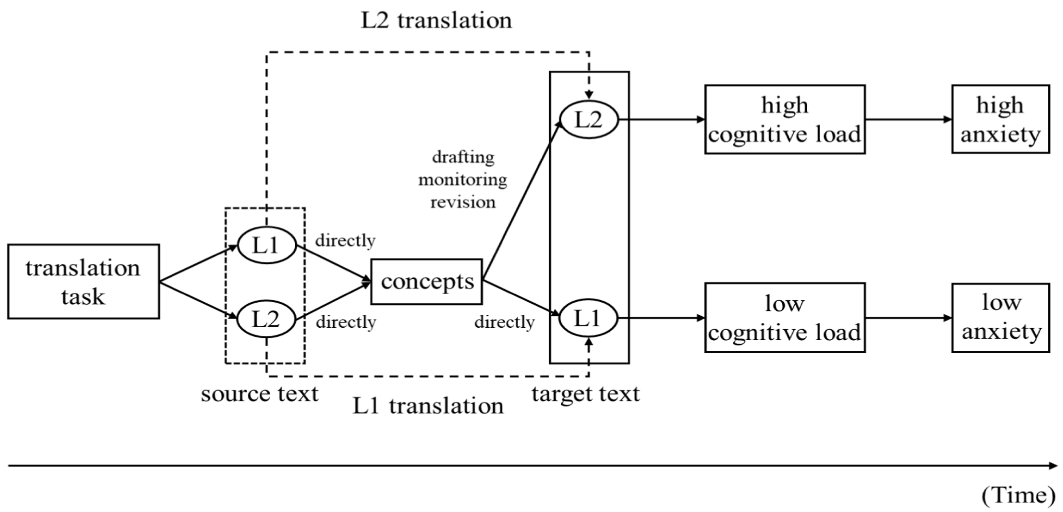


FIGURE 8
The cognitive mechanism of anxiety in L1-L2 translations.

complicated nature of cognitive activities in the process of target language output, which in turn impacts the anxiety level of the translator.

The reason for higher anxiety in L2 translation can also be explained with reference to the translator's previous experience of language learning and translation practice. In later translation tasks, after confirming the translation direction, the translator's anxiety will be released in advance according to the previous experience (experience of task and memory of anxiety), thus giving rise to anticipatory anxiety prior to the commencement of the translation task.

## Conclusion

The study has found that cognitive load and anxiety in the process of translation are positively correlated, thus suggesting that a high cognitive load is likely to give rise to high anxiety in translation. It has also revealed that there were significant differences between task duration, fixation count, fixation duration, pause count and pause duration discernible in the two translation direction tasks. Further, the average value of the five variables in the C-E task (L2 translation) was significantly higher than that identified in the E-C task (L1 translation), thus implying that cognitive load in L2 translation is significantly higher than in L1 translation.

The difference of cognitive load between the two translation tasks is found to be attributable to the difficulty of the two translation tasks. For medium- or high-level language learners, L1 translation has proved to be less difficult than L2 translation. This is possibly because irrespective of the language of ST (mother tongue, second language or foreign language), language comprehension tends to be semi-automatic without requiring excessive cognitive effort. However, in the process of language output, the production of mother tongue is notably easier than the production of second or foreign language, thus reflecting the difference in difficulty between L1 and L2 translations. Meanwhile, the higher BAI scores observed in participants performing L2 translation also suggest that in comparison with L1 translation, L2 translation entails greater anxiety. Therefore, it would appear that L2 translation is likely to be more difficult for translators than L1 translation and lead to greater translation anxiety.

In relation to the third question, the study found that the cognitive load of processing in L2 was greater than that for L1 across L1 and L2 translations. The analysis of data showed that it was the language type of TT rather than ST which contributed to the cognitive load in the subsequent processing procedure. In summary, the results of the study corroborate the key premises of the Processing Efficiency Model and the REM, confirming that the taking up of working memory resources by anxiety negatively impacts the processing efficiency and that high-level learners can directly access the conceptual system from the second language vocabulary rather than through the first language vocabulary. The current study also offers important insights in relation to the relationship between translation directionality and anxiety. As a small-scale but original contribution to the body of knowledge, the current study further delineates the cognitive mechanism of L2 translation task performance and anxiety.

To test whether the findings of this research hold true, future research may be designed with a larger sample size of subjects and/or investigate educational settings, unlike the present setting (a top university in China) reputed for being more achievement-oriented (and thus likely to host learners subject to greater performance anxiety) than locales elsewhere. The practical implications of this study pertain to translation pedagogy in particular. Translation teachers should work to increase L2 translation practice so as to improve their students' familiarity with the translation tasks and reduce attendant anxiety as well as encourage their students by giving positive feedback during translation practice in order to build up their confidence and decrease their fear of L2 translation.

## Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

## Ethics statement

The studies involving human participants were reviewed and approved by Research Ethics Board of Zhejing University. The patients/participants provided their written informed consent to participate in this study.

## Author contributions

ZW and XW conceived and designed the experiments. ZW and HC performed the experiments. JJ, ZW, and XW analyzed the data and wrote the manuscript. JJ and XW revised the manuscript. All authors contributed to the article and approved the submitted version.

## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

## Publisher's note



## Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2023.1120140/full#supplementary-material

## References

Arnold, J., and Brown, H. D. (1999). "A map of the terrain" in *Affect in language learning*. ed. J. Arnold (Cambridge: Cambridge University Press)

Baddeley, A. D., and Hitch, G. (1974). Working memory. *Psychol. Learn. Motiv.* 8, 47–89. doi: 10.1016/S0079-7421(08)60452-1

Beeby, L. A. (2009). *Teaching translation from Spanish to English: Words beyond words*, in Didactics of Translation Series 3. ed. L. Haywood Ottawa: University of Ottawa Press.

Chang, C. Y. (2009). *Testing applicability of eye-tracking and fMRI to translation and interpreting studies: An investigation into directionality*. London: University of London.

Chen, H. C., Vaid, J., and Wu, J. T. (2009). Homophone density and phonological frequency in Chinese word recognition. *Lang. Cogn. Proc.* 24, 967–982. doi: 10.1080/01690960902804515

de Lima Fonseca, N. B. (2015). Directionality in translation: investigating prototypical patterns in editing procedures. *Transl. Interpr.* 7, 111–125.

Derakshan, N., and Eysenck, M. W. (2009). Anxiety, processing efficiency, and cognitive performance: new developments from attentional control theory. *Eur. Psychol.* 14, 168–176. doi: 10.1027/1016-9040.14.2.168

Dornic, S. (1977). *Mental load, effort, and individual differences*. Stockholm: Department of Psychology, University of Stockholm.

Dornic, S. (1980). *Efficiency vs. effectiveness in mental work: The differential effect of stress*. Stockholm: Department of Psychology, University of Stockholm.

Eysenck, M. W. (1985). Anxiety and cognitive-task performance. *Personal. Individ. Differ.* 6, 579–586. doi: 10.1016/0191-8869(85)90007-8

Eysenck, M. W., and Calvo, M. G. (1992). Anxiety and performance: the processing efficiency theory. *Cognit. Emot.* 6, 409–434. doi: 10.1080/02699939208409696

Feng, J. (2017). Comparing cognitive load in L1 and L2 translation: evidence from eye-tracking. *For. Lang. China* 4, 79–91. doi: 10.13564/j.cnki.issn.1672-9382.2017.04.012

Feng, J., and Wang, K. F. (2016). A new window to explore the translation process: keyboard recording and eye tracking. *Chin. Transl. J.* 1, 12–18.

Ferreira, A. (2014). Analyzing recursiveness patterns and retrospective protocols of professional translators in L1 and L2 translation tasks. *J. Am. Transl. Interpr. Stud. Assoc.* 9, 109–127. doi: 10.1075/tis.9.1.06fer

Hammond, R. M. (1990). "The affective filter and pronunciation proficiency—attitudes and variables in second language acquisition" in *Language proficiency*. eds. Louis A. Arena. (Boston, MA: Springer), 65–71. doi: 10.1007/978-1-4899-0870-4_6

Harley, T. A. (2001). *The psychology of language: From data to theory* (*2nd ed.*). London: Psychology Press, doi: 10.4324/9780203345979

Henter, R. (2014). Affective factors involved in learning a foreign language. *Procedia Soc. Behav. Sci.* 127, 373–378. doi: 10.1016/j.sbspro.2014.03.274

Horwitz, E. K., Horwitz, M. B., and Cope, J. (1986). Foreign language classroom anxiety. *Mod. Lang. J.* 70, 125–132. doi: 10.1111/j.1540-4781.1986.tb05256.x

Jensen, K., and Pavlović, N. (2009). Eye tracking translation directionality: In translation research projects 2. eds. A. Pys and A. Perekrestenko Tarragona: Intercultural Studies Group, 93–109.

Krashen, S. (1982). *Principles and practice in Ssecond language acquisition*. Oxford: Pergamon Press.

Krashen, S. (1985). *The input hypothesis: Issues and implications*. London, UK: Longman Publishing Press.

Kroll, J. F., and Stewart, E. (1994). Category interference in translation and picture naming: evidence for asymmetric connections between bilingual memory representations. *J. Mem. Lang.* 33, 149–174. doi: 10.1006/jmla.1994.1008

Lin, W. Y. (2004). *A supportive study of processing efficacy theory in foreign language anxiety*. Shanghai: East China Normal University.

MacIntyre, P. D., and Gardner, R. C. (1994). The subtle effects of language anxiety on cognitive processing in the second language. *Lang. Learn.* 44, 283–305. doi: 10.1111/j.1467-1770.1994.tb01103.x

Muñoz Martín, R., and Apfelthaler, M. (2021). "The task segment framework" in *Translation & interpreting special issue on "probing the process in cognitive translation studies: Towards more integrative research practices"*. eds. A. M. R. López and M. R. Caro

Osborne, T. (2006). Shared material and grammar: a dependency grammar theory of non-gapping coordination. *Z. Sprachwiss.* 25, 39–94. doi: 10.1515/zfs.2006.002

Oxford, R. L. (1999). Anxiety and the language learner: new insights. *Affect Lang. Learn.* 58:67

Pavlović, N. (2007). Directionality in translation and interpreting practice: report on a questionnaire survey in Croatia. *Int. J. Interpr. Transl.* 5, 79–99. doi: 10.1075/forum.5.2.05pav

Pedersen, P. (2000). *A handbook for developing multicultural awareness*. Alexandria: American Counseling Association (*3rd Edition*).

Phillips, E. M. (1992). The effects of language anxiety on students' oral test performance and attitudes. *Mod. Lang. J.* 76, 14–26. doi: 10.1111/j.1540-4781.1992.tb02573.x

Pokorn, N. (2000). "Tranlation into a non-mother tongue in translation theory" in *Translation in Context*. eds. A. Chestemanet al. (Amsterdam: John Benjamins), 61–72. doi: 10.1075/btl.39.09pok

Sweller, J. (1988). Cognitive load during problem solving: effects on learning. *Cogn. Sci.* 12, 257–285. doi: 10.1207/s15516709cog1202_4

Wang, Q. N. (2019). *Directionality and cognitive load in translation: An eve-tracking and key-logging study*. Beijing: Beijing Foreign Studies University.

Wang, Y. (2021). The reinterpretation of literal translation and paraphrase based on embodied-cognitive translatology. *Transl. Res. Teach.* 1, 1–6.

Wang, X. L., and Wang, Y. Z. (2018). A study on the reliability and validity of NASA-TLX as a measurement of translation difficulty: taking CET-4 Chinese-English translation test as examples. *Transl. Res. Teach.* 2, 79–87.

Weinberg, R. S. (1978). The effects of success and failure on the patterning of neuromuscular energy. *J. Mot. Behav.* 10, 53–61. doi: 10.1080/00222895.1978.10735135

Woodrow, L. (2006). Anxiety and speaking English as a second language. *RELC J.* 37, 308–328. doi: 10.1177/0033688206071315

Xu, L. (2014). *Trait anxiety and emotional word Processing's eye movement*. Tianjing: Tianjing Normal University.

Yan, J. X., and Wang, H. (2012). Second language writing anxiety and translation: performance in a Hong Kong tertiary translation class. *Interpr. Transl. Trainer* 6, 171–194. doi: 10.1080/13556509.2012.10798835

Yu, X. M. (2019). *The influence of second language working memory capacity and proficiency on advanced English learners' syntactic processing*. Jinan: Shandong Normal University.

Zheng, P. Y. (2003). Question asking and anxiety control in the EFL classroom. *For. Lang. World* 3, 26–30.

frontiers | Frontiers in Psychology

TYPE Original Research
PUBLISHED 23 February 2023
DOI 10.3389/fpsyg.2023.1126673

Check for updates

OPEN ACCESS

EDITED BY
Huili Wang,
Dalian University of Technology, China

REVIEWED BY
Tao Zeng,
Hunan University,
China
Alberto Dominguez,
University of La Laguna,
Spain

*CORRESPONDENCE
Tongquan Zhou
✉ zhoutongquan@126.com
Yiming Yang
✉ yangym@jsnu.edu.cn

†These authors have contributed equally to this work and share first authorship

SPECIALTY SECTION
This article was submitted to Language Sciences, a section of the journal Frontiers in Psychology

RECEIVED 18 December 2022
ACCEPTED 06 February 2023
PUBLISHED 23 February 2023

CITATION
Wang T, Geng M, Wang Y, Zhao M, Zhou T and Yang Y (2023) Chinese EFL learners different from English natives in cataphora resolution: Evidence from eye-tracking studies.
*Front. Psychol.* 14:1126673.
doi: 10.3389/fpsyg.2023.1126673



# Chinese EFL learners different from English natives in cataphora resolution: Evidence from eye-tracking studies

Tao Wang[1†], Mingyao Geng[2†], Yue Wang[3], Min Zhao[4], Tongquan Zhou[5]* and Yiming Yang[6,7]*

[1]School of Psychology, Qufu Normal University, Qufu, China, [2]School of Translation Studies, Qufu Normal University, Rizhao, China, [3]College of Foreign Languages, Qufu Normal University, Qufu, China, [4]School of Foreign Languages, University of Jinan, Jinan, China, [5]School of Foreign Languages, Southeast University, Nanjing, China, [6]School of Linguistic Sciences and Arts, Jiangsu Normal University, Xuzhou, China, [7]Collaborative Innovation Center for Language Ability, Jiangsu Normal University, Xuzhou, China

Previous studies on English natives have shown that encountering an English cataphoric pronoun triggers an active search for its antecedent and this searching process is modulated by syntactic constraints. It remains unknown whether the conclusion is universal to EFL (English as a Foreign Language) learners, particularly those with distinct L1 like Chinese in linguistic typology. Therefore, this study used two eye-tracking experiments to investigate how Chinese EFL learners resolve English cataphora. The experiments adopted the gender-mismatch paradigm. Experiment 1 investigated whether Chinese EFL learners with different proficiency would adopt the similar processing pattern to English natives and found that gender congruency elicited longer reading times than gender incongruency between the first potential antecedent and the cataphoric pronoun, the effect early observed in high-proficiency relative to low-proficiency learners. Experiment 2 explored whether the cataphora resolution process was modulated by Binding Principle B and revealed that longer first fixation durations and first pass reading times were observed in gender-mismatch than in gender-match conditions no matter the antecedents are binding-accessible or not while longer regression path durations occurred in gender-mismatch than in gender-match conditions only as the antecedents are binding-accessible. Taken together, these results indicate that Chinese EFL learners also adopt an active search mechanism to resolve cataphoric pronouns, yet along a processing path distinct from English natives'. Specifically, Chinese EFL learners predictively link a cataphoric pronoun to the first potential antecedent in the sentence but only a gender-matching antecedent can prompt them to engage in deep processing of the antecedent. Moreover, the processing time varies with the learners' English proficiency. Furthermore, unlike native English speakers' early application of syntactic constraints in their cataphora resolution, Chinese EFL learners try to establish co-reference relations between cataphoric pronouns and antecedents regardless of following or flouting Binding Principle B in early processing stages whereas they exclusively link the cataphoric pronouns to the binding-accessible antecedents in late processing stages. This study adds evidence to the Shallow Structure Hypothesis whereby L2 learners resort to lexical prior to syntactic cues to process sentences in general, which is just opposite to the fashion adopted by the natives.

KEYWORDS

cataphora resolution, Chinese EFL learners, active search mechanism, L2 proficiency, eye-tracking

## 1. Introduction

Cohesive devices abound in human language. Of all the cohesive devices, anaphora is used in English more often than not. Anaphora refers to the linguistic phenomenon whereby the interpretation of one linguistic element (anaphor) depends on the interpretation of another (antecedent) (Huang, 2000; Kazanina, 2005). Based on the linear position between the two linguistic elements, anaphora is classified into two types: forwards anaphora where the forwards anaphor appears after its antecedent and backwards anaphora (also referred to as cataphora) where the backwards anaphor (cataphor) appears before its antecedent. The process of finding the antecedent for an anaphor is called anaphora resolution (Mitkov, 2002). Anaphora resolution has been a central topic in the field of psycholinguistics for the last few decades (e.g., Felser et al., 2009; Felser and Cunnings, 2012; Chow et al., 2014; Cunnings et al., 2014; Wu, 2016, 2017; Cunnings et al., 2017; Yu and Zhai, 2017; Liang et al., 2018; Yu and Dong, 2019; Liu, 2020; Tang and Wen, 2020), for the correct interpretation of anaphors underlies successful sentence comprehension. Though both being the commonly used cohesive devices in English, backwards anaphora has received much less attention than forwards anaphora in empirical studies. To date, the majority of cataphora resolution studies have been conducted on native speakers (Kazanina et al., 2007; Kazanina and Phillips, 2010; Clackson and Clahsen, 2011; Yoshida et al., 2014; Pablos et al., 2015; Patterson and Felser, 2019; Kush and Dillon, 2021) while few on L2 learners (Rodríguez, 2008; Bertenshaw, 2009; Drummer and Felser, 2018; Wu et al., 2019). Although the EFL learners in the L2 cataphora resolution studies exhibited similar processing patterns as English natives, they basically have a L1 similar to English in linguistic typology. As a consequence, it remains unknown how English learners with a typologically distinct L1 resolve English cataphora. Since Chinese as a semantics-driven language contrasts with English as a syntax-driven language, an examination is required to test whether this typological difference influences Chinese EFL learners' online processing of English cataphoric pronouns. Against this background, the current study aims to investigate Chinese EFL learners' online processing of English cataphoric pronouns.

Previous cataphora resolution studies on native speakers have shown that encountering a cataphoric pronoun triggers an active search for its antecedent (Cowart and Cairns, 1987; van Gompel and Liversedge, 2003; Filik and Sanford, 2008). In van Gompel and Liversedge's (2003) eye-tracking study, the gender-mismatch paradigm was adopted for the first time to test whether the use of morphological information preceded the computation of coreference relations during pronoun resolution. They used materials like those in (1), in which the gender of the first noun phrase in the main clause was manipulated to either match or mismatch the cataphoric pronoun in the subordinate clause.

(1) a. gender-match

When he was at the party, *the boy* cruelly teased the girl during the party games.

b. gender-mismatch.

When he was at the party, *the girl* cruelly teased the boy during the party games.

Their results showed that English native speakers exhibited longer reading times in gender-mismatch than gender-match conditions at the adverb region immediately following the first noun phrase. This suggested that English native speakers predictively assigned the cataphoric pronoun to the first noun phrase, and the gender-incongruency between the cataphoric pronoun and the first noun phrase caused reader's processing difficulty. This processing difficulty was thus referred to as GMME effect (Gender-Mismatch effect). The presence of GMME effect indicated that readers were so eager to resolve the cataphoric pronoun that they predictively linked the cataphoric pronoun to the first syntactic position that could contain a potential antecedent even before the gender information of the potential antecedent became available. This searching process in cataphora resolution is much like the active search mechanism adopted in processing filler-gap dependencies (e.g., Crain and Fodor, 1985; Stowe, 1986; Frazier and Flores D'Arcais, 1989), for both parsers attempt to find an antecedent or gap at the earliest possible syntactic position in order to establish the dependencies as soon as possible, without considering the plausibility of the constituent at that position (Kazanina et al., 2007). On this basis, active search mechanism is also used to describe the process of actively searching for antecedents in cataphora resolution.

English native speakers initiate an active search for the antecedent after encountering a cataphoric pronoun. This finding gave rise to another research question, i.e., whether the search process in cataphora resolution proceeds unconstrained or is subject to some constraints. The Binding Theory proposed by Chomsky (1981) offers theoretical justification for the interpretation of pronouns. Of the three principles contained in the Binding Theory, what is relevant to the interpretation of cataphoric pronouns is Principle C whereby referring expressions cannot co-refer with noun phrases including pronouns that c-command them. In the context of cataphora, Principle C can be restated as cataphoric pronouns cannot establish coreference relations with noun phrases that are c-commanded by them. Naturally, Principle C is able to be used to test whether the active searching process in cataphora resolution is restricted by the syntactic constraint.

Kazanina et al. (2007) were the first to demonstrate that Principle C constrained English natives' online processing of cataphoric pronouns. Results from Kazanina et al.'s (2007) study showed that significantly longer reading times in gender-mismatch than in gender-match conditions were only observed in no-constraint pairs. This suggested that English native speakers only tried to establish coreference relations between the cataphoric pronoun and the first potential antecedent in the no-constraint conditions, indicating that Principle C indeed constrained English native speakers' online processing of cataphoric pronouns Later, Principle C's constraint in cataphora resolution was also confirmed by other studies (Kazanina and Phillips, 2010; Clackson and Clahsen, 2011; Yoshida et al., 2014; Pablos et al., 2015).

The active searching for the antecedent in cataphora resolution was restricted not only by Principle C, but also by Principle B, the principle that regulates co-arguments of the same predicate cannot establish coreference relations. For instance, Kush and Dillon (2021) employed self-paced reading technique to test whether Principle B constrained English native speakers' cataphora resolution.

(2) a. Constraint, gender-match/gender-mismatch

While (PRO) driving him/her to school on Friday, Christopher casually told Juan/Hannah that he would pick up everyone early for a surprise.

b. No-constraint, gender-match/gender-mismatch.

While (PRO) driving his/her daughter to school on Friday, Christopher casually told Juan/Hannah that he would pick up everyone early for a surprise.

They designed cataphoric pronouns to appear in a fronted participle clause, with its implicit subject obligatorily interpreted as the matrix subject according to Control Theory (Chomsky, 1981), consequently making the coreference between the cataphoric pronoun and the matrix subject syntactically-illicit, as illustrated in (2a). In (2b), by contrast, with the cataphoric pronoun being embedded inside the noun phrase *his/her daughter*, the implicit subject PRO and the cataphoric pronoun were no longer co-arguments of the same predicate, which allowed for coreference between PRO and the cataphoric pronoun, and further made the coreference between the cataphoric pronoun and matrix subject syntactically-licit. Kush and Dillon (2021)'s results showed that the GMME effect at the matrix subject region (Christopher) and its spillover region (casually) was only present in the no-constraint conditions, demonstrating that Principle B restricted English native speakers' active searching for the cataphor antecedent.

In summary, cataphora resolution studies on native speakers have consistently shown that encountering a cataphoric pronoun triggers an active search for the antecedent and this searching process is restricted by syntactic constraints (Principle B and Principle C) such that only syntactically-licit noun phrases can be considered as antecedents of cataphoric pronouns.

Compared to cataphora resolution studies on native speakers, very little research has been conducted to investigate how L2 learners resolve cataphoric pronouns (Rodríguez, 2008; Bertenshaw, 2009; Drummer and Felser, 2018; Wu et al., 2019). Using eye-tracking technique, Drummer and Felser (2018) compared the online performance of German native speakers and Russian German learners in processing German cataphoric pronouns, revealing that Russian German learners behaved themselves just as German native speakers in using an active search mechanism that was constrained by Principle C. Similarly, Bertenshaw (2009) found that both English native speakers and Japanese English learners followed Principle C when resolving cataphoric pronouns online. Another comparative study using self-paced reading technique indicated that both English native speakers and Spanish English learners abided by Principle C in processing English cataphoric pronouns while the GMME effect restricted to no-constraint conditions did not reach statistical significance in Chinese English learners (Rodríguez, 2008). Wu et al. (2019), who adopted self-paced reading technique to compare Chinese EFL learners' processing of forwards anaphora and cataphora, found that the GMME effect was not statistically significant in their processing of cataphoric pronouns.

Evidently, previous cataphora resolution studies on English native speakers have consistently shown that native speakers initiate an active search for the cataphor antecedent, in accordance with Principle B and C. Though a few studies on EFL learners revealed similar results, the learners have L1s basically similar to English in linguistic typology. It remains unknown how EFL learners with typologically distinct L1s like Chinese resolve English cataphora. Whether there exists cataphora in Chinese has been a controversial issue. Some scholars (Xu and He, 2007; Gao, 2010; Yu, 2011) hold that zero pronouns in the preposed (clause-initial) modifiers can form cataphoric relations with noun phrases which act as the main clause subjects or the modifiers of the main clause subjects. For example, Gao (2010) used the following sentences in (3) to exemplify his view that zero cataphoric pronouns exist in both Chinese and English and they are used in a similar way in the two languages. However, other scholars (Wang, 1994; Wang, 2000, 2006; Zhao and Shao, 2002) believes that third person pronouns in Chinese do not have the cataphoric function, as can be seen in (4). Combining the two views together, we can conclude that zero cataphoric pronouns are present in both Chinese and English while overt cataphoric pronouns exist only in English. Since there are no overt cataphoric pronouns in Chinese, it is more informative to investigate Chinese EFL learners' online processing of English overt cataphoric pronouns.

(3) $\varnothing_i$自得地点了点头之后，蒋老虎$_i$关心地问…

When $\varnothing_i$ introducing Huan-chih to the boys of course, Ping-ju$_i$ was at greater pain to create a good impression.

(4) *他$_i$看见了小李$_i$的妈妈。

Against the above-mentioned background, the current study was undertaken to explore how Chinese EFL learners resolve English cataphoric pronouns by two eye-tracking experiments. Unlike previous studies on cataphora resolution, we referred to Kush and Dillon (2021) to test whether Principle B would affect Chinese EFL learners' online processing of cataphoric pronouns. This option arises from the theoretical assumption by which Principle B is more suitable than Principle C for testing the role of syntactic constraint in cataphora resolution, for the application of Principle C in cataphora resolution involves some semantic and pragmatic considerations (Reinhart, 1983; Levinson, 1991; Reinhart and Reuland, 1993; Huang, 1994; Huang, 2000; Büring, 2005) while the application of Principle B is purely syntactic. In addition, considering learners' proficiency level plays an important role in L2 sentence processing, we included two groups of Chinese EFL learners (high-proficiency group and low-proficiency group, HG and LG henceforth), to explore how learners' proficiency level might modulate their online processing of cataphoric pronouns.

Specifically, this study was conducted to investigate whether Chinese EFL learners with different proficiency levels would adopt the pattern (i.e., an active search mechanism) similar to English natives in English cataphora resolution and whether the cataphora processing would be modulated by Principle B. In association with previous studies, we made the following hypotheses corresponding to the two research questions.

Firstly, both HG and LG learners would adopt an active search mechanism like English natives when resolving cataphoric pronouns, as would be indicated by longer reading times at the critical word region or its spillover region in gender-mismatching than in gender-matching sentences (i.e., GMME effect). Besides, learners' English proficiency discrepancy might modulate the processing time-course, i.e., HG learners could be earlier than LG learners in initiating the search mechanism, as would be indicated by the GMME effect being observed in both early and late eye-movement measures at the critical word region and its spillover region for HG learners while the GMME effect being found in only late eye-movement measures at the critical word region or its spillover region for LG learners.

Secondly, Chinese EFL learners would observe Principle B in processing English cataphora, as would be suggested by a GMME effect restricted to no-constraint sentences at the critical word region or its spillover region. Furthermore, the processing pattern might vary with the learners' English proficiency as well. Specifically, HG learners might behave more like English natives, exhibiting early application of Principle B in cataphora resolution, as would be indexed by the GMME effect restricted to no-constraint sentences being found in both early and late eye-movement measures at the critical word region and its spillover region, while LG learners would show delayed application of Principle B, as would be evidenced by the GMME effect restricted to no-constraint sentences being found in only late eye-movement measures at the critical word region or its spillover region.

## 2. Experiment 1

Experiment 1 was conducted to explore whether Chinese EFL learners would adopt an active search mechanism to resolve cataphoric pronouns as English natives do, and how learners' proficiency would modulate this cataphora resolution process.

### 2.1. Participants

Thirty-one English majors who had passed TEM-8 (Test for English Majors-Band 8) and thirty-two non-English majors who had scored between 430 and 480 on the CET-4 (College English Test Band 4) but had not passed the CET-6 (College English Test Band 6) were recruited as our participants. Of all the participants, the data of five participants (1 English majors and 4 non-English majors) were excluded from further analyses as their accuracy rate was below 60%. The data to enter into final analysis consisted of 30 English majors (age: $M = 22$ years, SD = 1.11 years, ranging from 20 years to 24 years; gender: 10 males, 20 females) and 28 non-English majors (age: $M = 21$ years, SD = 1.17 years, ranging from 19 years to 23 years; gender: 10 males, 18 females). Before the experiment, all the participants were required to complete an adapted version of language history questionnaire (Li et al., 2006) in which they needed to report their AoA (Age of Acquisition) of English and make a self-assessment on their English listening, speaking, reading and writing abilities (five points for full marks for each ability). Besides, they also needed to complete the Oxford Placement Test (QPT), a standardized test for English proficiency. Results of the questionnaire and QPT scores are given in Table 1.

TABLE 1 Results of the language history questionnaire and QPT scores in Experiment 1.

| | HG (English majors) | | LG (non-English majors) | |
|---|---|---|---|---|
| | *M* | SD | *M* | SD |
| **Self-rating** | | | | |
| Listening | 2.86 | 0.69 | 2.46 | 0.63 |
| Speaking | 3.23 | 0.63 | 2.40 | 0.75 |
| Reading | 3.77 | 0.55 | 3.12 | 0.80 |
| Writing | 3.19 | 0.74 | 2.77 | 0.85 |
| AoA | 9.75 | 1.97 | 8.88 | 2.01 |
| QPT | 53.10 | 1.77 | 36.18 | 1.68 |

English majors ($M = 53.10$, SD = 1.77) scored significantly higher than non-English majors ($M = 36.18$, SD = 1.68) in the QPT ($t(56) = 37.312$, $p < 0.001$). Two independent-sample $t$-test on participants' total scores of four English abilities also showed that English majors ($M = 13.05$, SD = 1.86) scored significantly higher than non-English majors ($M = 10.75$, SD = 2.09; $t(56) = -4.421$, $p < 0.001$). At the same time, the self-rated score on English reading ability was positively correlated with the OPT score for both English majors ($r(28) = 0.817$, $p < 0.001$) and non-English majors ($r(26) = 0.899$, $p < 0.001$). On account of this, we took English majors as HG learners and non-English majors as LG learners. Both HG and LG learners are late second language learners, with no significant difference in their AoA of English (HG: $M = 9.75$, SD = 1.97; LG: $M = 8.88$, SD = 2.01; $t(56) = -1.651$, $p = 0.104$). All participants were right-handed (Oldfield, 1971) native Chinese speakers with normal or corrected to normal vision and did not have any psychiatric or reading disorders. Each participant signed a formal inform consent before the experiment and were paid for their participation after the experiment. The experiment was approved by the Ethics Committee of Qufu Normal University.

### 2.2. Materials

Our stimuli consisted of 50 pairs of sentences as shown in (5). Of the 50 pairs of sentences, 24 pairs were adapted from the sentences in no-constraint conditions in Kush and Dillon (2021)'s Experiment 2, using familiar names and words to substitute for the corresponding unfamiliar counterparts, and the other 26 pairs were constructed by referring to the sentence structures in Kush and Dillon (2021). The 50 pairs of experimental sentences were selected from a total of 80 pairs of sentences. Thirty-four LG learners who did not participate in the formal experiment but were selected from non-English majors based on the same criteria as in formal experiment were recruited to rate the comprehensibility of all the sentences on a 5-point Likert scale (1 = totally incomprehensible, 5 = totally comprehensible). As a result, the sentences with over 3.75 rating score on average were chosen as the experimental stimuli ($M = 4.33$, SD = 0.31) so that all were equally understood by both HG and LG learners.

(5) a. gender-match

After a stranger bought her an iced coffee, Linda generously offered Elsa the best seat at the meeting table.

b. gender-mismatch.

After a stranger bought him an iced coffee, Linda generously offered Victor the best seat at the meeting table.

As shown in (5), all the stimuli are made up of two parts, the subordinate clause (headed by *while*, *before* or *after*) as the first part and the main clause as the second part. The cataphoric pronoun occurs in the direct object position of the subordinate clause with an indefinite noun phrase (e.g., *a stranger*) or an indefinite pronoun (someone, anyone) as the subject. The main clause contains two names, one in subject position (followed by an adverb) and the other in object position. Adverbs following the matrix subject name were those with a weak pragmatic function, such as *casually*, *generously*, *kindly* and the like. All the adverbs were selected from the lexical syllabus for CET-4 and acquired an average rating score of more than 3.75 on a 5-ponit Likert scale ($M = 4.01$, $SD = 0.58$) in a familiarity pretest (1 = totally unfamiliar, 5 = totally familiar) by the same group of LG learners who participated in the sentence comprehensibility rating. The gender of the cataphoric pronoun was manipulated to either match or mismatch the gender of the matrix subject. The gender of the matrix object name was designed to match that of the cataphoric pronoun so that the pronoun could be resolved intra-sententially. All the sentences in gender-match conditions were counterbalanced so that the cataphoric pronouns *him* and *her* appeared evenly in the stimuli.

The experimental sentences were divided into two lists by a Latin-Square design, with 75 extra sentences as fillers which were similar to the target sentences in length and complexity, but did not contain cataphoric pronouns. To ensure that participants could attend to the reading task, 25 experimental sentences and 38 filler sentences were followed by a comprehension question for each. In case participants did not resolve cataphoric pronouns during reading, 7 out of the 25 comprehension questions following the experimental sentences required the interpretation of cataphoric pronouns (e.g., Who got an iced coffee?) and the remaining questions asked about argument roles in the main clause or subordinate clause (Who offered someone the best seat?/Who got the best seat?/Who bought someone an iced coffee?).

As illustrated in (5), four regions (underlined parts) were selected for experimental analyses: Region 1 (e.g., Linda), the main clause subject (the first potential antecedent of the cataphoric pronoun); Region 2 (e.g., generously), the adverb following the matrix subject, serving as the spillover region of Region 1; Region 3 (e.g., Elsa/Victor), the direct object in the main clause (the other potential antecedent for the cataphoric pronoun); Region 4 (e.g., the best), the spillover region of Region 3, containing two words immediately following Region 3.

## 2.3. Procedure

The whole experiment was carried out in a quiet laboratory room. Participants were seated ~75 cm away from the display screen and 60 cm away from the eye-tracker. The eye-movement data were recorded using the desk-mounted Eyelink 1000 plus eye-tracker (SR Research, Toronto, ON, Canada) with a sampling rate of 1,000 Hz and a refresh rate of 150 Hz. Right eye was recorded. All the experimental sentences were displayed in 19-point Consolas font across two lines on a 19-inch computer screen.

Each participant was randomly assigned to one of the two presentation lists in which sentences were presented in a pseudo-randomized order such that two sentences in the same condition would not appear more than two consecutive times. Before the formal experiment, a nine-point calibration procedure was performed, followed by a practice session of five sentences for each participant. Drift corrections were performed between trials. All participants were instructed to read the sentences in a natural speed. After finishing reading the sentences, they should press the space key to answer questions or move into next trial. Once a question sentence appeared, participants should press either "F" or "J" to make a response, with the two keys counterbalanced across participants. The whole experiment was comprised of two sessions with a short interval in between. The whole experiment lasted about 40–50 min for HG learners and 60–70 min for LG learners.

## 2.4. Data analysis

Following Drummer and Felser (2018), we reported four eye-movement measures in each of the four regions: First Fixation Duration (FFD), First Pass Reading Time (FPRT), Regression Path Duration (RPD) and Total Reading Time (TRT).

Before exporting the eye-movement data, fixations that were shorter than 80 ms but within one character space of the previous or next fixations were merged with their neighboring fixations. The remaining fixations that were shorter than 80 ms or longer than 800 ms were excluded because they could not reflect proper language processing (Rayner and Pollatsek, 1989; Rayner, 1998). For each eye-movement measure, the data above or below three standard deviations were removed from further analyses. For HG learners, this accounted for 5.76% of the data in the by-participant analysis and 6.12% of the data in the by-item analysis. For LG learners, this accounted for 4.91% of the data in the by-participant analysis and 4.57% of data in the by-item analysis.

Two-way mixed repeated measures ANOVAs with participants (*F1*) and items (*F2*) as random variables were carried out for each eye-movement measure with between-subject factor Group (HG vs. LG) and within-subject factor Gender Match (yes vs. no) using SPSS Statistics 26.0. Table 2 displays two participant groups' mean reading times on the four regions per condition and Table 3 provides a summary of ANOVAs for each region.

## 2.5. Results

### 2.5.1. Behavioral data

The mean accuracy was 81.38% ($SD = 0.10$) for HG learners and 71.38% ($SD = 0.09$) for LG learners, which were both significantly above the chance level (HG: $t\ (29) = 17.960$, $p < 0.001$; LG: $t\ (27) = 12.475$, $p < 0.001$), showing that all the participants were attentive to the reading task.

### 2.5.2. Eye-tracking data

The following is the statistical results of the eye-tracking data in association with each region. By convention, only the significant

 10.3389/fpsyg.2023.1126673

TABLE 2 Mean reading times in milliseconds by region in Experiment 1 (SDs in parentheses).

| | | FFD | | FPRT | | RPD | | TRT | |
|---|---|---|---|---|---|---|---|---|---|
| Region | Condition | High | Low | High | Low | High | Low | High | Low |
| 1 | Match | 235 (22) | 234 (31) | 394 (50) | 436 (87) | 409 (58) | 471 (94) | 1,011 (239) | 1,228 (315) |
| | Mismatch | 229 (29) | 237 (30) | 373 (55) | 450 (86) | 394 (64) | 476 (98) | 947 (243) | 1,264 (295) |
| 2 | Match | 252 (38) | 271 (28) | 362 (57) | 466 (81) | 557 (108) | 698 (123) | 990 (239) | 1,353 (370) |
| | Mismatch | 249 (40) | 265 (25) | 343 (61) | 472 (79) | 579 (121) | 674 (139) | 951 (209) | 1,305 (323) |
| 3 | Match | 262 (33) | 273 (29) | 312 (42) | 361 (58) | 2,580 (865) | 332 (1182) | 990 (254) | 1,185 (352) |
| | Mismatch | 251 (29) | 275 (34) | 301 (40) | 345 (41) | 2,361 (920) | 316 (1162) | 915 (257) | 1,099 (342) |
| 4 | Match | 234 (26) | 252 (21) | 362 (45) | 452 (62) | 2,875 (989) | 3,661 (1,342) | 765 (168) | 1,003 (269) |
| | Mismatch | 235 (27) | 249 (20) | 370 (55) | 447 (63) | 2,640 (1043) | 3,661 (1,445) | 751 (171) | 957 (208) |

TABLE 3 Summary of ANOVAs for each region in Experiment 1.

| | Region 1 | | Region 2 | | Region 3 | | Region 4 | |
|---|---|---|---|---|---|---|---|---|
| | *F1*(1, 56) | *F2*(1, 98) | *F1*(1, 56) | *F2*(1, 98) | *F1*(1, 56) | *F2*(1, 98) | *F1*(1, 56) | *F2*(1, 98) |
| **FFD** | | | | | | | | |
| Group | 0.244 | 0.752 | 4.506* | 21.369*** | 5.442* | 20.414*** | 7.360** | 31.336*** |
| Match | 0.175 | 0.655 | 1.930 | 1.630 | 1.602 | 2.062 | 0.354 | 0.153 |
| Gr*Mat | 2.296 | 2.155 | 0.112 | 0.339 | 3.533(*) | 2.366 | 0.789 | 0.641 |
| **FPR** | | | | | | | | |
| Group | 11.314** | 37.404*** | 46.614*** | 75.533*** | 18.269*** | 55.202*** | 40.676*** | 26.748*** |
| Match | 0.475 | 0.429 | 1.146 | 0.725 | 8.003** | 4.876* | 0.034 | 0.220 |
| Gr*Mat | 12.626** | 9.568** | 3.647(*) | 1.495 | 0.275 | 0.336 | 0.835 | 0.247 |
| **RPD** | | | | | | | | |
| Group | 12.865** | 41.914*** | 16.307*** | 29.222*** | 8.580** | 133.969*** | 8.645** | 96.993*** |
| Match | 0.801 | 1.073 | 0.002 | 0.058 | 12.203** | 8.708** | 2.985 | 2.566 |
| Gr*Mat | 3.468(*) | 2.242 | 2.789 | 2.702 | 0.280 | 0.501 | 2.952 | 3.066 |
| **TRT** | | | | | | | | |
| Group | 14.549*** | 61.266*** | 24.397*** | 150.809*** | 6.051* | 51.642*** | 19.181*** | 32.503*** |
| Match | 0.732 | 0.552 | 4.494* | 3.542(*) | 19.784*** | 13.362*** | 2.569 | 3.058 |
| Gr*Mat | 9.891** | 8.082** | 0.046 | 0.018 | 0.087 | 0.000 | 0.777 | 0.903 |

(*)$p < 0.1$; *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

results are reported as below. All significant and non-significant results may be seen at Table 3.

#### 2.5.2.1. Region 1

For first fixation durations, no significant main effects or interactions were found ($ps > 0.1$).

For first pass reading times, a significant interaction between Gender Match and Group was found ($p1 = 0.001$; $p2 = 0.003$). Simple effects analysis revealed that only HG learners spent significantly longer reading times in gender-match than in gender-mismatch conditions ($F1(1, 56) = 10.039$, $p = 0.002$; $F2(1, 98) = 7.025$, $p = 0.009$).

For regression path durations, a marginally significant interaction between Gender Match and Group in the participant analysis was observed ($p1 = 0.068$; $p2 = 0.137$). Simple effects analysis showed that only HG learners exhibited significantly longer regression path durations in gender-match than in gender-mismatch conditions ($F1(1, 56) = 4.239$, $p = 0.044$; $F2(1, 98) = 3.209$, $p = 0.076$).

For total reading times, a significant interaction between Gender Match and Group was found ($p1 = 0.003$; $p2 = 0.005$). Simple effects analysis showed that only HG learners demonstrated significantly longer total reading times in gender-match than in gender-mismatch conditions ($F1(1, 56) = 8.926$, $p = 0.004$; $F2(1, 98) = 6.428$, $p = 0.013$).

#### 2.5.2.2. Region 2

For first fixation durations, no significant main effects or interactions were found ($ps > 0.1$).

For first pass reading times, a marginally significant interaction between Gender Match and Group in the participant analysis was observed ($p1 = 0.061$; $p2 = 0.224$). Simple effects analysis showed that only HG learners spent longer reading times in gender-match than in gender-mismatch conditions ($F1(1, 56) = 4.954$, $p = 0.030$; $F2(1, 98) = 2.152$, $p = 0.146$).

For regression path durations, no significant main effects or interactions were found ($ps > 0.1$).

For total reading times, a significant main effect of Gender Match in the participant analysis was observed ($p1 = 0.038$; $p2 = 0.063$). Both HG and LG learners spent significantly longer reading times in gender-match than in gender-mismatch conditions.

#### 2.5.2.3. Region 3

For first fixation durations, a marginally significant interaction between Gender Match and Group in the participant analysis was found ($p1 = 0.065$; $p2 = 0.127$). Simple effects analysis showed that only in gender-mismatch conditions, did LG learners exhibit longer first fixation durations than HG learners ($F1(1, 56) = 8.237$, $p = 0.006$; $F2(1, 98) = 21.842$, $p < 0.001$). Meanwhile, HG learners spent longer first fixation durations in gender-match than in gender-mismatch conditions ($F1(1, 56) = 5.517$, $p = 0.022$; $F2(1, 98) = 4.423$, $p = 0.038$).

For first pass reading times, a significant main effect of Gender Match was found ($p1 = 0.006$; $p2 = 0.030$). First pass reading times in gender-match conditions were significantly longer than those in gender-mismatch conditions for both HG learners and LG learners.

For regression path durations, a significant main effect of Gender Match was found ($p1 = 0.001$; $p2 = 0.004$). Both HG and LG learners showed significantly longer reading times in gender-match than in gender-mismatch conditions.

For total reading times, a significant main effect of Gender Match was observed ($p1 < 0.001$; $p2 < 0.001$). Both HG and LG learners spent significantly longer reading times in gender-match than in gender-mismatch conditions.

#### 2.5.2.4. Region 4

For all eye-movement measures (first fixation durations, first pass reading times, regression path durations, total reading times), no significant main effects or interactions were observed at this region (ps > 0.05).

## 2.6. Discussion

Experiment 1 intended to explore whether Chinese EFL learners initiated an active searching process in cataphora resolution and whether learners' proficiency level influenced this searching process. The eye-movement data revealed a GME effect (Gender Match Effect) for all participants, but the effect was observed earlier in HG learners than in LG learners.

Contrary to a GMME effect that has been consistently observed in previous studies on cataphora resolution (van Gompel and Liversedge, 2003; Kazanina et al., 2007; Kazanina and Phillips, 2010; Clackson and Clahsen, 2011; Yoshida et al., 2014; Pablos et al., 2015; Patterson and Felser, 2019), our study unexpectedly revealed a GME effect at region 1 (subject name) and region 2 (adverb), suggesting that a gender-matching potential antecedent elicited longer reading times than its gender-mismatching counterpart at the matrix subject position. GMME effect has been taken as an indication of readers' employment of active search mechanism in cataphora resolution, so did the absence of GMME effect mean Chinese EFL learners did not resolve the cataphoric pronoun in an active way? It seems hasty to jump to such a strong conclusion. Since readers' active search for the cataphor's antecedent implies a link has already been established between the cataphoric pronoun and the first syntactic position that could contain a noun phrase even before the information (e.g., gender and number) about the noun phrase is accessed, the nature of the active search mechanism lies in whether readers predictively link a cataphoric pronoun to the first syntactic position that could contain a potential antecedent. Based on this rationale, we believe that Chinese EFL learners were also engaged in an active search for the antecedent in the cataphora resolution process, otherwise the gender features of the first potential antecedent would not affect their reading times (though in a different direction from English natives). However, this active searching process adopted by Chinese EFL learners was distinct from the one used by English natives in that only a gender-matching antecedent could prompt Chinese EFL learners to engage in a deep processing of this antecedent, contrasting with English natives' deep processing of both gender-matching and gender-mismatching antecedents, consequently resulting in GME effect for Chinese EFL learners while GMME effect for English natives. As for the reason why Chinese EFL learners behaved differently from English native speakers when facing a gender-mismatching name at the matrix subject position, we will elaborate it in the General Discussion part.

Consistent with our predictions, LG learners were found to behave differently from HG learners in the processing of cataphoric pronouns. HG learners exhibited a GME effect in first pass reading times, regression path durations and total reading times at region 1, while LG learners only showed a GME effect in total reading times at region 2, i.e., gender features of subject names did not affect LG learners' processing time until region 2 (the spillover region of the subject name). This suggests that LG learners, relative to HG learners, delayed their active searching process in cataphora resolution.

Significantly longer reading times in gender-match than in gender-mismatch conditions were also observed in first pass reading times, regression path durations and total reading times at region 3 (object name region). However, the gender-match effect at region 3 was different from that at region 1 and region 2. The name at region 3 provides another antecedent candidate in gender-match conditions while it is the only suitable antecedent in gender-mismatch conditions. Therefore, the longer reading times observed in gender-match than in gender-mismatch conditions might due to the competition between two gender-matching names for acting as the antecedent of the cataphoric pronoun. In addition, it appeared that HG learners were earlier influenced by the competition between subject name and object name in gender-match conditions as indicated by longer first fixation durations in gender-match conditions observed only for HG learners.

In summary, the results of Experiment 1 suggest that Chinese EFL learners also adopt an active search mechanism to resolve cataphoric pronouns, yet along a processing path distinct from English natives'. Specifically, Chinese EFL learners predictively link a cataphoric pronoun to the first potential antecedent in the sentence but only a gender-matching antecedent can prompt them to engage in deep processing of the antecedent. Moreover, the learners' proficiency level modulates the time-course of their active searching process, with HG learners initiating an active search for the antecedent earlier than LG learners.

Both HG and LG Chinese EFL learners initiate an active search for the antecedent after encountering a cataphoric pronoun. Whether this searching process is also constrained by Binding Principles in the same way as English natives has not been clear, the issue Experiment 2 was to explore.

# 3. Experiment 2

Experiment 1 has shown that Chinese EFL learners initiated an active search for the cataphor's antecedent. Experiment 2 was thus conducted to further investigate whether Chinese EFL learners' active searching process is governed by the Binding Principle B. If so, we also want to explore whether learners' proficiency influences the time-course of the application of Binding Principle B.

## 3.1. Participants

The recruitment criteria for participants were the same as in Experiment 1. A total of 27 English majors and 30 non-English majors participated in this experiment. The data of three participants (all non-English majors) were discarded as their accuracy rate was below 60%. The data for final analysis comprised of 27 English majors (age: $M$ = 22.17 years, SD = 1.26 years, ranging from 20 years to 26 years; gender: 9 males, 18 females) and 27 non-English majors (age: $M$ = 20.88 years, SD = 1.19 years, ranging from 19 years to 23 years; gender: 10 males, 17 females). All participants completed an adapted version of language history questionnaire (Li et al., 2006) and the QPT before the experiment. The results of the language history questionnaire and QPT scores are provided in Table 4.

As in Experiment 1, English majors ($M$ = 52.37, SD = 1.52) were more proficient than non-English majors ($M$ = 35.81, SD = 1.75; $t(52) = 37.023$, $p < 0.001$), which was also confirmed by the results from participants' total scores of four English abilities, showing that English majors ($M$ = 13.41, SD = 2.02) scored significantly higher than non-English majors ($M$ = 11.22, SD = 2.68; $t(52) = -3.433$, $p = 0.001$). Similarly, self-rated score on English reading ability was positively correlated with the OPT score for both English majors ($r(25) = 0.749$, $p < 0.001$) and non-English majors ($r(25) = 0.863$, $p < 0.001$). Therefore, we grouped English majors as HG learners and non-English majors as LG learners. Both two participant groups were late second language learners, with no significant difference in their AoA of English (HG: $M$ = 8.80 years, SD = 1.90 years; LG: $M$ = 9.38 years, SD = 1.74 years; $t(52) = 1.146$, $p = 0.257$). All participants signed a written inform consent before the experiment and were paid for their participation after the experiment.

TABLE 4 Results of the language history questionnaire and QPT scores in Experiment 2.

| | HG (English majors) | | LG (non-English majors) | |
|---|---|---|---|---|
| | *M* | SD | *M* | SD |
| **Self-rating** | | | | |
| Listening | 3.11 | 0.76 | 2.44 | 0.80 |
| Speaking | 3.10 | 0.87 | 2.48 | 0.76 |
| Reading | 3.90 | 0.56 | 3.35 | 0.85 |
| Writing | 3.31 | 0.72 | 2.96 | 0.95 |
| AoA | 8.80 | 1.90 | 9.38 | 1.74 |
| QPT | 52.37 | 1.52 | 35.81 | 1.75 |

## 3.2. Materials

The materials consisted of 60 sets of sentences as shown in (6). Each sentence was made up of one main clause and one fronted participle clause headed by *while*, *before* or *after*. All the materials were constructed following a two-factors (Constraint and Gender-Match) within-subjects design. The factor Constraint manipulated whether the coreference between the cataphoric pronoun and the matrix subject was constrained by Binding Principle B. In constraint conditions, the cataphor was the direct object of the infinitival verb while in no-constraint conditions, the cataphor was a possessive pronoun embedded in the direct object noun phrase. Across constraint and no-constraint conditions, the gender of the cataphoric pronoun was manipulated to either match or mismatch the gender of the matrix subject. As in Experiment 1, all the adverbs following the matrix subjects were selected from the lexical syllabus for CET-4 and met the requirement of an average rating score of more than 3.75 on a 5-ponit Likert scale ($M$ = 4.12, SD = 0.46) in a familiarity pretest (1 = totally unfamiliar, 5 = totally familiar) by an additional group of 60 LG learners who were selected from non-English majors based on the same criteria as in formal experiment. There was a gender-matching name at the matrix object position across four conditions to ensure that each cataphoric pronoun was to have an intra-sentential referent.

Of the 60 sets of target sentences, 24 sets were adapted from Kush and Dillon (2021)'s Experiment 1 and the other 26 sets were constructed following the same sentence patterns. The 60 sets of target sentences were selected from a total of 85 sets of sentences. The same group of LG learners who participated in the familiarity test on adverbs were also asked to rate the comprehensibility of those sentences on a 5-point Likert scale (1 = totally incomprehensible, 5 = totally comprehensible). Sentences with 3.75 rating score on average were selected as the experimental items ($M$ = 4.34, SD = 0.28).

(6) a. constraint, gender-match.
After buying her an iced coffee, Linda generously offered Elsa the best seat at the meeting table.
b. constraint, gender-mismatch.
After buying him an iced coffee, Linda generously offered Victor the best seat at the meeting table.
c. no-constraint, gender-match.
After buying her colleague an iced coffee, Linda generously offered Elsa the best seat at the meeting table.
d. no-constraint, gender-mismatch.
After buying his colleague an iced coffee, Linda generously offered Victor the best seat at the meeting table.

To ensure that each participant would receive a sufficient number of target sentences from each condition, the 60 sets of experimental sentences were divided into two lists in such a way that each participant could see two sentences from one set, one in constraint condition, and the other in no-constraint condition. Each list consisted of 120 experimental sentences (30 experimental sentences for each condition) and mixed with equal 120 fillers. As in Experiment 1, the fillers were of similar length and complexity to the experimental sentences and did not contain cataphoric pronouns. Similarly, half of the experimental sentences and filler sentences were followed by a comprehension question. In case participants did not resolve cataphoric pronouns during reading, 12 out of the 60 comprehension questions following the experimental sentences required the interpretation of cataphoric pronouns (e.g., Who got an iced coffee?/Whose colleague got an iced coffee?) and the remaining questions mainly targeted the interpretation of argument roles in the main clause (e.g., Who offered someone the best seat?/Who got the best seat?) or the interpretation of the implicit subject in the adjunct clause (e.g., Who bought someone an iced coffee?).

Also similar to Experiment 1, four regions were selected for further analyses. Region 1 was the matrix subject name; Region 2 was the adverb following the matrix subject; Region 3 was the matrix object name; Region 4 consisted of two words that came after Region 3.

## 3.3. Procedure

The procedure was identical to Experiment 1. The formal part of the experiment was divided into three blocks with a short break in between. After each break, a nine-point calibration procedure was conducted again. All the stimuli in each presentation list were presented in a pseudo-randomized order such that two sentences in the same condition would not consecutively appear more than twice. The entire experiment lasted about 70–80 min for HG learners and 80–90 min for LG learners.

## 3.4. Data analysis

The same four eye-movement measures were reported as in Experiment 1: first fixation duration, first pass reading time, regression path duration and total reading time.

Before exporting the eye-movement data, fixations shorter than 80 ms but within one character space of the previous or next fixations were merged with their neighboring fixations. The fixations that were shorter than 80 ms or longer than 800 ms were excluded as well. For each eye-movement measure, the data that were above or below three standard deviations were discarded from further analyses. For HG learners, this accounted for 7.90% of data in the by-participant analysis and 5.66% of data in the by-item analysis. For LG learners, this accounted for 6.14% of the data in the by-participant analysis and 6.28% of data in the by-item analysis.

Three-way mixed repeated measures ANOVAs with participants (*F1*) and items (*F2*) as random variables were carried out for each eye-movement measure with between-subject factor Group (HG vs. LG) and within-subject factors Constraint (yes vs. no) and Gender Match (yes vs. no) using SPSS Statistics 26.0. Table 5 displays two participant groups' mean reading times on the four regions per condition and Table 6 provides a summary of ANOVAs for each region.

## 3.5. Results

### 3.5.1. Behavioral data

The mean accuracy was 87.28% (SD = 0.06) for HG learners and 80.83% (SD = 0.06) for LG learners, which were both significantly above the chance level ($t(29) = 32.543$, $p < 0.001$; $t(23) = 24.147$, $p < 0.001$), showing that all the learners completed the reading task attentively.

### 3.5.2. Eye-tracking data

The significant statistical results of eye-tracking measurement are reported as below for each region. All significant and non-significant results may be seen at Table 6.

#### 3.5.2.1. Region 1

For first fixation durations, a significant main effect of Constraint was found ($p1 < 0.001$; $p2 = 0.001$). Matrix subject names in constraint conditions required significantly longer first fixations than those in no-constraint conditions. A significant interaction was observed between Gender Match and Group in the item analysis ($p1 = 0.108$; $p2 = 0.044$). Simple effects analysis revealed that LG learners spent significantly longer fixations than HG learners only in the gender-mismatch conditions ($F1(1, 52) = 1.767$, $p = 0.190$; $F2(1, 118) = 14.765$, $p < 0.001$). Besides, first fixation durations were significantly longer in gender-mismatch than in gender-match conditions but only occurred for LG learners ($F1(1, 52) = 3.253$, $p = 0.077$; $F2(1, 118) = 5.789$, $p = 0.018$). In addition, a significant interaction between Constraint and Gender Match was observed in first fixation durations ($p1 = 0.031$; $p2 = 0.039$). Simple effects analysis revealed that significantly longer first fixation durations in gender-mismatch than in gender-match conditions appeared only for no-constraint conditions ($F1(1, 52) = 5.747$, $p = 0.020$; $F2(1, 118) = 5.545$, $p = 0.020$) and significantly longer first fixation durations in constraint conditions than in no-constraint conditions appeared only in gender-match conditions ($F1(1, 52) = 19.276$, $p < 0.001$; $F2(1, 118) = 17.286$, $p < 0.001$).

For first pass reading times and regression path durations, no significant main effects or interactions were found ($ps > 0.05$).

For total reading times, a significant main effect of Constraint was found ($p1 < 0.001$; $p2 = 0.045$). Reading times were significantly longer in no-constraint conditions than in constraint conditions. There was also a significant interaction between Constraint and Group in the participant analysis ($p1 = 0.021$; $p2 = 0.151$). Simple effects analysis showed that only LG learners spent significantly longer reading times in no-constraint than in constraint conditions ($F1(1, 52) = 17.493$, $p < 0.001$; $F2(1, 118) = 6.015$, $p = 0.016$).

#### 3.5.2.2. Region 2

For first fixation durations, a significant main effect of Constraint was found ($p1 = 0.006$; $p2 = 0.009$). Significantly longer fixations were observed in constraint than in no-constraint conditions. A significant main effect of Gender Match was also found ($p1 = 0.013$; $p2 = 0.008$). First fixation durations in gender-mismatch conditions were significantly longer than those in gender-match conditions.

For first pass reading times, a significant main effect of Constraint was found in the participant analysis ($p1 = 0.010$; $p2 = 0.108$). Reading times were significantly longer in constraint conditions than in no-constraint conditions. There was a significant main effect of Gender Match ($p1 < 0.001$; $p2 = 0.003$). Reading times in gender-mismatch conditions were significantly longer than those in gender-match conditions. Besides, a significant interaction between Constraint and Group was observed in the participant analysis

TABLE 5 Mean reading times in milliseconds by region in Experiment 2 (SDs in parentheses).

| Region | Condition | | FFD | | FPRT | | RPD | | TRT | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | High | Low | High | Low | High | Low | High | Low |
| 1 | Constraint | Match | 247 (26) | 248 (25) | 363 (67) | 426 (57) | 377 (72) | 477 (71) | 858 (172) | 1,359 (283) |
| | | Mismatch | 240 (24) | 250 (34) | 355 (62) | 438 (67) | 369 (65) | 469 (64) | 816 (164) | 1,339 (237) |
| | No-constraint | Match | 234 (24) | 237 (24) | 348 (61) | 433 (52) | 360 (63) | 475 (57) | 857 (187) | 1,421 (281) |
| | | Mismatch | 238 (20) | 246 (30) | 351 (59) | 433 (46) | 368 (64) | 470 (52) | 849 (168) | 1,413 (263) |
| 2 | Constraint | Match | 253 (28) | 285 (37) | 308 (47) | 413 (65) | 412 (72) | 646 (92) | 669 (142) | 1,179 (190) |
| | | Mismatch | 260 (28) | 291 (31) | 320 (35) | 437 (77) | 401 (62) | 611 (106) | 634 (118) | 1,176 (207) |
| | No-constraint | Match | 251 (28) | 274 (25) | 308 (41) | 403 (66) | 435 (77) | 635 (92) | 727 (165) | 1,191 (201) |
| | | Mismatch | 254 (28) | 283 (27) | 316 (46) | 408 (61) | 444 (74) | 658 (111) | 694 (108) | 1,234 (212) |
| 3 | Constraint | Match | 254 (19) | 284 (18) | 299 (32) | 361 (46) | 1,928 (606) | 3,585 (871) | 867 (257) | 1,377 (310) |
| | | Mismatch | 259 (22) | 283 (24) | 298 (33) | 357 (41) | 1,792 (582) | 3,455 (763) | 783 (223) | 1,336 (302) |
| | No-constraint | Match | 247 (17) | 286 (20) | 291 (29) | 365 (40) | 2,063 (679) | 3,676 (813) | 847 (251) | 1,439 (312) |
| | | Mismatch | 255 (26) | 279 (23) | 292 (30) | 362 (47) | 1,941 (564) | 3,780 (772) | 860 (247) | 1,505 (319) |
| 4 | Constraint | Match | 232 (18) | 258 (17) | 318 (36) | 439 (70) | 2,101 (645) | 3,936 (991) | 546 (98) | 929 (198) |
| | | Mismatch | 238 (21) | 248 (17) | 344 (45) | 442 (67) | 1,945 (614) | 3,887 (894) | 533 (88) | 964 (195) |
| | No-constraint | Match | 234 (19) | 256 (23) | 332 (42) | 442 (79) | 2,250 (680) | 4,182 (970) | 587 (103) | 1,007 (198) |
| | | Mismatch | 237 (20) | 252 (21) | 331 (46) | 443 (62) | 2,170 (639) | 4,260 (937) | 563 (94) | 1,016 (193) |

($p1 = 0.029$; $p2 = 0.207$). Simple effects analysis suggested that only LG learners exhibited significantly longer reading times in constraint than in no-constraint conditions ($F1(1, 52) = 10.958$, $p = 0.002$; $F2(1, 118) = 4.180$, $p = 0.043$).

For regression path durations, a significant main effect of Constraint was found in the participant analysis ($p1 < 0.001$; $p2 = 0.062$). Significantly longer regression times were elicited in no-constraint conditions than in constraint conditions. There occurred a significant interaction between Constraint and Gender Match ($p1 = 0.013$; $p2 = 0.054$). Simple effects analysis revealed that significantly longer regression path durations were observed in no-constraint than in constraint conditions but only for gender-mismatch conditions ($F1(1, 52) = 20.457$, $p < 0.001$; $F2(1, 118) = 6.538$, $p = 0.012$).

For total reading times, a significant main effect of Constraint was found ($p1 < 0.001$; $p2 = 0.027$). Reading times were significantly longer in no-constraint conditions than in constraint conditions. A significant interaction between Gender Match and Group was also found ($p1 = 0.025$; $p2 = 0.047$). Simple effects analysis showed that only HG learners demonstrated significantly longer reading times in gender-match than in gender-mismatch conditions ($F1(1, 52) = 4.808$, $p = 0.033$; $F2(1, 118) = 2.812$, $p = 0.096$).

### 3.5.2.3. Region 3

For first fixation durations, a significant main effect of Constraint in the participant analysis was found ($p1 = 0.033$; $p2 = 0.108$). First fixations were significantly longer in constraint than in no-constraint conditions. There was also a significant interaction between Gender Match and Group ($p1 = 0.037$; $p2 = 0.022$). Simple effects analysis showed that only HG learners spent significantly longer fixations in gender-mismatch than in gender-match conditions ($F1(1, 52) = 3.937$, $p = 0.053$; $F2(1, 118) = 4.369$, $p = 0.039$).

For first pass reading times, a significant interaction between Constraint and Group was found in the participant analysis ($p1 = 0.033$; $p2 = 0.259$). Simple effects analysis showed that only HG learners spent significantly longer reading times in constraint than in no-constraint conditions ($F1(1, 52) = 4.092$, $p = 0.048$; $F2(1, 118) = 1.112$, $p = 0.294$).

For regression path durations, a significant main effect of Constraint was found ($p1 < 0.001$; $p2 = 0.001$). Regression path durations were significantly longer in no-constraint than in constraint conditions.

For total reading times, a significant main effect of Constraint was found ($p1 < 0.001$; $p2 = 0.002$). Reading times were significantly longer in no-constraint conditions than in constraint conditions. There appeared a significant interaction between Constraint and Group ($p1 = 0.004$; $p2 = 0.050$). Simple effects analysis revealed that only LG learners spent significantly longer reading times in no-constraint than in constraint conditions ($F1(1, 52) = 28.228$, $p < 0.001$; $F2(1, 118) = 13.633$, $p < 0.001$). Furthermore, a significant interaction between Constraint and Gender Match was found ($p1 = 0.002$; $p2 = 0.003$). Simple effects analysis showed that significantly longer reading times were observed in gender-match than in gender-mismatch conditions but only for constraint conditions ($F1(1, 52) = 8.941$, $p = 0.004$; $F2(1, 118) = 7.004$, $p = 0.009$) while significantly longer reading times were observed in no-constraint than in constraint conditions but only for gender-mismatch conditions ($F1(1, 52) = 28.268$, $p < 0.001$; $F2(1, 118) = 22.409$, $p < 0.001$).

### 3.5.2.4. Region 4

For first fixation durations, a significant interaction between Gender Match and Group was found ($p1 = 0.005$; $p2 = 0.010$). Simple effects analysis revealed that only LG learners spent

TABLE 6 Summary of ANOVAs for each region in Experiment 2.

| | Region 1 | | Region 2 | | Region 3 | | Region 4 | |
|---|---|---|---|---|---|---|---|---|
| | *F1*(1, 52) | *F2*(1, 118) | *F1*(1, 52) | *F2*(1, 118) | *F1*(1, 52) | *F2*(1, 118) | *F1*(1, 52) | *F2*(1, 118) |
| **FFD** | | | | | | | | |
| Group | 0.810 | 13.654*** | 17.574*** | 123.271*** | 42.892*** | 129.505*** | 16.791*** | 78.652*** |
| Constraint | 15.444*** | 11.306** | 8.377** | 6.965** | 4.826* | 2.618 | 0.188 | 0.025 |
| Match | 1.107 | 1.867 | 6.576* | 7.274** | 0.256 | 0.405 | 0.454 | 0.010 |
| Gr × Cons | 0.032 | 0.030 | 1.110 | 0.719 | 1.919 | 0.755 | 0.000 | 0.024 |
| Gr × Mat | 2.678 | 4.146* | 0.082 | 0.095 | 4.578* | 5.382* | 8.523** | 6.889* |
| Cons×Mat | 4.924* | 4.353* | 0.004 | 0.091 | 0.142 | 0.060 | 0.054 | 0.516 |
| Gr × Cons×Mat | 0.391 | 0.143 | 0.684 | 0.669 | 1.043 | 1.059 | 2.611 | 3.569 |
| **FPR** | | | | | | | | |
| Group | 27.342*** | 183.765*** | 57.322*** | 193.050*** | 56.992*** | 250.599*** | 66.110*** | 143.287*** |
| Constraint | 1.158 | 0.817 | 7.223* | 2.630 | 0.251 | 0.127 | 0.155 | 0.031 |
| Match | 0.202 | 0.337 | 15.617*** | 9.231** | 0.280 | 0.004 | 2.346 | 1.011 |
| Gr × Cons | 2.108 | 0.826 | 5.050* | 1.612 | 4.825* | 1.289 | 0.027 | 0.002 |
| Gr × Mat | 1.316 | 2.029 | 0.679 | 0.256 | 0.175 | 0.000 | 1.469 | 2.779 |
| Cons×Mat | 0.009 | 0.002 | 2.040 | 1.704 | 0.069 | 0.016 | 3.195 | 2.825 |
| Gr × Cons×Mat | 2.499 | 1.443 | 0.773 | 0.412 | 0.022 | 0.023 | 2.184 | 2.535 |
| **RPD** | | | | | | | | |
| Group | 41.694*** | 195.344*** | 118.234*** | 223.450*** | 86.139*** | 508.318*** | 89.355*** | 476.871*** |
| Constraint | 1.424 | 0.641 | 17.116*** | 3.538(*) | 21.034*** | 10.833** | 35.765*** | 15.824*** |
| Match | 1.064 | 0.385 | 0.158 | 0.042 | 3.742 | 2.803 | 1.703 | 3.304 |
| Gr × Cons | 1.004 | 0.509 | 1.576 | 0.363 | 0.746 | 0.518 | 2.154 | 1.009 |
| Gr × Mat | 0.902 | 0.151 | 0.091 | 0.143 | 2.493 | 2.334 | 2.801 | 1.001 |
| Cons×Mat | 1.310 | 1.461 | 6.619* | 3.782(*) | 3.802 | 1.562 | 1.856 | 1.284 |
| Gr × Cons×Mat | 0.769 | 0.281 | 1.448 | 0.268 | 3.035 | 1.898 | 0.119 | 0.291 |
| **TRT** | | | | | | | | |
| Group | 89.424*** | 486.376*** | 153.063*** | 295.218*** | 65.583*** | 418.565*** | 131.622*** | 227.672*** |
| Constraint | 14.846*** | 4.093* | 16.641*** | 5.042* | 24.496*** | 10.526** | 20.181*** | 4.518* |
| Match | 2.778 | 2.623 | 0.377 | 0.132 | 0.581 | 0.386 | 0.027 | 0.343 |
| Gr × Cons | 5.673** | 2.089 | 1.086 | 0.187 | 8.825** | 3.910(*) | 1.763 | 0.331 |
| Gr × Mat | 0.246 | 0.102 | 5.334* | 4.034* | 2.501 | 2.115 | 3.790 | 0.762 |
| Cons×Mat | 1.153 | 0.541 | 1.148 | 0.612 | 11.041** | 9.441** | 1.121 | 0.099 |
| Gr × Cons×Mat | 0.281 | 0.111 | 0.955 | 0.357 | 0.025 | 0.042 | 0.174 | 0.055 |

(*)$p < 0.1$; *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

significantly longer first fixations in gender-match than in gender-mismatch conditions (*p1* = 0.020; *p2* = 0.057).

For first pass reading times, no significant main effects or interactions were found (*ps* > 0.05).

For regression path durations, a significant main effect of Constraint was found (*p1* < 0.001; *p2* < 0.001). Regression path durations were significantly longer in no-constraint than in constraint conditions.

For total reading times, a significant main effect of Constraint was observed (*p1* < 0.001; *p2* = 0.036). Total reading times were significantly longer in no-constraint than in constraint conditions.

## 3.6. Discussion

Experiment 2 was conducted to further examine whether Chinese EFL learners' cataphora resolution process was restricted by the syntactic constraint Binding Principle B and whether the processing pattern varied with the learners' proficiency. Interpretations of the major results are presented in the following.[1]

1 early eye-tracking data at region 3 and region 4 were excluded from further discussion since only the late processing of those regions was related to our

Main effects of Gender Match were found for early eye-movement measures (first fixation durations and first pass reading times) at region 2, the spillover region of region 1. A gender-mismatching subject name elicited significantly longer reading times than a gender-matching one in both constraint pair and no-constraint pair. This GMME effect unaffected by the factor Constraint suggested that Chinese EFL learners tried to establish coreference relations between the cataphoric pronoun and the matrix subject in both constraint and no-constraint conditions, even if the coreference in constraint conditions violated Binding Principle B. The expected interaction between Constraint and Gender Match, however, just occurred in the late eye-movement measure (regression path durations) at region 2. A gender-mismatching subject induced more regressions in no-constraint conditions than in constraint conditions. In other words, the gender-incongruency between the cataphoric pronoun and the matrix subject only induced greater processing difficulty when the coreference between the cataphoric pronoun and the matrix subject was free from the constraint of Binding Principle B, suggesting that syntactically-illicit subject in constraint conditions was no longer considered as the potential antecedent of the cataphoric pronoun. Therefore, the early and late eye-tracking data at region 2 together demonstrated that Binding Principle B did not constrain Chinese EFL learners' early processing of cataphoric pronouns, but only played its role in the late stage of cataphora resolution. Meanwhile, Chinese EFL learners' delayed application of Binding Principle B also came up in the different effects of Constraint on first fixation durations and total reading times at region 2. While the main effect of Constraint on first fixation durations indicated that learners had more difficulty in processing constraint sentences, the main effect of Constraint on total reading times at the same region showed that the learners had more difficulty with no-constraint sentences. This indicates that in early processing, Chinese EFL learners were considering a potential antecedent which should be ruled out by Binding Principle B, but in later processing, they only considered a syntactically-licit antecedent for the cataphoric pronoun, which was consistent with the conclusion drawn from the effects of Gender Match and its interaction with Constraint.

Further evidence supporting Chinese EFL learners' late application of Binding Principle B was also found in late eye-tracking data at region 3. In this region, the object elicited more regressions in no-constraint than in constraint conditions. In no-constraint conditions, both the subject and object could be the antecedent of the cataphoric pronoun in terms of their syntactic position. In constraint conditions, however, only the object was licensed to co-refer with the cataphoric pronoun. If Chinese EFL learners abided by Binding Principle B in the late processing stage, the matrix subject would not interfere with the late integration stage during cataphora resolution in constraint conditions, but would exert its influence in no-constraint conditions. As a result, more regressive eye-movements from the object would be made in no-constraint than in constraint conditions which was just the pattern we observed in regression path durations at region 3. Besides, this effect of Constraint kept constant at region 4 as indicated by longer regression path durations and total reading times in no-constraint than in constraint conditions. In spite of Chinese EFL learners' late application of the binding constraint, however, the gender feature of the syntactically-illicit name (i.e., matrix subject in constraint conditions) could still exert its influence on the integration stage in cataphora resolution, which can be seen from the longer total reading times in constraint, gender-match conditions than in constraint, gender-mismatch conditions at region 3.

It is worth-noting that a significant Constraint by Gender Match interaction was also observed in first fixation durations at region 1 (matrix subject name). We did not take this interaction as evidence that Principle B was early applied by Chinese EFL learners to constrain the cataphora resolution process because this interaction was only found in first fixation durations at region 1 and was absent in other early eye-movement measures in this region and its spillover region (region 2). Considering the experimental materials used in our experiment were quite different from what were used in previous cataphora resolution studies, the interpretation of this seemingly odd interaction should start from the structure of our own materials. It might be related to the process in which matrix subject is first assigned as the subject of the adjunct clause. This may also explain why the effect of Gender Match manifested itself in the form of longer reading times in gender-mismatch than in gender-match conditions. A detailed explanation is given in the General Discussion part.

The experimental data also show that learners' proficiency did not influence their processing pattern in cataphora resolution. Except for the overall longer reading times observed in LG learners, LG and HG learners behaved remarkably alike in terms of the time-course during which Binding Principle B was applied to constrain their cataphora resolution process, suggesting that learners' proficiency did not affect when the syntactic constraint was applied in cataphora resolution. However, it seems that LG learners are less skilled in applying Binding Principle B than HG learners during late stages of cataphora resolution, as indexed by the Constraint and Group interactions observed for total reading times at both region 1 and region 3. Moreover, the Constraint and Group interaction observed for first pass reading times at region 2 seems to suggest that LG learners have more difficulty in retrieving the gender feature of the cataphoric pronoun when they started the cataphora resolution process just after finishing the interpretation of PRO. This is supposed to arise from the fact that the LG learners in our Experiment have lower working memory than HG learners. L2 learners' working memory has been found to positively correlate with their proficiency (van den Noort et al., 2006).

In brief, Binding Principle B constrains Chinese EFL learners' cataphora resolution process, but just works at late stages of cataphora resolution. As a whole, the time-course of learners' application of Binding Principle B in English cataphora processing is not modulated by their proficiency.

## 4. General discussion

The two eye-tracking studies aim to investigate how Chinese EFL learners with different English proficiency resolve English cataphoric pronouns and whether their cataphora resolution process is restricted by the syntactic constraint Binding Principle B. Experiment 1 shows that Chinese EFL learners initiate an active search in processing the cataphoric pronouns, yet along a processing path distinct from English natives, and HG learners initiate the active searching process earlier than LG learners. Experiment 2 shows that Binding Principle B constrains Chinese EFL learners' cataphora resolution process, but

research questions.

works only at later stages of cataphora resolution, unlike the early application of Binding Principle B by English natives in cataphora resolution.

## 4.1. Active search mechanism adopted by Chinese EFL learners in cataphora resolution

Just as English natives, Chinese EFL learners also trigger an active search for the antecedent upon encountering an English cataphoric pronoun. However, the specific searching process is quite different from that of English native speakers. Reading times of English natives are slowed down by a gender-mismatching name at the matrix subject position while reading times of Chinese EFL learners are slowed down by a gender-matching name at the same position. This unexpected gender-match effect contradicts the gender-mismatch effect that has been consistently found in previous studies except for Bertenshaw (2009). Bertenshaw (2009) ascribed the gender-match effect observed in Japanese EFL learners to the influence of learners' first language in which disjointed coreference between the cataphoric pronoun and the first name was preferred in the context of experimental sentences. However, this explanation cannot account for the gender-match effect in our study for two reasons. The first reason is that experimental sentences in Bertenshaw's study differed from what we used. In Bertenshaw's (2009) study, a lead-in sentence containing one male name and one female name preceded the critical sentence containing the cataphoric pronoun, which made the pronoun not strictly cataphoric since it can access interpretation from the male or female name based on its gender co-indexation. Therefore, the existence of the lead-in sentence might be the real reason that Japanese EFL learners' first language had an impact on their interpretation of the cataphoric pronoun. The second reason is that Chinese EFL learners do not possess prior knowledge regarding the resolution of cataphoric pronouns, for there is no intra-sentential cataphora in Chinese (Wang, 1994; Wang, 2000, 2006; Zhao and Shao, 2002). Then how to account for the gender-match effect in our study? One possibility is that Chinese EFL learners are affected by their awareness of first language in the option of processing strategies in cataphora resolution. The transfer of L1 processing strategies in L2 sentence processing has been confirmed by a number of studies (e.g., Gass, 1987; Harrington, 1987; Kilborn and Cooreman, 1987; Kilborn, 1989; Hernandez et al., 1994; Su, 2001). As Chinese is a semantics-driven language (Xu, 1999), Chinese native speakers are more concerned with semantic congruity than syntactic congruity when processing sentences. This processing preference might be transferred to their L2 sentence processing, which makes them less error-tolerant in semantic plausibility than English natives upon encountering a gender-mismatching potential antecedent in cataphora resolution. As mentioned above, before the gender feature of the matrix subject name becomes available, a link between the cataphoric pronoun and the name has already been established by both English native speakers and Chinese EFL learners. When the subject name mismatches the cataphoric pronoun in gender, Chinese EFL learners can quickly revoke the previously established coreference relation and stop taking the subject name as a potential antecedent. By contrast, when the information of that name matches the cataphoric pronoun in gender, they retain the link and engage in a deep processing of the subject name. As a result, more reading time was spent on a gender-matching subject name compared to a gender-mismatching name. However, a gender-mismatching subject name cannot make English native speakers abandon the established coreference relation in a short time as they are more error-tolerant than Chinese EFL learners in English sentence processing. Consequently, whether the subject name matches or mismatches the cataphoric pronoun in gender, English native speakers keep engaged in a deep processing of the name, yielding greater processing difficulty at the gender-mismatching relative to the gender-matching name region. From a cognitive perspective, the L1 transfer found in our study is conceptual transfer whose basic idea is that a person's comprehension and production of one language is affected by the concepts and conceptualization patterns he acquires in another language (Jarvis, 2007, 2011). Experientialism argues that although people of different nations share the ability to conceptualize their experience, they have developed different conceptual systems due to differences in their specific life experiences, environments, and cultures (Lakoff, 1987). Therefore, Chinese natives differ from English natives in terms of their specific conceptual system and conceptual patterns, as revealed by their language typology (Chinese, a semantics-first language contrasts English, a syntax-first language). As a result, Chinese EFL learners' processing of English sentences in our study is subject to the influence of their native language.

At the object name region (region 3), the regression path durations and total reading times were significantly longer in gender-match conditions than in gender-mismatch conditions. This can be explained by the Competition Model (McDonald and MacWhinney, 1995). According to the Model, processing should be much more difficult when there are two potential antecedents than when there is only one for the anaphoric pronoun, because the two potential antecedents might compete for the final interpretation of the anaphoric pronoun whereas there is no competition involved when only one potential antecedent is available. In our Experiment 1, the object name in gender-match conditions serves as another potential antecedent for the cataphoric pronoun, competing with the subject name for being chosen as the final interpretation of the cataphoric pronoun during later stages of cataphora resolution. In contrast, the object name in gender-mismatch conditions is the only appropriate antecedent for the cataphoric pronoun and no competition will arise between the object name and the subject name, for the gender feature of the subject name clashes with that of the cataphoric pronoun. Evidently, Competition Model can not only be used to reveal the processing mechanism behind ambiguous forwards anaphora resolution, but also holds explanatory power in ambiguous cataphora resolution as in our study.

Apart from the two above-mentioned findings, Experiment 1 also demonstrated a modulating effect of learners' proficiency on the time-course of their active searching process. Specifically, LG learners delayed their active searching process relative to HG learners. Following the above-mentioned L1 transfer account, LG learners should be more affected by their L1, thereby showing earlier and stronger GME effect. However, what we found was just the opposite. HG learners exhibited earlier and stronger GME effect than LG learners, which means there was another force playing a greater role. This dominating force stems from learners' employment of active search mechanism in cataphora resolution. As we have discussed in the preceding text, readers' employment of an active search mechanism implies two steps: the first step is to predictively establish the coreference relationship between the cataphoric pronoun and the matrix subject position, and the second step is to access the gender feature of the matrix subject to confirm their analysis. Accordingly, two reasons might help to explain our results. One is related to LG learners' reduced predictive ability compared to HG learners in L2 sentence comprehension, which has been demonstrated by several studies (e.g., Kaan, 2014; Peters et al., 2015). As a result of LG learners' reduced predictive ability, the predictive process of linking the cataphoric pronoun to the matrix subject position (region 1) might be slower and more cognitive-demanding for LG learners than HG learners. The other reason for our results might be that LG learners are slower and less efficient than HG learners in accessing the gender features of the matrix subject. According to the revised hierarchical model (RHM), L2 and L1 words in the bilingual mental lexicon share one conceptual system while their corresponding forms are represented separately (Kroll and Stewart, 1994). Several scholars (Chen, 1990; Dufour and Kroll, 1995; Cheung and Chen, 1998) interpreted the RHM from a developmental perspective and held that L2 learners with lower proficiency access L2 word meaning through L1 lexicon while learners with higher proficiency access L2 word meaning directly *via* the shared conceptual system, the claim being confirmed by several studies (e.g., Jared and Kroll, 2001; Kroll et al., 2006, 2010). Therefore, it is rational to assume that LG learners in our study are slower than HG learners in accessing the gender information of the matrix subject. In a word, LG learner's reduced predictive ability and slower access to the gender information of the matrix subject together contribute to their relatively delayed employment of the active search mechanism in cataphora resolution.

## 4.2. Late application of principle B by Chinese EFL learners in cataphora resolution

Chinese EFL learners' cataphora resolution process was constrained by Principle B. However, unlike English native's early application of Principle B, Chinese EFL learners, irrespective of their proficiency levels, resorted to Principle B to resolve cataphora at a later stage. Before further exploring the underlying reasons for the different processing patterns between Chinese EFL learners and English native speakers, we first take a look at the seemingly odd Gender Match and Constraint interaction observed in first fixation durations at region 1. As we have mentioned in 3.6, the interpretation of this interaction should be based on the structure of the experimental materials used. For better illustration, the exemplar sentences in Experiment 2 are repeated here as (7).

(7) a. constraint, gender-match/mismatch

After PRO buying her/him an iced coffee, <u>Linda</u> <u>generously</u> offered <u>Elsa/Victor</u> <u>the best</u> seat at the meeting table.

b. no-constraint, gender-match/mismatch.

After PRO buying her/his colleague an iced coffee, <u>Linda</u> <u>generously</u> offered <u>Elsa/Victor</u> <u>the best</u> seat at the meeting table.

The experimental sentences involve two types of cataphoric relations, one of which is between PRO and the matrix subject and the other is between the cataphoric pronoun and its antecedent. Using the same materials, Kush and Dillon (2021) demonstrated that English native speakers could process the two types of cataphoric relations simultaneously by incrementally integrating syntactic and pragmatic information. However, our experimental data suggest that Chinese EFL learners could only process the two cataphoric relations one by one. Though a couple of studies claim that cataphoric pronouns are not used in Chinese (Wang, 1994; Wang, 2000, 2006; Zhao and Shao, 2002), some scholars take a different view in this issue (Xu and He, 2007; Gao, 2010; Yu, 2011). For instance, Gao (2010) held that cataphoric pronouns existed in Chinese in an invisible and inaudible way, i.e., zero cataphoric pronouns are present in Chinese. Gao (2010) conducted a corpus-based contrastive study of cataphora in Chinese and English, and found that cataphora in Chinese manifested itself only in the form of zero pronouns while cataphora in English existed in the form of both zero and overt pronouns. At the same time, zero cataphoric pronouns in Chinese and English are used in a similar way in which the invisible pronoun appears in a preposed modifier and the antecedent appears in the matrix subject position or as a modifier of the matrix subject. The PRO in our experimental sentence is just the kind of zero cataphoric pronouns Gao (2010) has identified. Since this kind of zero cataphoric pronouns exists in both Chinese and English and is used in a similar way across two languages, Chinese EFL learners might prioritize the processing of PRO (i.e., zero cataphoric pronoun) over the processing of the overt cataphoric pronoun which is rarely used in Chinese. Following this assumption, we can well explain the seemingly odd Constraint and Gender Match interaction observed in first fixation durations at region 1. Specifically, during the early processing of region 1, Chinese EFL learners only completed the interpretation of PRO, assigning it to the matrix subject (region 1) while the resolution of the cataphoric pronoun had not yet started at this time. After the matrix subject was interpreted as the subject of the subordinate clause, the meaning of the subordinate clause in no-constraint, gender-match conditions was accessed more easily than the meaning of the adjunct clause in no-constraint, gender-mismatch conditions due to the gender-incongruency between the matrix subject and the cataphoric pronoun, thereby resulting in significantly longer first fixations in no-constraint, gender-mismatch conditions than in no-constraint, gender-match conditions. At the same time, the process of assigning the matrix subject name to PRO made the gender feature of the matrix subject available to the parser before the resolution of cataphoric pronouns started, consequently leading to longer reading times being spent on a gender-mismatching subject name during cataphora resolution, contrastive to the GME effect observed in Experiment 1 where coreference between the cataphoric pronoun and the matrix subject was already established even before the gender information of the subject name becomes available to the parser. In addition to a Constraint and Gender Match interaction, there came up a significant Gender Match and Group interaction for first fixation durations at region 1. Further analysis on this interaction indicated that LG learners were more easily disrupted than HG learners by the gender feature of the cataphoric pronoun stored in their working memory when assigning the matrix subject to PRO.

Chinese EFL learners behave themselves differently from English natives in using Binding Principle B from the perspective of time course regarding cataphora resolution. Concerning the time-course of syntactic constraints in cataphora resolution, there are two major hypotheses. One is the early filter hypothesis, claiming that syntactic constraints play an early role in the parser's active searching process so that only positions licensed by the grammatical constraints can be predictively considered as holding potential antecedents. The other one is the delayed filter hypothesis, holding that syntactic constraints are applied at a later processing stage to filter out ungrammatical interpretations, which implies noun phrases at positions not licensed by syntactic constraints are initially considered as potential antecedents. So to speak, the performance of English native speakers in Kush and Dillon (2021)'s study is consistent with the early filter hypothesis while the performance of Chinese EFL learners in our experiment 2 is in line with the delayed filter hypothesis. Why does Principle B function as an early filter in English natives' cataphora resolution but a delayed filter in Chinese EFL learners' cataphora resolution? The difference between L1 and L2 sentence processing might be responsible for the discrepancy. According to Shallow Structure Hypothesis (Clahsen and Felser, 2006a,b), L2 learners prioritize semantic and pragmatic cues over syntactic cues to guide their sentence processing, which leads to shallow and less detailed syntactic representations being computed by L2 learners, as compared to native speakers. Given that our experimental sentences involve two types of cataphoric relations, it is rational to assume that Chinese EFL learners have not established the required syntactic representations to correctly resolve the cataphoric pronoun when first encountering the matrix subject. As a result, the EFL learners made the ungrammatical interpretation that is based solely on the gender-match between the cataphoric pronoun and the matrix subject, without taking the syntactic constraint into account.

Previous forwards anaphora resolution studies show that L2 learners tend to delay the application of binding constraints (Felser et al., 2009; Felser and Cunnings, 2012). Targeting at L2 English learners' online processing of reflexives, both Felser et al. (2009) and Felser and Cunnings (2012) found that L2 learners were initially affected by a discourse-salient but binding-inaccessible antecedent while English native speakers could immediately apply Binding Principle A to resolve reflexives, suggesting that L2 learners' early processing of reflexives was not restricted by syntactic constraints. In our study, Chinese EFL learners were also found to have delayed their application of the binding constraint in cataphora resolution. Therefore, the delayed application of binding constraints by L2 learners in both forwards anaphora and cataphora resolution adds evidence to the claim that L2 learners have more difficulty than native speakers in establishing nonadjacent syntactic dependencies in real time (Clahsen and Felser, 2006a).

Both Binding Principle B and Binding Principle C are observed by EFL learners in English cataphora resolution. Unlike the delayed application of Binding Principle B by learners in our study, previous cataphora resolution studies demonstrated that native speakers and L2 learners patterned alike in terms of the time-course of their application of Binding Principle C when resolving cataphoric pronouns (Rodríguez, 2008; Bertenshaw, 2009; Drummer and Felser, 2018). This implies that Binding Principle B and Binding Principle C are treated differently by L2 learners. To be more specific, it seems that Binding Principle C was more easily applied than Binding Principle B by L2 learners in their online resolution of cataphoric pronouns. Comparing the materials used in previous L2 cataphora resolution studies and those used in our study, we find that the coreference relations subject to Binding Principle C was more easily detected than those subject to Binding Principle B because the structure of sentences involving Principle C constraint was much simpler than those involving Principle B constraint. On this account, it appears safe to argue that L2 learners' sensitivity to different binding constraints in cataphora resolution is also dependent on the complexity of sentences involved. Despite L2 learners' divergent sensitivity to Binding Principle B and Binding Principle C, all L2 learners can follow these two syntactic constraints in the corresponding sentences to exclude ungrammatical antecedents when resolving cataphoric pronouns online.

### 4.3. Chinese EFL learner's English proficiency and their cataphora processing

Chinese EFL learners' proficiency did not modulate the time-course of their application of Binding Principle B in cataphora resolution. Specifically, both HG and LG learners delayed their application of the binding constraint when resolving cataphoric pronouns. Nevertheless, the data in Experiment 1 showed that learners' proficiency affected when they initiated an active search for the antecedent. What is dedicated to the absence of the modulation effect of learners' proficiency in Experiment 2? We resort to Shallow Structure Hypothesis to explain the absence. The key tenet of Shallow Structure Hypothesis is that L2 sentence processing is fundamentally different from L1 sentence processing and even highly proficient learners cannot achieve native-like level in terms of processing complex syntactic structures like ambiguous relative clauses and filler-gap dependencies while native-like processing of simple syntactic structures like subject-predicate agreement can be attained as the learners' proficiency increases. As mentioned in the preceding part, the sentences in Experiment 2 involve two types of cataphoric relations and the correct resolution of cataphoric pronouns necessitates the successful representation of these two types of cataphoric relations. In contrast, the sentences in our Experiment 1 are relatively simple and the successful resolution of cataphoric pronouns relies more on whether the name matches the cataphoric pronoun in gender. That is, since the sentences were more complex in Experiment 2 than in Experiment 1, learners' proficiency modulated their online performance in Experiment 1 but became invisible in Experiment 2.

## 5. Conclusion

We conducted two eye-tracking studies to investigate how Chinese EFL learners with different proficiency resolved cataphoric pronouns and whether their cataphora resolution process was restricted by Binding Principle B. The results revealed that Chinese EFL learners initiated an active search for the antecedent when encountering a cataphoric pronoun, yet along a processing path distinct from English natives. Specifically, Chinese EFL learners predictively linked a cataphoric pronoun to the first potential antecedent, but only a gender-matching antecedent could prompt them to engage in a deep processing of the antecedent, the reason being that concepts and conceptualization patterns Chinese EFL learners acquired in their mother tongue influenced their English sentence processing. In addition, learners' proficiency modulated the time point at which they initiated an active searching process, with HG learners earlier than LG learners. Moreover, our results demonstrated that Chinese EFL learners' cataphora resolution process was restricted by Binding Principle B, but the application of Binding Principle B was delayed in both HG and LG learners compared with English natives, suggesting that Chinese EFL learners were not so much sensitive to syntactic constraints as English natives in cataphora resolution.

To conclude, this study demonstrated how Chinese EFL learners resolve cataphoric pronouns. By extending cataphora resolution studies to a group of English learners with a distinct L1 (i.e., Chinese) in typology, we provide more insights into L2 sentence processing and adds more evidence to the Shallow Structure Hypothesis. Subsequent studies are expected to explore how English learners with various L1 backgrounds resolve cataphoric pronouns, as well as whether other factors such as learners' working memory influence their online performance on resolving cataphoric pronouns, so as to provide a real panorama for the L2 cataphora resolution mechanism.

## Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding authors.

## Ethics statement

The studies involving human participants were reviewed and approved by Ethics Committee of Qufu Normal University. The patients/participants provided their written informed consent to participate in this study.

## Author contributions

TW, MG, and YW conceived the study. MG, YW, and MZ performed the experiments. MG collated and analyzed the date. TW and MG drafted the first manuscript, which was revised by TZ and YY. All authors contributed to the article and approved the submitted version.

## Funding

This work was supported by the National Social Science Fund of China under grant 21BYY103.

## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

## Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

## Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2023.1126673/full#supplementary-material

## References

Bertenshaw, N. (2009). *The application of binding constraints by Japanese L2 learners of English. Ph.D. dissertation.* Essex: University of Essex.

Büring, D. (2005). *Binding theory*. Cambridge: Cambridge University Press.

Chen, H. C. (1990). Lexical processing in a non-native language: effects of language proficiency and learning strategy. *Psychon. Sci.* 18, 279–288. doi: 10.3758/BF03213881

Cheung, H., and Chen, H. C. (1998). Lexical and conceptual processing in Chinese-English bilinguals: further evidence for asymmetry. *Psychon. Sci.* 26, 1002–1013. doi: 10.3758/BF03201179

Chomsky, N. (1981). *Lectures on government and binding*. Dordrecht: Foris.

Chow, W. Y., Lewis, S., and Phillips, C. (2014). Immediate sensitivity to structural constraints in pronoun resolution. *Front. Psychol.* 5:630, 1–16. doi: 10.3389/fpsyg.2014.00630

Clackson, K., and Clahsen, H. (2011). "Online processing of cataphoric pronouns by children and adults: evidence from eye-movements during listening" in *Proceedings of BUCLD 35*. eds. N. Danis, K. Mesh and H. Sung (Somerville: Cascadilla Press), 119–131.

Clahsen, H., and Felser, C. (2006a). Grammatical processing in language learners. *Appl. Psycholinguist.* 27, 3–42. doi: 10.1017/S0142716406060024

Clahsen, H., and Felser, C. (2006b). How native-like is non-native language processing? *Trends Cogn. Sci.* 10, 564–570. doi: 10.1016/j.tics.2006.10.002

Cowart, W., and Cairns, H. S. (1987). Evidence for an anaphoric mechanism within syntactic processing: some reference relations defy semantic and pragmatic constraints. *Mem. Cogn.* 15, 318–331. doi: 10.3758/BF03197034

Crain, S., and Fodor, J. (1985). "How can grammars help parsers?" in *Natural language parsing. Psychological, computational, and theoretical perspectives*. eds. D. Dowty, L. Karttunen and A. M. Zwicky (Cambridge: Cambridge University Press), 94–128.

Cunnings, I., Fotiadou, G., and Tsimpli, I. (2017). Anaphora resolution and reanalysis during L2 sentence processing: evidence from the visual world paradigm. *Stud. Second. Lang. Acquis.* 39, 621–652. doi: 10.1017/S0272263116000292

Cunnings, I., Patterson, C., and Felser, C. (2014). Variable binding and coreference in sentence comprehension: evidence from eye movements. *J. Mem. Lang.* 71, 39–56. doi: 10.1016/j.jml.2013.10.001

Drummer, J. D., and Felser, C. (2018). Cataphoric pronoun resolution in native and non-native sentence comprehension. *J. Mem. Lang.* 101, 97–113. doi: 10.1016/j.jml.2018.04.001

Dufour, R., and Kroll, J. F. (1995). Matching words to concepts in two languages: a test of the concept mediation model of bilingual representation. *Psychon. Sci.* 23, 166–180. doi: 10.3758/BF03197219

Felser, C., and Cunnings, I. (2012). Processing reflexives in a second language: the timing of structural and discourse-level constraints. *Appl. Psycholinguist.* 33, 571–603. doi: 10.1017/S0142716411000488

Felser, C., Sato, M., and Bertenshaw, N. (2009). The on-line application of binding principle a in English as a second language. *Biling. Lang. Congn.* 12, 485–502. doi: 10.1017/S1366728909990228

Filik, R., and Sanford, A. J. (2008). When is cataphoric reference recognised? *Cognition* 107, 1112–1121. doi: 10.1016/j.cognition.2007.11.001

Frazier, L., and Flores D'Arcais, G. B. (1989). Filler driven parsing: a study of gap filling in Dutch. *J. Mem. Lang.* 28, 331–344. doi: 10.1016/0749-596X(89)90037-5

Gao, J. (2010). A contrastive study of cataphora in English and Chinese texts. *J. Foreign Lang.* 33, 32–39.

Gass, S. (1987). The resolution of conflicts among competing systems: a bidirectional perspective. *Appl. Psycholinguist.* 8, 329–350. doi: 10.1017/S0142716400000369

Harrington, M. (1987). Processing transfer: language-specific processing strategies as a source of interlanguage variation. *Appl. Psycholinguist.* 8, 351–377. doi: 10.1017/S0142716400000370

Hernandez, A., Bates, E., and Avila, L. (1994). On-line sentence interpretation in Spanish-English bilinguals: what does it mean to be "in between"? *Appl. Psycholinguist.* 15, 417–446. doi: 10.1017/S014271640000686X

Huang, Y. (1994). *The syntax and pragmatics of anaphora*. Cambridge: Cambridge University Press.

Huang, Y. (2000). *Anaphora: a cross-linguistic study*. Oxford: Oxford University Press.

Jared, D., and Kroll, J. F. (2001). Do bilinguals activate phonological representations in one or both of their languages when naming words? *J. Mem. Lang.* 44, 2–31. doi: 10.1006/jmla.2000.2747

Jarvis, S. (2007). Theoretical and methodological issues in the investigation of conceptual transfer. *Vigo Int. J. Appl. Ling.* 4, 43–71.

Jarvis, S. (2011). Conceptual transfer: Crosslinguistic effects in categorization and construal. *Biling. Lang. Congn.* 14, 1–8. doi: 10.1017/S1366728910000155

Kaan, E. (2014). Predictive sentence processing in L2 and L1. *Ling. Approaches Bilingualism* 4, 257–282. doi: 10.1075/lab.4.2.05kaa

Kazanina, N. (2005). *The acquisition and processing of backwards anaphora. Ph.D. dissertation.* Maryland: University of Maryland.

Kazanina, N., Lau, E. F., Lieberman, M., Yoshida, M., and Philips, C. (2007). The effect of syntactic constraints on the processing of backwards anaphora. *J. Mem. Lang.* 56, 384–409. doi: 10.1016/j.jml.2006.09.003

Kazanina, N., and Phillips, C. (2010). Differential effects of constraints in the processing of Russian cataphora. *Q. J. Exp. Psychol.* 63, 371–400. doi: 10.1080/17470210902974120

Kilborn, K. (1989). Sentence processing in a second language: the timing of transfer. *Lang. Speech* 32, 1–23. doi: 10.1177/002383098903200101

Kilborn, K., and Cooreman, A. (1987). Sentence interpretation strategies in adult Dutch-English bilinguals. *Appl. Psycholinguist.* 8, 415–431. doi: 10.1017/S0142716400000394

Kroll, J., Bobb, S., and Wodniecka, Z. (2006). Language selectivity is the exception, not the rule: arguments against a fixed locus of language selection in bilingual speech. *Biling. Lang. Congn.* 9, 119–135. doi: 10.1017/S1366728906002483

Kroll, J. F., and Stewart, E. (1994). Category interference in translation and picture naming: evidence for asymmetric connections between bilingual memory representations. *J. Mem. Lang.* 33, 149–174. doi: 10.1006/jmla.1994.1008

Kroll, J. F., van Hell, J. G., Tokowicz, N., and Green, D. W. (2010). The revised hierarchical model: a critical review and assessment. *Biling. Lang. Congn.* 13, 373–381. doi: 10.1017/S136672891000009X

Kush, D., and Dillon, B. (2021). Principle B constrains the processing of cataphora: evidence for syntactic and discourse predictions. *J. Mem. Lang.* 120:104254. doi: 10.1016/j.jml.2021.104254

Lakoff, G. (1987). *Women, fire and dangerous things: what categories reveal about the mind*. Chicago: Chicago University Press.

Levinson, S. (1991). Pragmatic reduction of the binding conditions revisited. *J. Ling.* 27, 107–161. doi: 10.1017/S0022226700012433

Li, P., Sepanski, S., and Zhao, X. (2006). Language history questionnaire: a web-based interface for bilingual research. *Behav. Res. Methods* 38, 202–210. doi: 10.3758/BF03192770

Liang, L., Wen, Y., and Dong, Y. (2018). Gender constraint in L1 and L2 reflexive pronoun resolution by Chinese-English bilinguals. *J. Neurolinguistics* 45, 1–12. doi: 10.1016/j.jneuroling.2017.08.001

Liu, X.-P. (2020). The time-course of Chinese EFL learners' reflexive anaphora resolution. *Mod. Foreign Lang. (Bimonthly).* 43, 236–243.

McDonald, J., and MacWhinney, B. (1995). The time course of anaphor resolution: effects of implicit causality and gender. *J. Mem. Lang.* 34, 543–566. doi: 10.1006/jmla.1995.1025

Mitkov, R. (2002). *Anaphora resolution.* London: Longman.

Oldfield, R. C. (1971). The assessment and analysis of handedness: the Edinburgh inventory. *Neuropsychologia* 9, 97–113. doi: 10.1016/0028-3932(71)90067-4

Pablos, L., Doetjes, J. S., Ruijgrok, B. J., and Cheng, L. L. (2015). Active search for antecedents in cataphoric pronoun resolution. *Front. Psychol.* 6:1638. doi: 10.3389/fpsyg.2015.01638

Patterson, C., and Felser, C. (2019). Delayed application of binding condition C during cataphoric pronoun resolution. *J. Psycholinguist. Res.* 48, 453–475. doi: 10.1007/s10936-018-9613-4

Peters, R. E., Gruter, T., and Borovsky, A. (2015). "Anticipatory and locally coherent lexical activation varies as a function of language proficiency," in *Proceedings of the Cognitive Science Society*. 1865–1870.

Rayner, K. (1998). Eye movements in reading and information processing: 20 years of research. *Psychol. Bull.* 124, 372–422. doi: 10.1037/0033-2909.124.3.372

Rayner, K., and Pollatsek, A. (1989). *The psychology of Reading*. New Jersey: Prentice-Hall.

Reinhart, T. (1983). *Anaphora and semantic interpretation*. London: Croom Helm.

Reinhart, T., and Reuland, E. (1993). Reflexivity. *Ling. Inq.* 24, 657–720. Available at: http://www.jstor.org/stable/4178836

Rodríguez, G. A. (2008). *Second language sentence processing: Is it fundamentally different? Ph.D. dissertation.* Pittsburgh: University of Pittsburgh.

Stowe, L. A. (1986). Parsing WH-constructions: evidence for on-line gap location. *Lang. Cogn. Process.* 1, 227–245. doi: 10.1080/01690968608407062

Su, I. R. (2001). Transfer of sentence processing strategies: a comparison of L2 learners of Chinese and English. *Appl. Psycholinguist.* 22, 83–112. doi: 10.1017/S0142716401001059

Tang, H.-J., and Wen, X. (2020). Pronoun ambiguity resolution in English sentence processing: evidence from eye-tracking. *Foreign Lang. Teach. Res (Bimonthly).* 52, 77–89. doi: 10.19923/j.cnki.fltr.2020.01.008

van den Noort, M. W. M. L., Bosch, P., and Hugdahl, K. (2006). Foreign language proficiency and working memory capacity. *Eur. Psychol.* 11, 289–296. doi: 10.1027/1016-9040.11.4.289

van Gompel, R. P. G., and Liversedge, S. P. (2003). The influence of morphological information on cataphoric pronoun assignment. *J. Exp. Psychol. Learn. Mem. Cogn.* 29, 128–139. doi: 10.1037/0278-7393.29.1.128

Wang, Z.-Y. (1994). Can English personal pronouns refer cataphorically? *Foreign Lang. Teach. Res.* 26, 36–39.

Wang, C.-L. (2000). On the anaphoric function of the personal pronoun ta. *Stud. Chin. Lang.* 3, 228–237.

Wang, C.-L. (2006). Unidirectionality of the anaphora of third person pronouns in English and Chinese. *Foreign Lang. Teach. Res.* 38, 17–24.

Wu, M.-J. (2016). The online resolution mechanism of English pronoun her by Chinese L2 learners. *Foreign Lang. Teach. Res. (Bimonthly).* 48, 899–912.

Wu, M.-J. (2017). The acquisition of the binding properties of English reflexives by Chinese-speaking learners. *Ling. Sci.* 16, 573–585.

Wu, D., Wu, M. J., Gao, X. Z., and Zhang, J. L. (2019). The online processing of anaphoric and cataphoric pronouns in L2. *Foreign Lang. Their Teach.* 4, 90–100. doi: 10.13458/j.cnki.flatt.004607

Xu, T.-Q. (1999). A study on Chinese characteristics and language universality. *Linguistic Res* 4, 1–13.

Xu, Y.-L., and He, X.-D. (2007). Cataphora in Chinese and English texts: a functional-pragmatic analysis. *Foreign Lang. Teach. Res. (Bimonthly)* 39, 417–423.

Yoshida, M., Kazanina, N., Pablos, L., and Sturt, P. (2014). On the origin of islands. *Lang. Cognit. Neurosci.* 29, 761–770. doi: 10.1080/01690965.2013.788196

Yu, Z.-C. (2011). A functional account of English and Chinese cataphora-with critical comments on van Hoek (1997). *Foreign Lang. Teach. Res. (Bimonthly).* 43, 197–208.

Yu, Z., and Dong, Y. (2019). The neurocognitive mechanisms of semantic gender processing in L1 and L2 personal nouns by Chinese-English bilinguals. *Lang. Cognt. Neurosci.* 34, 901–915. doi: 10.1080/23273798.2019.1591472

Yu, S.-Z., and Zhai, Q.-X. (2017). An empirical study of L2 pronoun comprehension by Chinese learners of English. *Foreign Lang. Teach. Res. (Bimonthly).* 49, 833–846.

Zhao, H., and Shao, Z.-H. (2002). A comparative study of the anaphoric function of the English and Chinese third person pronouns. *Foreign Lang. Teach. Res. (Bimonthly).* 34, 174–179.

 10.3389/fpsyg.2023.1126673

# Appendix

**TABLE 1** A comparison of results between English natives and Chinese EFL learners in Experiment 1.

| Note: M1: Match M2: Mismatch | | English natives | Chinese EFL learners | |
|---|---|---|---|---|
| | | | HG | LG |
| Region 1 | FFD | – | – | – |
| | FPD | – | M1 > M2 | – |
| | RPD | – | M1 > M2 | – |
| | TRT | M1 < M2 | M1 > M2 | – |
| Region 2 | FFD | – | – | – |
| | FPD | – | M1 > M2 | – |
| | RPD | – | – | – |
| | TRT | M1 < M2 | M1 > M2 | M1 > M2 |

**TABLE 2** A comparison of results between English natives and Chinese EFL learners in Experiment 2.

| Note: C1: Constraint C2: No-constraint M1: Match M2: Mismatch | | English natives | Chinese EFL learners | |
|---|---|---|---|---|
| | | | HG | LG |
| Region 1 | FFD | – | C2M2 > C2M1 | C1M2 > C1M1 |
| | | | – | C2M2 > C2M1 |
| | | | C1M1 > C2M1 | C1M1 > C2M1 |
| | FPD | – | – | – |
| | RPD | – | – | – |
| | TRT | C2M2 > C2M1 | – | C2M1 > C1M1 |
| | | C2M1 > C1M1 | | C2M2 > C1M2 |
| | | C2M2 > C1M2 | | |
| Region 2 | FFD | – | C1M1 > C2M1 | C1M1 > C2M1 |
| | | | C1M2 > C2M2 | C1M2 > C2M2 |
| | | | C1M2 > C1M1 | C1M2 > C1M1 |
| | | | C2M2 > C2M1 | C2M2 > C2M1 |
| | FPD | – | C1M2 > C1M1 | C1M2 > C1M1 |
| | | | C2M2 > C2M1 | C2M2 > C2M1 |
| | | | | C1M1 > C2M1 |
| | | | | C1M2 > C2M2 |
| | RPD | – | C2M2 > C1M2 | C2M2 > C1M2 |
| | TRT | C2M2 > C2M1 | C2M1 > C1M1 | C2M1 > C1M1 |
| | | | C2M2 > C1M2 | C2M2 > C1M2 |
| | | | C1M1 > C1M2 | |
| | | | C2M1 > C2M2 | |

frontiers | Frontiers in Psychology

TYPE Original Research
PUBLISHED 22 March 2023
DOI 10.3389/fpsyg.2023.1143064

Check for updates

OPEN ACCESS

EDITED BY
Fernando Marmolejo-Ramos,
University of South Australia,
Australia

REVIEWED BY
Chris F. Westbury,
University of Alberta,
Canada
Lin Fan,
Beijing Foreign Studies University,
China
Jin Xue,
University of Science and Technology Beijing,
China

*CORRESPONDENCE
Huili Wang
✉ wanghl@zucc.edu.cn

SPECIALTY SECTION
This article was submitted to
Language Sciences,
a section of the journal
Frontiers in Psychology

RECEIVED 12 January 2023
ACCEPTED 06 March 2023
PUBLISHED 22 March 2023

CITATION
Tang D, Fu Y, Wang H, Liu B, Zang A and Kärkkäinen T (2023) The embodiment of emotion-label words and emotion-laden words: Evidence from late Chinese–English bilinguals.
*Front. Psychol.* 14:1143064.
doi: 10.3389/fpsyg.2023.1143064



# The embodiment of emotion-label words and emotion-laden words: Evidence from late Chinese–English bilinguals

Dong Tang[1,2], Yang Fu[3], Huili Wang[4]*, Bo Liu[5], Anqi Zang[3] and Tommi Kärkkäinen[2]

[1]School of Foreign Languages, Dalian University of Technology, Dalian, China, [2]Faculty of Information Technology, University of Jyväskylä, Jyväskylä, Finland, [3]Instituto Universitario de Neurociencia, Universidad de La Laguna, Santa Cruz de Tenerife, Spain, [4]School of Foreign Languages, Hangzhou City University, Hangzhou, China, [5]School of Foreign Languages, Dalian Maritime University, Dalian, China

Although increasing studies have confirmed the distinction between emotion-label words (words directly label emotional states) and emotion-laden words (words evoke emotions through connotations), the existing evidence is inconclusive, and their embodiment is unknown. In the current study, the emotional categorization task was adopted to investigate whether these two types of emotion words are embodied by directly comparing how they are processed in individuals' native language (L1) and the second language (L2) among late Chinese-English bilinguals. The results revealed that apart from L2 negative emotion-laden words, both types of emotion words in L1 and L2 produced significant emotion effects, with faster response times and/or higher accuracy rates. In addition, processing facilitation for emotion-label words over emotion-laden words was observed irrespective of language operation; a significant three-way interaction between the language, valence and emotion word type was noted. Taken together, this study suggested that the embodiment of emotion words is modulated by the emotion word type, and L2 negative emotion-laden words tend to be affectively disembodied. The disassociation between emotion-label and emotion-laden words is confirmed in both L1 and L2 and therefore, future emotion word research should take the emotion word type into account.

KEYWORDS

**emotion-label words, emotion-laden words, emotion word type, valence, embodied cognition**

## 1. Introduction

The role of emotion in grounding conceptual-semantic representations during language processing should not be underestimated (Kousta et al., 2011). According to the traditional amodal theory, concepts are represented with abstract and arbitrary mental symbols, without the involvement of specific modalities (Fodor, 1975; Charniak, 1978). However, this disembodied account has been challenged by embodied cognition, a recent dominant view that posits that the comprehension of language is grounded in bodily perception, action, as well as emotion (for reviews: Horchak et al., 2014; Kühne and Gianelli, 2019). Accumulating evidence supporting this embodied account has reported that the processing of sensory or action-related linguistic items involves reactivation of the same neural mechanism as one executes a specific action (for a review: Fischer and Zwaan, 2008). In this line, given that emotion words carry a large emotional load, many studies have been conducted to examine the relationship between language and emotion. There is evidence suggesting that emotion words produce emotion activation automatically and are therefore embodied. For example, it has been reported that emotion words are processed with faster reaction times (Kousta et al., 2009) and increased neural correlates (Citron, 2012) compared to neutral words, and this processing advantage of emotion words is known as the "emotion effect" (Wang et al., 2019). Additionally, neuroscientific studies have revealed that the original sensory-motor and emotion-related regions get activated when participants are exposed to concepts with emotion-evoking content (e.g., Moseley et al., 2012). These findings suggested that language understanding is grounded in emotion simulation.

However, the emotion word processing in bilingualism poses a challenge to embodied cognition. It has been proposed that emotion words in a native language (L1) are more embodied compared to those in the second language (L2) (e.g., Baumeister et al., 2017). This is because L1 emotion words are more closely linked to specific contexts or situations where sensory-motor experiences and linguistic concepts are established. As a result, when encountering L1 emotion words, emotional experiences associated with those words are reactivated, thereby contributing to language understanding. In contrast, there is a greater emotional distance in L2 (Pavlenko, 2012), and therefore it remains open with respect to whether emotion words in L2 are embodied. Some studies revealed that emotion activation in response to L2 emotion words is similar to that in L1 (e.g., Ponari et al., 2015; Sheikh and Titone, 2016), whereas others suggested that emotion words in L2 may not activate or only weakly activate emotions compared to L1 emotion words (Conrad et al., 2011; Degner et al., 2012), especially for those acquired in adult age (Kühne and Gianelli, 2019).

Recently, an additional issue has emerged in the field of emotion word research regarding the precise definition of emotion words. Usually, two emotional dimensions, including valence (pleasant or unpleasant; positive or negative category of emotional stimuli) and arousal (calm or excited; low or high degree of emotion activation), were primarily explored in prior research (Hinojosa et al., 2020). However, critics have pointed out that in much of the prior research on emotion word processing, the emotion word type was not taken into account (Altarriba and Basnight-Brown, 2011; Zhang et al., 2017). Accordingly, emotion words can be categorized into two subtypes: emotion-label words (e.g., "happy," "sad") which straightforwardly elucidate or describe one's affective states, and emotion-laden words (e.g., "successful," "failed") which elicit individual's emotions through the word's connotations (Pavlenko, 2008; Zhang et al., 2017). The "emotion word type effect," which refers to the disassociation between these two kinds of emotion words (Wu and Zhang, 2019; Wu et al., 2021b), has been confirmed in an increasing number of studies. Specifically, in terms of monolingual research, the emotion word type effect was observed in behavioral studies with various cognitive tasks (Knickerbocker and Altarriba, 2013; Kazanas and Altarriba, 2015, 2016b; El-Dakhs and Altarriba, 2019). For example, Kazanas and Altarriba (2015) found facilitated processing of emotion-label words in both implicit (masked) and explicit (unmasked) lexical decision task (LDT), with faster response times (RTs) and greater priming effects relative to emotion-laden words. Research using event-related potentials (ERPs) has further demonstrated different neural mechanisms underlying the processing of L1 emotion-label and emotion-laden words (Zhang et al., 2017, 2019b; Wang et al., 2019; Wu et al., 2020, 2021a,b; Li et al., 2022; Liu et al., 2022a,b; Yeh et al., 2022). Zhang et al. (2017) for instance, compared the time course of emotion activation of the two kinds of emotion words in an LDT. They found that emotion-label words elicited enhanced N170 on the right hemisphere in comparison to emotion-laden words, and negative emotion-label words elicited larger Late Positivity Complex (LPC) on the right hemisphere relative to that on the left hemisphere. In addition, such discrepancies between emotion-label and emotion-laden words have also been observed in L2 processing in behavioral (Altarriba and Basnight-Brown, 2011; Kazanas and Altarriba, 2016a; El-Dakhs and Altarriba, 2019; Bromberek-Dyzman et al., 2021) and ERPs studies (Wu et al., 2019; Wu and Zhang, 2019; Zhang et al., 2019a, 2020). For example, in an ERPs study (Zhang et al., 2020), the emotion word type effect was found as the two kinds of emotion words in L2 were identified divergently across early and late processing stages.

The behavioral and neural studies outlined above present converging evidence confirming the emotion word type effect. Motivated by these findings, the present study aims to investigate and compare the potential modulation of the emotion word type on the embodiment of emotion words in L1 and L2 processing, given distinct associations of these two types of emotion words with emotional states. However, certain concerns must be addressed regarding the existing research on emotion word type. One such concern is that there has yet to be a consensus on which type of emotion word has the processing advantage in L1 and L2. While some studies found facilitated processing for emotion-label words relative to emotion-laden words in either L1 (e.g., Kazanas and Altarriba, 2015; Zhang et al., 2017) or L2 (e.g., Wu et al., 2019), or both (e.g., El-Dakhs and Altarriba, 2019), Kazanas and Altarriba (2016a) in their bilingual study found such processing superiority of emotion-label words was only restricted to the dominant language of participants. In contrast, others reported processing facilitation for emotion-laden words. For example, behavioral data from the ERPs study of Zhang et al. (2020) showed the processing advantage for L2 emotion-laden words over emotion-label words among Chinese-English bilinguals. In a similar vein, Bromberek-Dyzman et al. (2021) found a processing advantage for emotion-laden words in both L1 and L2 with a valence decision task, associating with faster RTs and higher accuracy rates (ACCs).

In addition, there are methodological concerns regarding the stimulus characteristics in prior examinations on the emotion word type. One methodological concern is the failure to control the concreteness of experimental stimuli in some studies (e.g., Kazanas and Altarriba, 2016a; Zhang et al., 2017). For instance, although Zhang et al. (2017) demonstrated differences in ERPs in processing these two types of emotion words, they did not manage to control the concreteness of experimental stimuli. Notably, when words' concreteness was strictly controlled, the differences in N170 and LPC components were not replicated in the study by Wang et al. (2019). Another methodological concern is that the lexical categories were intermixed (e.g., Kazanas and Altarriba, 2015; Zhang et al., 2017). For example, Kazanas and Altarriba (2015) used emotion-laden words that were all nouns (e.g., "candy," "coffin"), while the emotion-label words consisted of adjectives (e.g., "happy," "afraid") and nouns (e.g., "delight," "anger"). It is therefore still being determined whether the reported divergencies in processing emotion-label and emotion-laden words should be attributed to such methodological factors or the different types of emotion nature. More importantly, it is worth noting that other studies have shown no discrepancy between these two types of emotion words (Vinson et al., 2014; Martin and Altarriba, 2017). For instance, Martin and Altarriba (2017) found that emotion-label words were similarly processed with emotion-laden words as they produced similar response latency in an LDT employing hemifield presentation.

Therefore, there is no clear-cut answer regarding the emotion word type effect. In order to know the embodiment of emotion-label and emotion-laden words in L1 and L2, it is necessary to first determine whether a distinction between them exists, as well as which type of emotion word has a processing advantage. Another problem concerns the modulation of valence in emotion word processing. Although prior research has frequently reported the valence effect in emotion word processing, there is no consensus on whether it is positive or negative information that enhances word processing (Crossfield and Damian, 2021; for a review: Kauschke et al., 2019). For example, some studies found a positivity bias which shows that positive emotion words are responded to with faster response times (Goh et al., 2016), while others found the opposite pattern, a negative bias (e.g., Dijksterhuis and Aarts, 2003; Nasrallah et al., 2009). Given that the valence effect, for example, the positivity bias, has also been observed in processing these two types of emotion words (e.g., Kazanas and Altarriba, 2015, 2016a; El-Dakhs and Altarriba, 2019), the present study employed the emotional categorization task (ECT) in which the valence dimension is task-relevant. With this task, deep processing of emotion words is expected to be induced as participants internally simulate the emotional properties or contents of stimuli.

Furthermore, the existing behavioral research on the emotion word type in bilingualism was mainly conducted among Spanish-English bilinguals (e.g., see a series of studies conducted by Kazanas and Altarriba). However, emotions may be conceptualized divergently in different languages (Bromberek-Dyzman et al., 2021; Zhou et al., 2022). For instance, Zhou et al. (2022) pointed out that Chinese emotion words are embodied more interoceptive, while English emotion words are embodied more autonomic. This divergence may lead to Chinese speakers being more reflective and English speakers more proactive in emotional linguistic expressions. Murata et al. (2013) also found that Westerners are inclined to directly express what they feel as they value high-arousal emotions (emotional expression), whereas Asian people are culturally and historically trained to value low-arousal emotions (emotional control). Given these findings, the present study included the logographic L1 (Chinese) and alphabetic L2 (English) as the represented languages to investigate whether there are differences in processing L1 and L2 emotion words that directly name or indirectly evoke affective states among Chinese-English bilinguals.

Based on prior studies, we hypothesized (1) embodiment for both types of emotion words in L1 and L2, except for L2 emotion words with negative valence (Sheikh and Titone, 2016); (2) a processing advantage (faster RTs and higher ACCs) for words in L1 rather than in L2 (Chen et al., 2015), for words with positive valence rather than with negative valence, for emotion-label words rather than emotion-laden words in both L1 and L2, possibly with a more robust emotion word type effect in participants' dominant language (Chinese) than their non-dominant language (English) (Kazanas and Altarriba, 2016a); (3) the modulation of valence and language on the two categories of emotion word processing with faster RTs and/or higher ACCs for positive emotion-label words compared to negative emotion-laden words in L1 and L2.

## 2. Methodology

### 2.1. Participants

Fifty-two postgraduate and doctoral students were recruited in this experiment (17 males, mean age: 27.69, SD = 3.55), with Chinese as their L1 and English as their L2. According to their self-reports, all participants were born and live in China. They began learning English as their L2 at the mean age of 9.87 years old and had an average of 17.83 years of English acquisition, suggesting that they are late bilinguals (Pavlenko, 2012). In addition, all participants were right-handed and had normal or corrected-to-normal vision without neurobiological or psychiatric disorders. Prior to the experiment, all participants were required to complete an English proficiency test (especially the lexical knowledge) named LexTALE[1] (mean score = 67.33, SD = 11.09). One participant (No.22) was excluded due to data collection errors, and the other seven participants were also excluded due to low accuracy (< 70%). The final sample included 44 participants (14 males, mean age, 27.69, SD = 3.78). Their mean age of starting L2 learning was 9.8 years old and the average acquisition time for L2 was 17.89 years. The result of their LexTALE was 68.28 (SD = 11.5).

### 2.2. Materials

In bilingual research on word processing, although adopting translation equivalents is a common practice (i.e., Kazanas and Altarriba, 2016a), we compiled two separate sets of stimuli of each language since participants may show unconscious and nonselective access to words in L1 when they are undergoing a task exclusively in L2 (Wu and Thierry, 2012; see also one behavioral study: Bromberek-Dyzman et al., 2021). In this way, uncontrolled lexico-semantic priming could be avoided.

Given that there are no published normative studies on emotion word type, stimuli in both languages in this study were obtained through a yes/no voting method employed in prior studies (Wang et al., 2019; Liu et al., 2022a,b). In terms of English stimuli, 296 English adjectives whose valence ratings were below 3.5, ranged from 4.0 to 5.0 or above 5.5 on a 9-point Likert scale (1 = very unpleasant, 9 = very pleasant) were selected from an English affective norm database (Warriner et al., 2013) to form a word pool. Then, 20 participants were recruited to classify these selected words according to the definitions of emotion-label, emotion-laden and neutral words. In light of the standard that at least about 80% of participants voted for a specific word type, 83 emotion-label words, 82 emotion-laden words, and 75 neutral words were obtained. Secondly, we recruited three groups of 20 participants to evaluate the familiarity, concreteness, and valence, respectively, and a group of 21 participants to evaluate the arousal of

1 https://www.lextale.com/

these 240 words selected from the first step on a 7-point Likert scale (7 being very familiar, very abstract, very pleasant, very excited, respectively). All invited raters did not overlap with the samples of the experiment.

With respect to Chinese experimental stimuli, we adhered to the criteria used to select English materials. Firstly, a word pool of 408 words mostly taken from SUBTLEXCH (Cai and Brysbaert, 2010) and partly from prior studies on emotion word type (Zhang et al., 2017; Wang et al., 2019) was created. Then, 20 participants were invited to classify these 408 Chinese words into emotion-label, emotion-laden and neutral words according to their definitions, from which we obtained 101 emotion-label, 94 emotion-laden, and 81 neutral words. Next, we recruited four groups of 20 participants to evaluate these 276 words based on their familiarity, concreteness, valence and arousal, respectively, on the same 7-point Likert scale. All raters did not participate in the experiment.

Finally, 180 adjectives were selected, including 60 emotion-label words (30 positives, 30 negatives), 60 emotion-laden words (30 positives, 30 negatives), and 60 neutral words in Chinese and English. Five groups of words were matched on length/strokes, familiarity, and concreteness in each language ($ps > 0.1$). In both Chinese and English, valence ratings significantly decreased from positive words to neutral words to negative words ($ps < 0.001$). However, in each language, valence for emotion-label and emotion-laden words in each category did not differ ($ps > 0.15$). For the arousal rating of Chinese and English words, four groups of emotion words with different valence were rated significantly higher than neutral words ($ps < 0.001$). Meanwhile, there were no significant differences among them in each language ($ps > 0.1$) [see Table 1 on the Chinese and Table 2 on the English stimulus attributes, respectively].

TABLE 1 Means (M) and standard deviation (SD) for Chinese emotion-label, emotion-laden, and neutral words.

| | Positive words | | Negative words | | Neutral words |
|---|---|---|---|---|---|
| | Label | Laden | Label | Laden | |
| Valence | 5.7 (1.12) | 5.8 (1.04) | 2.4 (0.96) | 2.3 (1.14) | 4.2 (0.76) |
| Familiarity | 6.5 (1.16) | 6.5 (1.17) | 6.5 (1.08) | 6.3 (1.34) | 6.5 (1.05) |
| Arousal | 5.6 (1.21) | 5.4 (1.11) | 5.6 (1.04) | 5.5 (1.15) | 3.03 (1.61) |
| Concreteness | 4.3 (1.27) | 4.4 (1.60) | 4.2 (1.31) | 4.2 (1.55) | 4.2 (1.95) |
| Length | 17.6 (4.40) | 18.3 (4.73) | 17.6 (3.24) | 17.7 (3.49) | 17.7 (3.76) |

TABLE 2 Means (*M*) and standard deviation (SD) for English emotion-label, emotion-laden, and neutral words.

| | Positive words | | Negative words | | Neutral words |
|---|---|---|---|---|---|
| | Label | Laden | Label | Laden | |
| Valence | 5.5 (1.17) | 5.5 (1.16) | 2.6 (1.28) | 2.5 (1.27) | 4.1 (0.78) |
| Familiarity | 6.6 (0.96) | 6.7 (0.71) | 6.6 (0.89) | 6.6 (0.94) | 6.6 (0.83) |
| Arousal | 5.3 (1.26) | 5.2 (1.24) | 5.4 (1.21) | 5.2 (1.31) | 3.1 (1.52) |
| Concreteness | 5.2 (0.98) | 5.2 (1.18) | 5.2 (0.95) | 5.1 (1.08) | 5.2 (1.39) |
| Length | 7.5 (2.00) | 7.7 (1.54) | 7.5 (1.93) | 7.5 (2.22) | 7.5 (1.57) |

## 2.3. Procedure

Participants were tested in a quiet and dimly illuminated room. Experimental stimuli were presented in white on a gray background employing the psychological software PsychoPy (Peirce et al., 2019). This experiment consisted of two language blocks, Chinese and English, presented in random order. Chinese words were presented in Song font, size 24, and English words in Times New Roman font, size 24. In each language block, three unrepeated experiment blocks containing 60 trials (10 words for each emotion word category and 20 neutral words) were presented fully randomized. Prior to the experiment, there was a practice session with 24 trials (12 words in Chinese and 12 words in English) to familiarize participants with the procedure. Each trial started with a fixation "+" in white lasting 250 ms, followed by a blank screen varying between 300 and 500 ms. Subsequently, the stimuli word presented for a maximum duration of 3,000 ms at the center of the screen and would disappear immediately after a response was given. In this experiment, participants were instructed to judge whether a given word was positive, negative, or neutral as quickly and accurately as possible by pressing designated keys counterbalanced across participants. After the experiment, participants were asked to complete valence ratings for the experimental stimuli on a 7-point Likert scale (1 = very unpleasant, 7 = very pleasant).

## 2.4. Statistical modeling

The RTs and ACCs were analyzed by Linear Mixed Effect Models (LMEMs) (Baayen et al., 2008) and Generalized LMEMs (Lo and Andrews, 2015) respectively in R (Version 4.2.1; R Core Team, 2022), using the *lmer4* package (Bates et al., 2015). A box-cox power transformation of response latency (Osborne, 2010) was carried out since such transformation showed better performance in promoting the normality of the errors than log-transformed RTs and raw RTs, which was dependent on the residual sum of squares of our basic model. Participants and items were treated as random intercepts, allowing us to estimate how much variability in the random group factors of participants and items. Five groups of words (positive emotion-label words, positive emotion-laden words, negative emotion-label words, negative emotion-laden words, and neutral words) were treated as fixed effects. We adopted *hypr* package (Rabe et al., 2020) to design a repeated contrast coding to compare each type of emotion stimuli to neutral ones, and the same model was applied in Chinese and English, respectively. Given that random factors are the sources of stochastic variability (Barr et al., 2013), the 'maximal model' included all relevant random structures. Following the suggestions of Barr et al. (2013), we first removed the correlations among the random factors and then interactions when the full model did not reliably converge. To make sure the estimation did not end prematurely, all final models successfully converged after a restart with the appropriate choice of optimizers (using *lergotrile*). The resulting models were compared to the model with maximal random structure using the chi-square difference test and Akaike's Information Criterion, for which a lower value indicates better model fit (Kline, 2011). Notably, for the model trimming procedure, the final models and their corresponding maximal models did not diverge in their results, suggesting that a parsimonious and interpretable model could provide the best fit to the data.

A three-step approach was applied to code fixed terms due to the unbalanced nature of the current experiment. In Model 1, repeated contrasts were specified to compare and collapse the four groups of emotion words to the neutral words within each language. This allowed us to investigate the cost of emotion-label or emotion-laden words with positive or negative valence, examining the facilitation or interference elicited by emotion word type or valence. Model 2 excluded the neutral condition and sum-contrast coding was defined, in a way that the intercept of the model represented the grand mean value of the fixed factors (Schad et al., 2020). This model enabled us to directly examine the main effect of and interaction between emotion word type (emotion-label vs. emotion-laden), valence (positive vs. negative), and language (Chinese vs. English). The *emmeans* package (Lenth, 2017) was used to conduct post-hoc analysis in this model and first determine the estimated marginal means (EMMs) and their standard errors, and then make the pair-wise comparisons. To prevent *emmeans* from calculating the df for the EMMs, we applied asymptotic dfs (i.e., $z$ values and tests). In Model 3, we split the data into a corresponding subset of English words only and included L2 proficiency as a fixed factor. Then, we computed the statistical models again for valence, emotion word type and proficiency to detect the modulation effect of L2 proficiency on emotion word processing.

## 3. Results

Of the overall 18,720 data points, data from one participant (Subject No.22) were eliminated due to his/her failure to activate the response key. After applying a threshold of <70% correct response as exclusion criteria, data from the other seven participants, as well as a total of nine items presented either in Chinese ("紧急" means "urgent," "明确" means "clear," "准时" means "punctual," "冷静" means "calm") or in English ("concerned," "contented," "moved," "sympathetic," "thrilled") blocks were excluded, leaving a total of 44 participants and 351 stimuli for further accuracy analysis (15,307 trials). For the analysis of response latency, wrong (overall, $n=952$, 6% of trials) and missing (overall, $n=181$, 0.1%) responses were coded as errors and were discarded. We applied model criticism (see Baayen, 2008; Baayen and Milin, 2010) to remove data points ($n=477$, 3%) that deviated more than a range of −2.5 to 2.5 standardized residual errors. The models were afterward re-fitted on the truncated dataset with a total of 13,878 trials. The average RTs and ACCs across conditions are displayed in Table 3.

Firstly, to investigate the emotion effects elicited by emotion words, the comparison between neutral words and the four groups of emotion words reflected in RTs and ACCs in both L1 and L2 was made (see Table 4). For RTs, the results revealed that in L1, compared to neutral words, both types of emotion words were responded to significantly faster. In L2, while negative emotion-label words, positive emotion-label words, and positive emotion-laden words showed significant higher processing speed than neutral words, there was no difference between negative emotion-laden words and neutral words. For ACCs, it showed that L1 negative emotion-label words, negative emotion-laden words, and positive emotion-label words were responded to more accurately as compared to neutral words. However, the difference between positive emotion-laden and neutral words in L1 did not reach significance. In L2, negative emotion-label words, positive emotion-label words, and positive emotion-laden words had similar ACCs to neutral words. Nevertheless, it was found that more errors were made with negative emotion-laden words than neutral words.

TABLE 3 Mean RTs (ms) and ACCs (%) of five groups of words in L1 (Chinese) and L2 (English).

| | RTs (response times) | | ACCs (accuracy rates) | |
|---|---|---|---|---|
| | Chinese | English | Chinese | English |
| Positive emotion-label | 815 (264) | 1,029 (346) | 97.3 (16.4) | 92.5 (26.4) |
| Positive emotion-laden | 849 (269) | 1,053 (316) | 94.7 (22.3) | 93.5 (24.7) |
| Negative emotion-label | 886 (286) | 1,098 (333) | 96.6 (18.2) | 92.6 (26.1) |
| Negative emotion-laden | 895 (290) | 1,158 (353) | 96.4 (18.7) | 88.5 (31.9) |
| Neutral | 971 (309) | 1,187 (370) | 92.4 (26.6) | 94.2 (23.3) |

Secondly, the RTs and ACCs of the four groups of emotion words in L1 and L2 were compared (see Table 5). For RTs, the main effects of language, valence, and emotion word type were observed. Specifically, Chinese-English bilinguals responded faster to Chinese words relative to English words, to positive words relative to negative words, and to emotion-label words relative to emotion-laden words. No interactions between emotion word type, valence and language were observed in reaction times.

ACCs revealed a main effect of language, with Chinese words being responded to more accurately than English words. Moreover, the emotion word type × valence × language interaction was significant (see Figure 1). *Post hoc* analysis showed (1) in English, Chinese-English bilinguals responded significantly more accurately to positive emotion-laden words than negative emotion-laden words ($\beta=0.7415$, SE $=0.320$, $z=2.316$, $p=0.0206$), as well as marginally more accurately to negative emotion-label words than negative emotion-laden words ($\beta=0.594$, SE $=0.312$, $z=2.316$, $p=0.0570$). No such differences were found in Chinese. (2) Chinese positive emotion-label words ($\beta=1.147$, SE $=0.397$, $z=2.887$, $p=0.0039$), negative emotion-label words ($\beta=0.774$, SE $=0.363$, $z=2.131$, $p=0.0331$), and negative emotion-laden words were responded more accurately than those in English ($\beta=1.430$, SE $=0.362$, $z=3.956$, $p=0.0001$). However, there was no difference between positive emotion-laden words in Chinese and English ($\beta=0.340$, SE $=0.363$, $z=0.936$, $p=0.3492$).

In terms of the role of L2 proficiency, the effect of L2 proficiency was significant in English word processing ($\beta=-0.0012$, SE $=0.00039$, $t=-3$, $p=0.0046$), suggesting the higher the English proficiency, the faster the reaction times. However, it revealed null effects of L2 proficiency on the language effect, valence effect, emotion word type effect, and their interactions ($ps>0.66$) observed in L2.

The correlation coefficient between two variables is expected to have a minimum value of 0.2 to be practically significant. In the present study, the subjective valence ratings for all the experimental stimuli after the experiment showed a positive correlation with the established reference values of valence (Chinese: $r=0.56$, CrI [0.36, 0.74]; English: $r=0.44$, CrI [0.21, 0.64]).

TABLE 4 Statistical analysis of the RTs and ACCs of four groups of emotion words compared to neutral words in L1 (Chinese) and L2 (English).

| | | RTs (response times) | | | | ACCs (accuracy rates) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | *β* | SE | *t* | *p* | *β* | SE | *z* | *p* |
| Chinese | Positive emotion-label vs. Neutral | −0.005 | 0.00052 | −9.6 | <0.0001*** | 1.1 | 0.31 | 3.7 | 0.00025*** |
| | Positive emotion- laden vs. Neutral | −0.0037 | 0.00052 | −7.2 | <0.0001*** | 0.49 | 0.28 | 1.8 | 0.08 |
| | Negative emotion-label vs. Neutral | −0.0027 | 0.00052 | −5.2 | <0.0001*** | 0.79 | 0.29 | 2.7 | 0.0064** |
| | Negative emotion-laden vs. Neutral | −0.0024 | 0.00052 | −4.5 | <0.0001*** | 0.85 | 0.3 | 2.9 | 0.0043** |
| English | Positive emotion-label vs. Neutral | −0.0038 | 0.00082 | −4.7 | <0.0001*** | −0.25 | 0.28 | −0.88 | 0.38 |
| | Positive emotion-laden vs. Neutral | −0.0029 | 0.00077 | −3.8 | 0.00019*** | −0.12 | 0.27 | −0.47 | 0.64 |
| | Negative emotion-label vs. Neutral | −0.0018 | 0.00077 | −2.3 | 0.024* | −0.24 | 0.26 | −0.91 | 0.36 |
| | Negative emotion-laden vs. Neutral | −0.00053 | 0.00077 | −0.69 | 0.49 | −0.86 | 0.25 | −3.4 | 0.00074*** |

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

TABLE 5 Statistical analysis of the main effects of and interaction between valence, emotion word type and language reflected in RTs and/or ACCs among the four groups of emotion words in L1 (Chinese) and L2 (English).

| | RTs (response times) | | | | ACCs (accuracy rates) | | | |
|---|---|---|---|---|---|---|---|---|
| | *β* | SE | *t* | *p* | *β* | SE | *z* | *p* |
| Valence | 0.001 | 0.00021 | 4.9 | <0.0001*** | −0.18 | 0.19 | −0.99 | 0.32 |
| Emotion word type | −0.00048 | 0.0002 | −2.3 | 0.02* | −0.26 | 0.18 | −1.4 | 0.15 |
| language | −0.0033 | 0.00028 | −12 | <0.0001*** | −0.92 | 0.22 | −4.1 | <0.0001*** |
| Valence × Emotion word type | 8.7e-05 | 0.00019 | 0.44 | 0.66 | −0.022 | 0.34 | −0.065 | 0.95 |
| Valence × Language | −9.4e-05 | 0.00019 | −0.48 | 0.63 | −0.36 | 0.35 | −1 | 0.3 |
| Emotion word type × Language | 6.8e-05 | 0.00019 | 0.35 | 0.73 | 0.0076 | 0.35 | 0.22 | 0.83 |
| Valence × Emotion word type × Language | 0.00016 | 0.00019 | 0.84 | 0.4 | −1.5 | 0.68 | −2.2 | 0.03* |

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

## 4. Discussion

In the present study, we employed an ECT to examine whether emotion adjectives that straightforwardly label affective states (emotion-label words) and trigger emotions (emotion-laden words) are embodied in Chinese-English speakers, with Chinese as their dominant (L1) and English as the non-dominant language (L2). In the following parts, we discussed the embodiment of these two kinds of emotion words from two aspects, the emotion effect and the emotion word type effect in both L1 and L2, to further clarify how the two sorts of emotion words are embodied and processed differently from neutral stimuli and from each other.

### 4.1. The emotion effect of emotion-label and emotion-laden words in L1 and L2

As we mentioned in the Introduction, the emotion effect refers to the processing facilitation for emotion words relative to neutral words. In the present study, the emotion effect was observed for these two types of emotion words in L1. To be specific, facilitation was found for emotional stimuli, regardless of their emotion word type and valence, in comparison to neutral ones, corresponding to faster RTs. This disadvantage for neutral words relative to emotion words observed in past studies (e.g., Kousta et al., 2009; Goh et al., 2016) was replicated here, indicating that L1 emotion words, either explicitly label affective states or evoke emotions through words' connotations could activate emotions which speeds up the clarification. As for the ACCs, some researchers argued that the analysis of accuracy was inappropriate in some cognitive tasks in which the emotional dimension is task-relevant, such as the ECT and affective decision task (Ferré et al., 2018; Liao and Ni, 2021). The reason lies in the fact that valence categorization may involve subjective experience, leading participants to classify some words in a category that differs from the referenced one (González-Villar et al., 2014). However, such responses should not be regarded as categorization errors. In an attempt to rule out this confounding possibility, participants in the present study were required to rate the valence of stimuli after the experiment, and the result showed a positive correlation between the offline rating and the established reference values of valence. Therefore, ACCs were analyzed in this ECT task and responses that did not match the reference valence values were considered incorrect. Finally, the analysis of accuracy revealed that the emotion effect found in RTs was reflected in ACCs except for positive emotion-laden words. That is, while positively valenced emotion-label words and both types of negative emotion words were categorized more accurately than neutral words in L1, no significant difference was observed in ACCs between positive emotion-laden and neutral words. A possible interpretation might be that emotion-laden words have indirect semantic associations with emotions (Knickerbocker and Altarriba, 2013), as

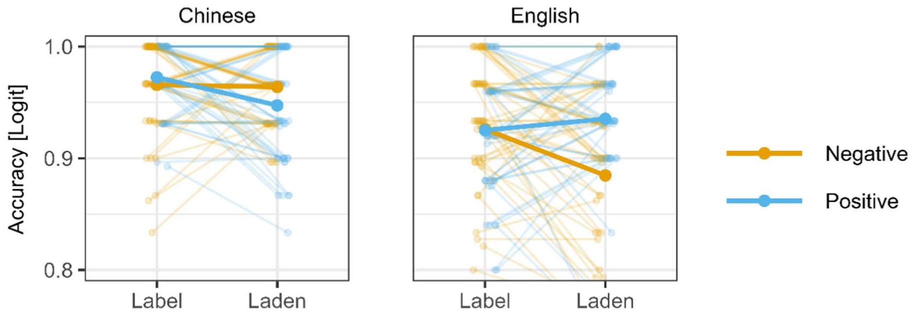


FIGURE 1
Triple interaction between valence (in color), language (L1 on the left, L2 right), and emotion word type (emotion-label and emotion-laden; on the x axis) reflected in ACCs (on the y axis). Single-subject indices (thin lines) are overlayed by group averages (thick lines).

one emotion-laden word corresponds to multiple connections with the general lexicon. For example, the emotion-laden adjective "successful" may evoke emotions like "happy" or "excited." In this sense, we think that such ambiguous associations with emotion concepts increase the difficulty in categorizing the valence of emotion-laden words. Furthermore, the positive effect may broaden the scope of attention, impair cognitive performance and widen associations with words resulting in more diffuse semantic activation (Phillips et al., 2002). This is exactly the case for the performance of healthy participants in this study. Therefore, no emotion effect of positive emotion-laden words was observed in ACCs.

In English, results from the RTs indicated that the emotion effect emerged for emotion words except for negative emotion-laden words. Specifically, negative emotion-label words and both types of positive emotion words were processed with significant shorter RTs, whereas no significant difference in processing negative emotion-laden words and neutral words was observed (negative emotion-laden words did not differ from neutral words). This finding suggested that negative emotion-laden words in English, the non-dominant language, activated similar emotion with neutral words. One possible reason for this finding is that emotion-laden words bear no direct connection to their affective meanings, and thus are not well grounded in emotional experiences, resulting in less or weak emotion activation in L2, the less emotionally embodied language (Caldwell-Harris, 2014). Additionally, emotion-laden words may be particularly susceptible to the negative valence in L2, leading to narrow and enhanced selective attention effect (Finucane, 2011), which in turn slows down responses. This finding found support in one previous ERPs study (Zhang et al., 2019a) which investigated how L2 emotion-label and emotion-laden words affected conflict processing in a flanker task. It was found that compared to the incongruent condition, enhanced left frontal N200 was elicited by merely L2 negative emotion-label words in the congruent condition. Nevertheless, negative emotion-laden and neutral stimuli did not shape N200. Taken together, the finding in this study allowed us to speculate that L2 negative emotion-laden words might be disembodied.

This finding in L2 was also reflected in the accuracy data, showing that negative emotion-laden words had the lowest ACCs among the four types of emotion words and neutral words. To be specific, both kinds of positive emotion words and negative emotion-label ones were classified as accurately as neutral words, whereas less accurate responses were made to negative emotion-laden words than neutral words. A possible reason for this finding was that the L2 experimental stimuli used in this study were quite familiar to participants, contributing to the ceiling effect. However, it needs to be aware that the lower ACCs of L2 negative emotion-laden words, together with their longer RTs, jointly indicate that they are disembodied. Prior studies, which unsystematically mixed the two sorts of emotion words, have controversial results about whether emotion words in L2 are disembodied (Kühne and Gianelli, 2019). Our results showed that the embodiment of L2 emotion words is modulated by the emotion word type (C. Wu and Zhang, 2019), thereby shedding light on the extant conflicting results concerning the embodiment in L2, at least for negative emotion-laden words.

## 4.2. The emotion word type effect on emotion word processing in L1 and L2

In this section, we discuss the effect of emotion word type effect, that is, how emotion-label and emotion-laden words are processed differently in both L1 and L2, as well as the modulation of valence on this effect. The results revealed several main effects. Firstly, a main effect of language demonstrated that participants showed slower and less accurate responses to emotion words in English compared to Chinese, suggesting that they were more proficient in L1. This finding is consistent with the language profile of participants who live in their L1 environment and are dominant in their L1 (Chen et al., 2015). As far as the role of L2 language proficiency is concerned, our finding showed that only RTs to L2 words were modulated by English proficiency, with faster responses observed among participants with higher levels of English proficiency. This finding is in line with the idea that increasing L2 proficiency strengthens the connection between L2 words' forms and their conceptual meanings (Kroll et al., 2010). Therefore, in the present study, late Chinese-English bilinguals who acquired L2 *via* instructional settings (e.g., school or class) responded more quickly to English words as their English proficiency improved.

In addition, it was found that Chinese–English bilinguals were slower in responding to negatively valenced words when compared to positively valenced words in both L1 and L2. This finding is consistent with some relevant research on the disassociation between emotion-label and emotion-laden words. For example, the behavioral data from a recent ERPs study (Liu et al., 2022b) demonstrated that negative words produced longer reaction times than positive words in both the ECT and emotional Stroop tasks. Similar effects were observed in a priming LDT (Kazanas and Altarriba, 2016a), which confirmed that emotion words with positive information enhance word processing across languages (Spanish and English). This superiority effect for positive words with faster performance is in line with the positivity bias (Hofmann et al., 2009). Two possible explanations have been proposed for this phenomenon. On the one hand, the density hypothesis suggests that positive words are more densely clustered and connected in memory than negative words, which results in the processing advantage for positive words (Unkelbach et al., 2008). On the other hand, from a survival perspective, negative stimuli can lead to a cognitive "freezing" when individuals are presented with negative or threatening information (Algom et al., 2004). As mentioned in the Introduction part, so far, the valence effect is still a controversial matter (Kauschke et al., 2019). Nevertheless, our study, together with other emotion word type research (e.g., Kazanas and Altarriba, 2016a; Bromberek-Dyzman et al., 2021), confirms the presence of a positivity bias in emotion word processing even after we systematically categorized emotion-label and emotion-laden words.

The most relevant finding of this experiment is the observation of the processing facilitation for emotion-label over emotion-laden words in both L1 and L2. Consistent with our hypothesis, Chinese-English bilinguals in this study tended to take a shorter time to respond to emotion-label words, regardless of language operation, even after controlling the concreteness and the word class of stimuli. This finding stands in contrast to a study by Bromberek-Dyzman et al. (2021), as well as the behavioral data reported in a previous ERPs study (Zhang et al., 2019b) which reported a processing advantage for emotion-laden words relative to emotion-label words, with higher processing speed and accuracy. However, our finding corroborated a series of behavioral studies (Knickerbocker and Altarriba, 2013; Kazanas and Altarriba, 2015, 2016a,b), as well as the behavioral data in a recent ERPs study (Liu et al., 2022a) which reported facilitated processing of emotion-label rather than emotion-laden words.

This finding showed that although both emotion-label and emotion-laden words eventually activate emotions in the ECT, these two types of emotion words are processed differently, providing evidence for the emotion word type effect. Such an effect could be explained from several possible explanations. One possible account is the "mediated account" (Altarriba and Basnight-Brown, 2011; Wu et al., 2021a) which suggests that emotion-laden words could be viewed as a kind of "mediated" affective concepts. Thus, their emotional meanings could be accessed only through a "mediated event" that links the conceptual meanings and associated affective experiences. On the contrary, emotion-label words explicitly label emotions, making it easier to automatically or unconsciously approach their affective components. Another possible explanation is the emotion duality model, which may shed light on the distinction between the two kinds of emotion words. Accordingly, emotions activated by emotion-label words are more automatic and biologically rooted, while emotions induced by emotion-laden words are thought to be based on a reflective system that needs more cognitive effort (Imbir et al., 2019; Liu et al., 2022b). Furthermore, from an embodied cognition perspective, emotion-label words are more strongly shaped in socialization and emotional interaction as they directly denote a specific emotional state (e.g., feeling happy or sad) (Liu et al., 2022a). It has also been shown that emotion-label words are acquired at an earlier age and are more attached to life experiences than emotion-laden words (Basnight-Brown and Altarriba, 2018). Therefore, it is conceivable that RTs to emotion-laden words were longer than those to emotion-label words. Another intriguing finding was the absence of an interaction between valence and emotion word type in RTs. However, a triple interaction between the emotion word type, valence and language was observed in ACCs. Specifically, Chinese-English bilinguals responded less accurately to negative emotion-laden words as compared to positive emotion-laden words and negative emotion-label words in English only. Given the participants in this study are native Chinese speakers, it is plausible to infer that they are able to ground emotion words in their emotional experiences so that equally fewer errors were made in categorizing the valence of stimuli in L1. However, L2 negative emotion-laden words are probably disembodied, resulting in more categorization errors relative to both L2 positive emotion-laden words and negative emotion-label words. Sheikh and Titone (2016) found in a previous study that the emotional embodiment might be absent for negative words but not positive words in L2. In the present study, we extended their findings by illustrating that it is L2 negative emotion-laden words but not L2 negative emotion-label words that are likely to be at risk of emotional disembodiment. It is also of importance to note that emotion-label words and negative emotion-laden words in Chinese were responded to more accurately than in English, while no difference was found in processing positive emotion-laden words between Chinese and English. The poor performance for positive emotion-laden words relative to the other three groups of words in L1 lent support to the claim that the processing difference between these two types of emotion words may be more robust in L1 positive words than in negative ones (Kazanas and Altarriba, 2015, 2016a; Wang et al., 2019), which still needs future studies to verify it.

## 4.3. Limitation and future direction

In this study, while the stimulus attributes were matched in each language, they did not match between L1 and L2. However, this does not impact our main findings, as the emotion effect and the effects of valence and emotion word type were observed across languages. Future research may benefit from strict control on stimuli between languages to make the results more comparable. In addition, it is urgent to conduct normative studies that distinguish emotion-label from emotion-laden words in Chinese or other languages. To our knowledge, currently, there is only one normative study (Pérez-Sánchez et al., 2021) that provides a set of 1,286 emotion words in the Spanish language using the prototypical approach. Accordingly, the higher the prototypicality of an emotion word is, the more likely it is to be defined as an emotion-label word. Furthermore, the direct comparison of emotion word type effect in L1 and L2 calls for future research using different neuroimaging techniques, such as the electroencephalogram and functional magnetic resonance imaging. Lastly, it has been pointed out that languages conceptualize emotions divergently (Bromberek-Dyzman et al., 2021), and culture is involved in the way individuals store and process emotional information

(Basnight-Brown and Altarriba, 2018). Therefore, cross-cultural and cross-linguistic studies are needed to investigate how these two types of emotion words, directly or indirectly related to emotions are processed among individuals with different cultural and linguistic backgrounds.

## 5. Conclusion

In the present study, we aimed to explore the extent to which emotion-label and emotion-laden words are embodied in L1 and L2 among Chinese-English bilinguals. Our results showed that while the emotion effect was absent for L2 negative emotion-laden words, the other types of emotion words, either explicitly refer to emotions or evoke emotional states indirectly, have a processing advantage (decreased RTs and/or higher categorization ACCs) over neutral words in both L1 and L2. Of particular importance, processing facilitation for emotion-label rather than emotion-laden words was found in both languages. In addition, it seems that negative emotion-laden words are responded to less accurately than positive emotion-laden words, as well as negative emotion-label words in L2 only. Altogether, the results indicated the disembodiment of L2 negative emotion-laden words and evidenced the disassociation between the two types of emotion words across languages. These findings provide new insights into the embodiment of emotion words in bilinguals and highlight the importance of considering the role of emotion word type in the context of emotion word research.

## Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

## Ethics statement

The studies involving human participants were reviewed and approved by the Research Ethics Committee of Dalian University of Technology. The patients/participants provided their written informed consent to participate in this study.

## Author contributions

DT, HW, and TK contributed to the experimental design and data collection. YF and DT analyzed the data. DT wrote the manuscript. HW and TK offered suggestions on the writing of the manuscript. DT, YF, HW, BL, AZ, and TK revised the manuscript. All authors contributed to the article and approved the submitted version.

## Funding

This work was supported by the scholarship from China Scholarship Council (No. 201906060171).

## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

## Publisher's note



## Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2023.1143064/full#supplementary-material

## References

Algom, D., Chajut, E., and Lev, S. (2004). A rational look at the emotional stroop phenomenon: a generic slowdown, not a stroop effect. *J. Exp. Psychol. Gen.* 133, 323–338. doi: 10.1037/0096-3445.133.3.323

Altarriba, J., and Basnight-Brown, D. M. (2011). The representation of emotion vs. emotion-laden words in english and spanish in the affective simon task. *Int. J. Biling.* 15, 310–328. doi: 10.1177/1367006910379261

Baayen, R. (2008). *Analyzing linguistic data: A practical introduction to statistics using R.* Cambridge: Cambridge University Press.

Baayen, R. H., Davidson, D. J., and Bates, D. M. (2008). Mixed-effects modeling with crossed random effects for subjects and items. *J. Mem. Lang.* 59, 390–412. doi: 10.1016/j.jml.2007.12.005

Baayen, R. H., and Milin, P. (2010). Analyzing reaction times. *Int. J. Psychol. Res.* 3, 12–28. doi: 10.21500/20112084.807

Barr, D. J., Levy, R., Scheepers, C., and Tily, H. J. (2013). Random effects structure for confirmatory hypothesis testing: keep it maximal. *J. Mem. Lang.* 68, 255–278. doi: 10.1016/j.jml.2012.11.001

Basnight-Brown, D. M., and Altarriba, J. (2018). The influence of emotion and culture on language representation and processing. *Intell. Syst. Ref. Libr.* 134, 415–432. doi: 10.1007/978-3-319-67024-9_19

Bates, D., Kliegl, R., Vasishth, S., and Baayen, H. (2015). Parsimonious mixed models. Available at: http://arxiv.org/abs/1506.04967

Baumeister, J. C., Foroni, F., Conrad, M., Rumiati, R. I., and Winkielman, P. (2017). Embodiment and emotional memory in first vs. second language. *Front. Psychol.* 8:394. doi: 10.3389/fpsyg.2017.00394

Bromberek-Dyzman, K., Jończyk, R., Vasileanu, M., Niculescu-Gorpin, A. G., and Bąk, H. (2021). Cross-linguistic differences affect emotion and emotion-laden word processing: evidence from Polish-English and Romanian-English bilinguals. *Int. J. Biling.* 25, 1161–1182. doi: 10.1177/1367006920987306

Cai, Q., and Brysbaert, M. (2010). SUBTLEX-CH: Chinese word and character frequencies based on film subtitles. *PLoS One* 5:e10729. doi: 10.1371/journal.pone.0010729

Caldwell-Harris, C. L. (2014). Emotionality differences between a native and foreign language: theoretical implications. *Front. Psychol.* 5:1055. doi: 10.3389/fpsyg.2014.01055

Charniak, E. (1978). On the use of framed knowledge in language comprehension. *Artif. Intell.* 11, 225–265. doi: 10.1016/0004-3702(78)90002-4

Chen, P., Lin, J., Chen, B., Lu, C., and Guo, T. (2015). Processing emotional words in two languages with one brain: ERP and fMRI evidence from Chinese-English bilinguals. *Cortex* 71, 34–48. doi: 10.1016/j.cortex.2015.06.002

Citron, F. M. M. (2012). Neural correlates of written emotion word processing: a review of recent electrophysiological and hemodynamic neuroimaging studies. *Brain Lang.* 122, 211–226. doi: 10.1016/j.bandl.2011.12.007

Conrad, M., Recio, G., and Jacobs, A. M. (2011). The time course of emotion effects in first and second language processing: a cross cultural ERP study with German-Spanish bilinguals. *Front. Psychol.* 2:351. doi: 10.3389/fpsyg.2011.00351

Crossfield, E., and Damian, M. F. (2021). The role of valence in word processing: evidence from lexical decision and emotional Stroop tasks. *Acta Psychol.* 218:103359. doi: 10.1016/j.actpsy.2021.103359

Degner, J., Doycheva, C., and Wentura, D. (2012). It matters how much you talk: on the automaticity of affective connotations of first and second language words. *Bilingualism* 15, 181–189. doi: 10.1017/S1366728911000095

Dijksterhuis, A., and Aarts, H. (2003). On wildebeests and humans: The preferential detection of negative stimuli. *Psychol Sci* 14, 14–18. doi: 10.1111/1467-9280.t01-1-01412

El-Dakhs, D. A. S., and Altarriba, J. (2019). How do emotion word type and valence influence language processing? The case of Arabic–English bilinguals. *J. Psycholinguist. Res.* 48, 1063–1085. doi: 10.1007/s10936-019-09647-w

Ferré, P., Anglada-Tort, M., and Guasch, M. (2018). Processing of emotional words in bilinguals: testing the effects of word concreteness, task type and language status. *Second. Lang. Res.* 34, 371–394. doi: 10.1177/0267658317744008

Finucane, A. M. (2011). The effect of fear and anger on selective attention. *Emotion* 11, 970–974. doi: 10.1037/a0022574

Fischer, M. H., and Zwaan, R. A. (2008). Embodied language: a review of the role of the motor system in language comprehension. *Q. J. Exp. Psychol.* 61, 825–850. doi: 10.1080/17470210701623605

Fodor, J. A. (1975). *The language of thought*. Cambridge, MA: Harvard University Press.

Goh, W. D., Yap, M. J., Lau, M. C., Ng, M. M. R., and Tan, L. C. (2016). Semantic richness effects in spoken word recognition: a lexical decision and semantic categorization megastudy. *Front. Psychol.* 7:976. doi: 10.3389/fpsyg.2016.00976

González-Villar, A. J., Triñanes, Y., Zurrón, M., and Carrillo-De-La-Peña, M. T. (2014). Brain processing of task-relevant and task-irrelevant emotional words: an ERP study. *Cogn. Affect. Behav. Neurosci.* 14, 939–950. doi: 10.3758/s13415-013-0247-6

Hinojosa, J. A., Moreno, E. M., and Ferré, P. (2020). Affective neurolinguistics: towards a framework for reconciling language and emotion. *Lang. Cogn. Neurosci.* 35, 813–839. doi: 10.1080/23273798.2019.1620957

Hofmann, M. J., Kuchinke, L., Tamm, S., Võ, M. L. H., and Jacobs, A. M. (2009). Affective processing within 1/10th of a second: high arousal is necessary for early facilitative processing of negative but not positive words. *Cogn. Affect. Behav. Neurosci.* 9, 389–397. doi: 10.3758/9.4.389

Horchak, O., Giger, J. C., Cabral, M., and Pochwatko, G. (2014). From demonstration to theory in embodied language comprehension: a review. *Cogn. Syst. Res.* 29–30, 66–85. doi: 10.1016/j.cogsys.2013.09.002

Imbir, K. K., Jurkiewicz, G., Duda-Goławska, J., and Żygierewicz, J. (2019). The role of valence and origin of emotions in emotional categorization task for words. *J. Neurolinguistics* 52:100854. doi: 10.1016/j.jneuroling.2019.100854

Kauschke, C., Bahn, D., Vesker, M., and Schwarzer, G. (2019). The role of emotional valence for the processing of facial and verbal stimuli - positivity or negativity bias? *Front Psychol* 10:1654. doi: 10.3389/fpsyg.2019.01654

Kazanas, S. A., and Altarriba, J. (2015). The automatic activation of emotion and emotion-laden words: evidence from a masked and unmasked priming paradigm. *Am. J. Psychol.* 128, 323–336. doi: 10.5406/amerjpsyc.128.3.0323

Kazanas, S. A., and Altarriba, J. (2016a). Emotion word processing: effects of word type and valence in Spanish–English bilinguals. *J. Psycholinguist. Res.* 45, 395–406. doi: 10.1007/s10936-015-9357-3

Kazanas, S. A., and Altarriba, J. (2016b). Emotion word type and affective valence priming at a long stimulus onset asynchrony. *Lang. Speech* 59, 339–352. doi: 10.1177/0023830915590677

Kline, R. B. (2011). "Convergence of structural equation modeling and multilevel modeling" in *Handbook of methodological innovation*. eds. M. Williams and W. P. Vogt (Thousand Oaks, CA: Sage), 562–589.

Knickerbocker, H., and Altarriba, J. (2013). Differential repetition blindness with emotion and emotion-laden word types. *Vis. Cogn.* 21, 599–627. doi: 10.1080/13506285.2013.815297

Kousta, S. T., Vigliocco, G., Vinson, D. P., Andrews, M., and del Campo, E. (2011). The representation of abstract words: why emotion matters. *J. Exp. Psychol. Gen.* 140, 14–34. doi: 10.1037/a0021446

Kousta, S. T., Vinson, D. P., and Vigliocco, G. (2009). Emotion words, regardless of polarity, have a processing advantage over neutral words. *Cognition* 112, 473–481. doi: 10.1016/j.cognition.2009.06.007

Kroll, J. F., van Hell, J. G., Tokowicz, N., and Green, D. W. (2010). The revised hierarchical model: a critical review and assessment. *Bilingualism* 13, 373–381. doi: 10.1017/S136672891000009X

Kühne, K., and Gianelli, C. (2019). Is embodied cognition bilingual? Current evidence and perspectives of the embodied cognition approach to bilingual language processing. *Front. Psychol.* 10:108. doi: 10.3389/fpsyg.2019.00108

Lenth, R. (2017). Emmeans: Estimated marginal means, aka least-squares means. R 18 Packag. version 1.0. Available at: https://cran.r-project.org/web/packages/emmeans/index.html

Li, W., Xu, Q., Liu, S., Yu, L., Yang, Y., Zhang, L., et al. (2022). Emotion concept in perception of facial expressions: effects of emotion-label words and emotion-laden words. *Neuropsychologia* 174:108345. doi: 10.1016/j.neuropsychologia.2022.108345

Liao, X., and Ni, C. (2021). The effects of emotionality and lexical category on L2 word processing in different tasks: evidence from late Chinese–English bilinguals. *Q. J. Exp. Psychol.* 75, 907–923. doi: 10.1177/17470218211041833

Liu, J., Fan, L., Jiang, J., Li, C., Tian, L., Zhang, X., et al. (2022a). Evidence for dynamic attentional bias toward positive emotion-laden words: a behavioral and electrophysiological study. *Front. Psychol.* 13:966774. doi: 10.3389/fpsyg.2022.966774

Liu, J., Fan, L., Tian, L., Li, C., and Feng, W. (2022b). The neural mechanisms of explicit and implicit processing of Chinese emotion-label and emotion-laden words: evidence from emotional categorisation and emotional Stroop tasks. *Lang. Cognit. Neurosci.* 1–18, 1–18. doi: 10.1080/23273798.2022.2093389

Lo, S., and Andrews, S. (2015). To transform or not to transform: using generalized linear mixed models to analyse reaction time data. *Front. Psychol.* 6:1171. doi: 10.3389/fpsyg.2015.01171

Martin, J. M., and Altarriba, J. (2017). Effects of valence on hemispheric specialization for emotion word processing. *Lang. Speech* 60, 597–613. doi: 10.1177/0023830916686128

Moseley, R., Carota, F., Hauk, O., Mohr, B., and Pulvermüller, F. (2012). A role for the motor system in binding abstract emotional meaning. *Cereb. Cortex* 22, 1634–1647. doi: 10.1093/cercor/bhr238

Murata, A., Moser, J. S., and Kitayama, S. (2013). Culture shapes electrocortical responses during emotion suppression. *Soc. Cogn. Affect. Neurosci.* 8, 595–601. doi: 10.1093/scan/nss036

Nasrallah, M., Carmel, D., and Lavie, N. (2009). Murder, she wrote: enhanced sensitivity to negative word valence. *Emotion* 9, 609–618. doi: 10.1037/a0016305

Osborne, J. (2010). Improving your data transformations: applying the box-cox improving your data transformations: applying the box-cox transformation transformation. *Pract. Assess. Res. Eval.* 15:12. doi: 10.7275/qbpc-gk17

Pavlenko, A. (2008). Emotion and emotion-laden words in the bilingual lexicon. *Bilingualism* 11, 147–164. doi: 10.1017/S1366728908003283

Pavlenko, A. (2012). Affective processing in bilingual speakers: disembodied cognition? *Int. J. Psychol.* 47, 405–428. doi: 10.1080/00207594.2012.743665

Peirce, J., Gray, J. R., Simpson, S., MacAskill, M., Höchenberger, R., Sogo, H., et al. (2019). PsychoPy2: experiments in behavior made easy. *Behav. Res. Methods* 51, 195–203. doi: 10.3758/s13428-018-01193-y

Pérez-Sánchez, M. Á., Stadthagen-Gonzalez, H., Guasch, M., Hinojosa, J. A., Fraga, I., Marín, J., et al. (2021). EmoPro – emotional prototypicality for 1286 Spanish words: relationships with affective and psycholinguistic variables. *Behav. Res. Methods* 53, 1857–1875. doi: 10.3758/s13428-020-01519-9

Phillips, L. H., Bull, R., Adams, E., and Fraser, L. (2002). Positive mood and executive function. Evidence from Stroop and fluency tasks. *Emotion* 2, 12–22. doi: 10.1037/1528-3542.2.1.12

Ponari, M., Rodríguez-Cuadrado, S., Vinson, D., Fox, N., Costa, A., and Vigliocco, G. (2015). Processing advantage for emotional words in bilingual speakers. *Emotion* 15, 644–652. doi: 10.1037/emo0000061

R Core Team. (2022). *R: A language and environment for statistical computing*. Vienna, Austria: R Foundation for Statistical Computing

Rabe, M., Vasishth, S., Hohenstein, S., Kliegl, R., and Schad, D. (2020). Hypr: an R package for hypothesis-driven contrast coding. *J. Open Source Soft.* 5:2134. doi: 10.21105/joss.02134

Schad, D. J., Vasishth, S., Hohenstein, S., and Kliegl, R. (2020). How to capitalize on a priori contrasts in linear (mixed) models: a tutorial. *J. Mem. Lang.* 110:104038. doi: 10.1016/j.jml.2019.104038

Sheikh, N. A., and Titone, D. (2016). The embodiment of emotional words in a second language: an eye-movement study. *Cognit. Emot.* 30, 488–500. doi: 10.1080/02699931.2015.1018144

Unkelbach, C., Fiedler, K., Bayer, M., Stegmüller, M., and Danner, D. (2008). Why positive information is processed faster: the density hypothesis. *J. Pers. Soc. Psychol.* 95, 36–49. doi: 10.1037/0022-3514.95.1.36

Vinson, D., Ponari, M., and Vigliocco, G. (2014). How does emotional content affect lexical processing? *Cognit. Emot.* 28, 737–746. doi: 10.1080/02699931.2013.851068

Wang, X., Shangguan, C., and Lu, J. (2019). Time course of emotion effects during emotion-label and emotion-laden word processing. *Neurosci. Lett.* 699, 1–7. doi: 10.1016/j.neulet.2019.01.028

Warriner, A. B., Kuperman, V., and Brysbaert, M. (2013). Norms of valence, arousal, and dominance for 13,915 English lemmas. *Behav. Res. Methods* 45, 1191–1207. doi: 10.3758/s13428-012-0314-x

Wu, Y. J., and Thierry, G. (2012). How reading in a second language protects your heart. *J. Neurosci.* 32, 6485–6489. doi: 10.1523/JNEUROSCI.6119-11.2012

Wu, C., and Zhang, J. (2019). Conflict processing is modulated by positive emotion word type in second language: an ERP study. *J. Psycholinguist. Res.* 48, 1203–1216. doi: 10.1007/s10936-019-09653-y

Wu, C., Zhang, J., and Yuan, Z. (2019). An ERP investigation on the second language and emotion perception: the role of emotion word type. *Int. J. Biling. Educ. Biling.* 25, 539–551. doi: 10.1080/13670050.2019.1703895

Wu, C., Zhang, J., and Yuan, Z. (2020). Affective picture processing is modulated by emotion word type in masked priming paradigm: an event-related potential study. *J. Cogn. Psychol.* 32, 287–297. doi: 10.1080/20445911.2020.1745816

Wu, C., Zhang, J., and Yuan, Z. (2021a). Can masked emotion-laden words prime emotion-label words? An ERP test on the mediated account. *Front. Psychol.* 12:721783. doi: 10.3389/fpsyg.2021.721783

Wu, C., Zhang, J., and Yuan, Z. (2021b). Exploring affective priming effect of emotion-label words and emotion-laden words: an event-related potential study. *Brain Sci.* 11:553. doi: 10.3390/brainsci11050553

Yeh, P.-W., Lee, C.-Y., Cheng, Y.-Y., and Chiang, C.-H. (2022). Neural correlates of understanding emotional words in late childhood. *Int. J. Psychophysiol.* 183, 19–31. doi: 10.1016/j.ijpsycho.2022.11.007

Zhang, J., Teo, T., and Wu, C. (2019a). Emotion words modulate early conflict processing in a flanker task: differentiating emotion-label words and emotion-laden words in second language. *Lang. Speech* 62, 641–651. doi: 10.1177/0023830918807509

Zhang, J., Wu, C., Meng, Y., and Yuan, Z. (2017). Different neural correlates of emotion-label words and emotion-laden words: an ERP study. *Front. Hum. Neurosci.* 11:455. doi: 10.3389/fnhum.2017.00455

Zhang, J., Wu, C., Yuan, Z., and Meng, Y. (2019b). Differentiating emotion-label words and emotion-laden words in emotion conflict: an ERP study. *Exp. Brain Res.* 237, 2423–2430. doi: 10.1007/s00221-019-05600-4

Zhang, J., Wu, C., Yuan, Z., and Meng, Y. (2020). Different early and late processing of emotion-label words and emotion-laden words in a second language: an ERP study. *Second. Lang. Res.* 36, 399–412. doi: 10.1177/0267658318804850

Zhou, P., Critchley, H., Nagai, Y., and Wang, C. (2022). Divergent conceptualization of embodied emotions in the English and Chinese languages. *Brain Sci.* 12:911. doi: 10.3390/brainsci12070911

frontiers | Frontiers in Communication

TYPE Original Research
PUBLISHED 17 April 2023
DOI 10.3389/fcomm.2023.1144018

Check for updates

OPEN ACCESS

EDITED BY
Laura M. Morett,
University of Alabama, United States

REVIEWED BY
Alejandro Javier Wainselboim,
CONICET Mendoza, Argentina
Antonio Mastrogiorgio,
IMT School for Advanced Studies Lucca, Italy

*CORRESPONDENCE
Jacob B. Phillips
✉ jbphillips@uchicago.edu

SPECIALTY SECTION
This article was submitted to Language Sciences, a section of the journal Frontiers in Communication

RECEIVED 13 January 2023
ACCEPTED 17 March 2023
PUBLISHED 17 April 2023

CITATION
Phillips JB, Grenoble LA and Mason P (2023) The unembodied metaphor: comprehension and production of tactile metaphors without somatosensation. *Front. Commun.* 8:1144018. doi: 10.3389/fcomm.2023.1144018



# The unembodied metaphor: comprehension and production of tactile metaphors without somatosensation

Jacob B. Phillips[1]*, Lenore A. Grenoble[1] and Peggy Mason[2]

[1]Department of Linguistics, University of Chicago, Chicago, IL, United States, [2]Department of Neurobiology, University of Chicago, Chicago, IL, United States

**Introduction:** Proposals for embodied metaphor and embodied cognition have suggested abstract concepts are understood indirectly through the simulation of previous sensory experiences in a different domain. While exceptions have been observed for sensory deficits and impairments that are common, such as vision and audition, it is commonly assumed that somatosensation (proprioception, haptic touch, pain, pressure, temperature, etc.) is fundamental for the comprehension of production of sensory metaphors and much abstract thought in general. In this way, our past sensory experiences are critical to our understanding not just of the world around us but also of our sense of selves. This would suggest that Kim, who was born without somatosensation, would have difficulty understanding, using, or even thinking about many abstract concepts typically linked to different sensory experiences through metaphor, including a creation of a sense of self.

**Methods:** To examine her comprehension of sensory metaphors, Kim was asked to select the best sensory idiomatic expression given its context. Her friends and family as well as a representative sample of individuals online were recruited to complete the survey as controls. Additionally, we transcribed and analyzed six hours of unprompted speech to determine if Kim spontaneously uses somatosensory metaphors appropriately.

**Results:** Results from the idiomatic expression survey indicate that Kim performs as well as controls despite lacking any previous direct sensory experiences of these concepts. Analysis of the spontaneous speech highlights that Kim appropriately uses tactile expressions in both their concrete sensory and abstract metaphorical meanings.

**Discussion:** Taken together, these two studies demonstrate that what is lost in sensory experiences can be made up in linguistic experiences, as Kim's understanding of tactile words was acquired in the complete absence of somatosensory experiences. This study demonstrates that individuals can comprehend and use tactile language and metaphor without recruiting past somatosensory experiences, and thus challenges a strong definition of embodied cognition which requires sensory simulations in language comprehension and abstract thought.

KEYWORDS
**embodied metaphor, embodied cognition, Conceptual Metaphor Theory, somatosensation, tactile perception**

## 1. Introduction

A metaphor[1] is a linguistic device to understand one idea in terms of another. Appealing to other domains and concepts can deepen our understanding, allow for comparisons, and add in new perspectives. In particular, in describing and understanding abstract ideas, metaphor allows us to understand something that cannot be directly observed or sensed by appealing to something that can, according to Conceptual Metaphor Theory (Lakoff and Johnson, 1980, 1999), take, for example, the phrase *had a rough day*. In it, a basic idea like *disappointing* or *difficult* is expressed by an association with tactile experiences, even though the same idea may be articulated without sensory language, like *had a bad day*.

The exact nature of the association from a mental state, like *difficult*, to a tactile experience, like *rough*, has been treated differently by different schools of thought. In early proposals of Conceptual Metaphor Theory (Lakoff and Johnson, 1980), a "primary metaphor" simply requires an implicit association between the source domain, which is concrete and can be experienced through the senses, and the target domain, which is more abstract and can only be experienced through introspection (Lakoff and Johnson, 1980). An "embodied metaphor" makes this association explicit, proposing that our understanding of one abstract element is dependent on simulating a concrete sensory experience in the relevant modality-specific sensory cortex of the brain (Barsalou, 1999; Barsalou et al., 2003; Barsalou and Wiemer-Hastings, 2005). In the example of *had a rough day*, the somatosensory cortex would simulate past experiences of feeling rough textures like a swatch of sandpaper or the bark of a tree. In contrast, a non-embodied or unembodied metaphor would be simulated entirely in modality non-specific regions of the brain. Experimental evidence supports the notion of the embodied metaphor. For example, Lacey et al. (2012) used functional magnetic resonance imaging (fMRI) to show that, for seven participants, there was more activation in the haptic and visual areas of the brain for texture metaphors, *had a rough day*, than for non-sensory equivalents, *had a bad day*.

According to Conceptual Metaphor Theory, it stands to reason that if we use metaphors in language, we must also use them in thought (Lakoff and Johnson, 1999; Landau et al., 2010; Lakoff, 2014). And if we engage in embodied metaphor, we must also engage in embodied cognition. Consequently, the notion of embodied cognition suggests that abstract thoughts are processed *via* simulations of concrete sensory experiences. This idea has been taken in diverse directions in different fields, including linguistics, cognitive science, psychology, philosophy, and neuroscience, but in each of these fields, the central tenet remains: that which cannot be experienced directly through our senses is understood through a proxy sensory experience. As the notions of embodied metaphor and embodied cognition have been expanded and extended, it has ballooned into a theory that is so large and multifaceted that it cannot be easily defined or tested (Wilson and Golonka, 2013; Casasanto and Gijssels, 2015). Even for the notion of the embodied metaphor, much more narrowly testable than embodied cognition, it remains unclear whether modality-specific regions of the brain are always activated during the processing of such memories. Casasanto and Gijssels (2015) review the large body of work that has examined the processing of metaphor in language and thought, concluding that there is a "a Grand Canyon-sized gap between the strength of many researchers' belief in "embodied metaphors" and the strength of the evidence on which their beliefs should be based" (Casasanto and Gijssels, 2015, p. 334). Based on the perceptual and behavioral data, Casasanto and Gijssels propose the notion of the "mental metaphor," which requires a mental association between source and target domains instead of a direct simulation of the source domain.

Exceptions to Conceptual Metaphor Theory have been observed for individuals with different sensory experiences who lack direct sensory perception of the target domain but are still able to use and comprehend the metaphor at hand. For example, individuals who are congenitally blind or deaf do not have any deficit in using or comprehending metaphors that make association with their impaired domain (Iran-Nejad et al., 1981; Minervino et al., 2018). And some sign languages are known to employ metaphors that represent knowledge or learning through an auditory source domain[2] despite the reality that most of the language users have no, limited, or impaired hearing (Zeshan and Palfreyman, 2019). Thus, rather than leading to the conclusion that sensory experiences can be, but need not be, recruited, the capacity of deaf and blind individuals to use metaphors has been viewed as demonstrations that somatosensation is special and exceptional, standing apart from vision and hearing. There is an entrenchment in the role of somatosensory experiences in embodied cognition (Wilson, 2008; Kilteni et al., 2012; Häfner, 2013). Sensory experience can now be taken to mean somatosensory experiences, appealing to the intero- and exteroceptive sensory experiences on the skin or deep tissue. We suggest that this is not due to the immutable connection of somatosensation to language and cognition, but rather to the lack of known individuals who have impaired or absent somatosensation.

In the present article, we provide the case study for Kim, a woman born without any somatosensation or sense of taste. She cannot sense, nor has she ever sensed, haptic touch, temperature, pain, or pressure. Her sense of body comes through vision rather than proprioception. With this case study, we challenge the proposal that cognition must be embodied. We do not claim that thought is never embodied, rather we argue that it simply need not be. Kim challenges not just the notion of embodied cognition but also the narrower, and more testable, notion of the embodied metaphor. Through an idiomatic expression survey and an examination of her spontaneous speech,[3] we demonstrate that

1 We use the term *metaphor* in the broadest sense of the word, including all ways of understanding one concept in terms of another. This differs from, but includes, the more restrictive definitions often given to literary metaphors in which an object is described by directly equating it with another object, e.g., *time is money*, to the exclusion of other literary devices. As such, other literary comparisons like similes, e.g., *straight as an arrow*, or synecdoches, e.g., *lend a hand*, are included in the broader understanding of metaphor here.

2 For example, in Indonesian Sign Language, the sign for NOT-WANT-TO-KNOW-ABOUT that is used regarding gossip typically involves a gesture of removing one's ear, despite the fact that the signer would acquire such gossip gesturally and not auditorily (Zeshan and Palfreyman, 2019).

3 Magnetic resonance imaging is contraindicated for Kim.

10.3389/fcomm.2023.1144018

Kim uses and understands metaphorical language involving tactile expressions without processing them *via* sensory simulations.

## 2. Kim

Kim is a 43-year-old American female who congenitally lacks all somatosensation, including touch, pain, temperature, pressure, and proprioception. Her neuropathy is both rare and severe, a one-of-a-kind variant of Hereditary Sensory Autonomic Neuropathy Type II (HSAN Type II) not attested in any other individual. There have been documented cases of acquired neuropathies with individuals, like IW, who lost touch, vibration, and proprioception below the neck, while retaining pain and temperature sensation, as the result of viral illness (Cole, 1991, 2016).

As detailed in forthcoming work by Mason and colleagues, Kim lacks all small- and large-fiber somatosensory afferents on her body, neck, and head and has since birth. When Kim's vision of her own body is blocked, she cannot sense where her torso or limbs are in space or in relation to one another, nor can she sense if any object is making contact with her body.

Kim's other sensory systems are variably affected as well. Her hearing is normal, with normal-to-excellent hearing from 250 to 8000 Hz and normal speech discrimination and identification. Kim's vision is normal and uncorrected, with 20/25 vision in her left eye and 20/20 in her right eye, despite extensive corneal scarring, with normal color vision. Kim is ageusic and unable to reliably distinguish among sweet, sour, salty, bitter, or no taste. Kim is not anosmic, but has poor detection, discrimination, and identification of smells. Nonetheless, she does express food likes and dislikes.

Kim has intact motor nerves and functions. Her muscle strength is normal, but she uses a wheelchair and has motor limitations due to her lack of sensory feedback: she cannot walk or stand without assistance due to the difficulty of balancing without proprioceptive feedback. She has no reflexes and does not cough in response to liquids entering her trachea; she can cough deliberately. Kim has no observed autonomic deficits: she tears, sweats, and accommodates normally during near vision.

Since Kim cannot perceive somatosensory stimuli, she must rely on other senses and information to perceive the world around her. For example, to perceive the texture of a table, Kim relies solely on visually interrogating its pattern and to determine the hardness of an object, Kim listens to what kind of sound it makes when struck against a surface. In this way, Kim's understanding of words and concepts like *rough* and *hard* are mediated through different sensory experiences than the average person. And since Kim has never experienced somatosensation, she does not have any stored memories or experiences such that a simulation of those experiences can later be activated. Thus, if a metaphor is truly embodied, it is essential that past sensory experiences be activated and simulated, something that should prove impossible for Kim in many domains.

## 3. Methods

Kim's comprehension and production of sensory metaphors was examined in two ways. First, we conducted an online idiomatic expression survey to compare Kim's understanding of tactile, taste, and body metaphors to a control population, including her friends and family. In Section 3.1, we introduce the participants, materials, and procedure for that task. Second, we qualitatively analyzed Kim's use of somatosensory metaphors in spontaneous and unprompted speech. The methods and motivations for the spontaneous production study are presented in Section 3.2.

### 3.1. Idiomatic expression survey methods

The idiomatic expression survey tests the comprehension of metaphors where the source domain depends on somatosensation, taste, or sense of body. This is tested by asking Kim and controls to select the appropriate idiomatic expression to complete a sentence. While Lacey et al. (2012) demonstrated that the somatosensory cortex can be recruited in the perception of tactile metaphors, e.g., *had a rough day*, relative to non-sensory expressions, e.g., *had a bad day*, the present study asks simply if Kim, who has never experienced those sensations such that they could later be activated and simulated, can comprehend these idiomatic expressions as well as the individuals who have those experiences and sensations to rely on. Thus, at stake in this study is not whether somatosensory (or taste) perceptual memories can be activated in the processing of tactile metaphors, but whether such simulation must occur to process tactile metaphors successfully.

#### 3.1.1. Participants

In addition to Kim, two control populations were recruited to participate online. A total of 24 of Kim's friends and family were recruited directly through email and an additional 39 native speakers of American English were recruited on Amazon Mechanical Turk. Kim's friends and family were recruited to account for any potential differences between Kim's speech community and the average speaker of North American English as idiomatic expressions can vary greatly between communities in their frequency and use. The mean age of the participants was 41 years, spanning a range of 22–72 years. In that, 30 participants were identified as female and 33 as male. Participants spanned the continental United States, with higher concentrations in the Midwest and Mid-Atlantic as a result of direct-recruiting friends and family of Kim. No control participants reported any history of sensory or neurological impairments, disorders, or disabilities. An additional 16 individuals recruited through Amazon Mechanical Turk participated in this study but were excluded from all analyses as they failed basic attention checks.

#### 3.1.2. Materials and procedure

The study was hosted on Qualtrics. Each question contained a short vignette of a sentence or two that ended in a choice of four idiomatic English expressions. There were four classes of idiomatic expressions included: tactile (e.g., *rough around the edges* and *hard as nails*), taste (e.g., *short and sweet and a bitter pill to swallow*), body part (e.g., *lend an ear and all skin and bones*), and visual or non-sensory fillers (e.g., *out of the blue, on cloud nine, and like a fish out of water*). Body part expressions, while not explicitly sensory in the same way as tactile and taste expression, were included as Kim has a different sensory experience with her body: Sensory understanding of her body is primarily visual, not haptic, proprioceptive, or interoceptive. As Kim is not only aware of her condition but also that the present study was in some way interrogating the relationship between her condition and her language, each multiple-choice question contained a competing expression of the same class as the target and two distractors of a different class to ensure that she's not selecting sensory expressions spuriously. There were 80 questions in total; 30 questions were targeted for a tactile response with non-sensory filler distractors and 30 with targeted non-sensory filler responses and tactile distractors; and 10 questions were targeted for a taste response with body part distractors and 10 for a body part response with taste distractors. An example question, including vignette and responses, is provided in 1.

1. *Liza bought her first car and successfully negotiated the price down five thousand dollars. Liza:*

   a) drove a hard bargain. (Correct tactile response)
   b) made a rough guess. (Tactile competitor)
   c) missed the mark. (Non-sensory/filler distractor)
   d) hit the hay. (Non-sensory/filler distractor)

The complete idiomatic expressions survey, including instructions to participants, is available in the Supplementary material.

Following the sensory idiom selection, participants completed a brief demographic survey. The entire survey took approximately 15 min. Participants were compensated, with compensation being optional for direct-recruited friends and family, at the rate of $20/h. Informed consent was obtained for all participants and all procedures performed were approved by the Social and Behavior Sciences Institutional Review Board at the University of Chicago.

#### 3.1.3. Analysis

The goal of this survey was to ask if Kim, who has never experienced somatosensation, taste, or a proprioceptive sense of body, is able to comprehend sensory metaphors and select the appropriate expression given the context. To test this quantitatively, a logistic mixed effects regression was fit to the accuracy of a given response (1,0) using the `glmer()` function in the `lme4` package (Bates et al., 2015) in `R` (R Core Team, 2015). The model included GROUP (Control, Family/Friend, or Kim; treatment-coded with Control as base), METAPHOR (Non-sensory, Tactile, Taste, Body; treatment-coded with Non-sensory as base), and BIRTHYEAR (scaled) as fixed effects. All interactions that did not reach a significance threshold of 0.05 were pruned from the final model. In addition, preliminary models included maximally specified random effects structures, with by-subject and by-item random slopes and intercepts, which were progressively simplified until convergence was achieved.

### 3.2. Spontaneous production methods

The idiomatic expression survey was designed to test Kim's understanding of tactile metaphors. To test her production and active use of these metaphors, we transcribed and analyzed 5 h 54 min and 2 s of spontaneous speech, recorded in a variety of settings and with different interlocutors, including the researchers and Kim's family members. Topics of spontaneous speech included introductions with the researchers, discussions of Kim's life and experiences, including reflections on her participation in medical and linguistics research, and retellings of short videos or storybooks. All conversations took place in the Neubauer Collegium for Culture and Society at the University of Chicago and were recorded at 48,000 Hz with a Zoom H5 Handy Recorder using the Zoom XYH-5 unidirectional X/Y microphone capsule. The spontaneous speech was analyzed qualitatively rather than quantitatively since any appropriate and spontaneous usage of sensory metaphors demonstrates that Kim is able to produce them despite never having experienced their relevant sensations.

### 3.3. Limitations

This study necessarily involves only one subject since Kim's condition is unique. We know of no other comparable subjects, since the known population of people with somatosensory deficits do not lack all modalities of somatosensation on all parts of their bodies and/or had typical sensory perception at some point in their lives. Thus, people such as IW had first-hand experiential knowledge of haptic touch and proprioception into adulthood and continue to perceive pain and temperature (Cole, 1991, 2016). Such a presentation renders those with acquired loss quite different from Kim. The results cannot be confirmed by testing a larger population of people like Kim because such people do not exist. Nonetheless, in line with other singular individuals who have provided neurobiology with knowledge not otherwise obtainable, we argue that data from Kim provide invaluable insight that inform the human condition and faculty for language as no other can.

## 4. Results

In this section, we report the results of how Kim performed in the idiomatic expressions survey with comparison to the control group. This is followed by a discussion of Kim's use of idioms in spontaneous speech, which serve as a further test of our methodologies and hypothesis.

### 4.1. Idiomatic expression survey results

Results for the tactile expressions and non-sensory fillers are illustrated in Figure 1. First and foremost, the inset included in Figure 1 demonstrates that Kim and her direct-recruited family and friends performed with a high degree of accuracy on both tactile and non-sensory expressions. Note that accuracy here is defined as selecting the intended expression to complete the vignette consistent with linguistic norms and cultural expectations, but we acknowledge that some variation may be expected. Despite the inclusion of attention checks, 13 of the 39 controls recruited on Amazon Mechanical Turk performed near chance, indicative of inattentive responses. Due to this relatively bimodal distribution, the primary figure and subsequent analyses focus on Kim and her

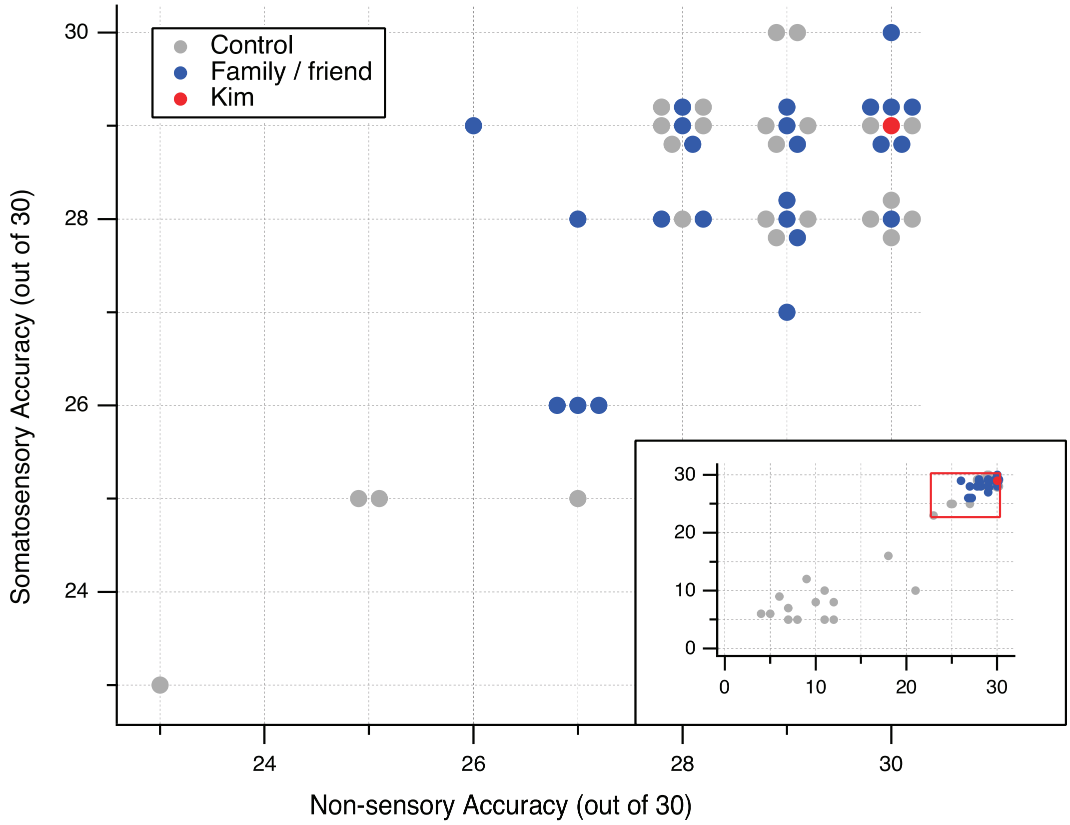


FIGURE 1
Number of expressions accurately selected given the context for the non-sensory (x-axis) and tactile (y-axis) expressions. The number 30 indicates that the accurate and anticipated expression was selected for every vignette, while 7.5 indicates performing at chance. The inset illustrates accuracy for all participants who passed the attention checks, but the primary pane focuses on the attentive participants performing well above chance. Note that Kim (in red) and all the direct-recruited friends and family of Kim (in blue) are performing near ceiling.

friends and family, and the remaining 26 controls who got at least 20 out of 30 non-sensory fillers correct.

The primary pane of Figure 1 illustrates that Kim, indicated in red, gave the anticipated and accurate response in all 30 of the non-sensory filler expressions and in 29 out of 30 of the tactile expressions. Kim's friends and family, indicated in blue, identified the anticipated and accurate response for a mean of 28.6 out of 30 questions in the non-sensory filler expressions (minimum 26, maximum 30, median 29) and a mean of 28.3 out of 30 for the tactile expressions (minimum 26, maximum 30, median 29). The attentive controls performed similarly, with accurate responses for a mean of 28.4 for non-sensory fillers and 28.0 for tactile expressions. Taken broadly, Figure 1 illustrates that Kim appears to perform as well as (or better than) controls, including her friends and family, in the selection of both tactile and non-sensory idiomatic expressions.

Results for the taste and body part expressions are illustrated in Figure 2. As in Figure 1, the inset on Figure 2 shows that a number of controls recruited online performed near chance despite the inclusion of attention checks. In the primary pane of the figure, we see that Kim, again indicated in red, gave the anticipated and accurate response on 9 out of 10 on both the body part and taste expressions, despite having different sensory experiences than controls for both domains. Kim's friends and family, indicated in blue, identified the anticipated and accurate response for a mean of 9.0 out of 10 questions in the taste expressions (minimum 6, maximum 10, median 9) and a mean of 9.3 out of 10 for the body part expressions (minimum 8, maximum 10, median 9). The attentive controls performed similarly to Kim's friends and family, with accurate responses for a mean of 8.9 out of 10 for taste expressions and 9.5 out of 10 for body part expressions. At its core, Figure 2 shows that despite her different sensory experiences relating to tastes and her body, Kim performs similarly to controls and her friends and family in selecting the best sensory expression to complete a short vignette.

The results of the logistic mixed effects regression corroborate the visual interpretation of Figure 1. First and foremost, the positive intercept of the model reached the significance threshold of 0.05, suggesting that all attentive participants are more likely to select the accurate expression than an inaccurate one ($z = 8.98, p < 0.001$). There was no statistical difference between Kim and the controls either across-the-board or with respect to the different METAPHOR conditions (Non-sensory, Tactile, Taste, or Body).

## 4.2. Spontaneous production results

Kim's own spontaneous speech demonstrates that not only can she comprehend tactile metaphors without directly experiencing the sensations herself but also can use them spontaneously and appropriately. Again, at stake here is not whether she is activating

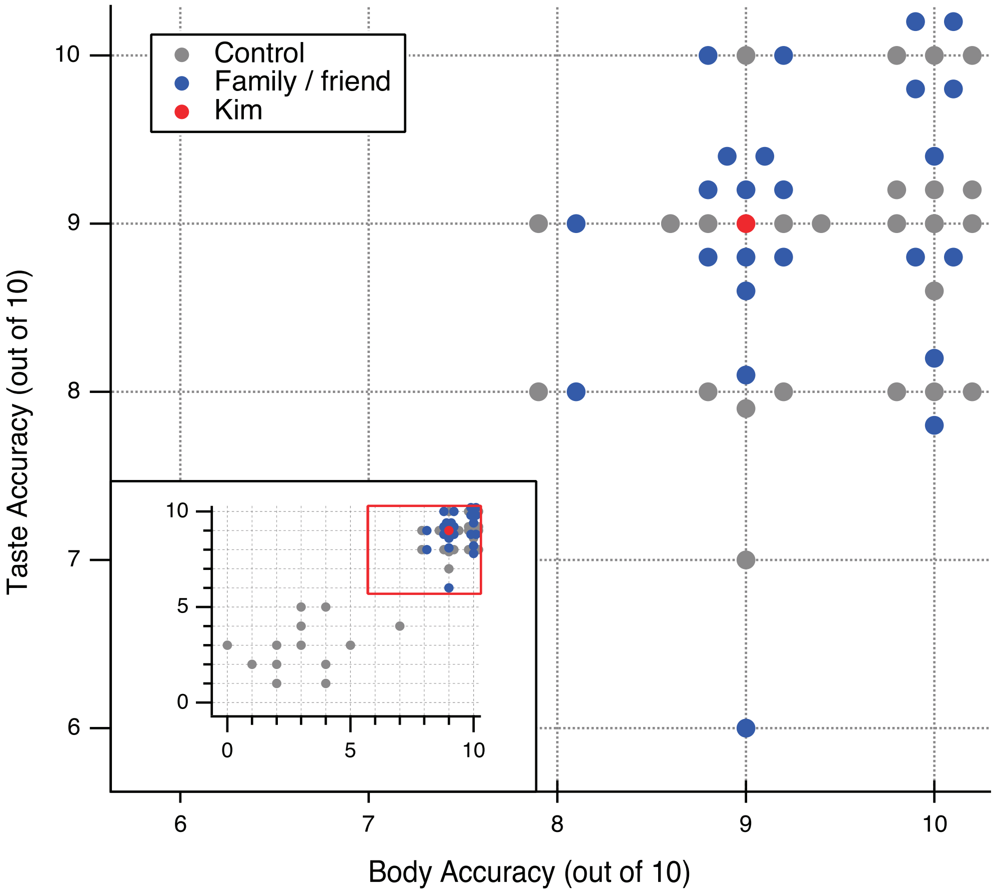


FIGURE 2
Number of expressions accurately selected given the context for the body part (x-axis) and taste (y-axis) expressions. The number 10 indicates that the accurate and anticipated expression was selected for every vignette, while 2.5 indicates performing at chance. The inset illustrates accuracy for all participants who passed the attention checks, but the primary pane focuses on the attentive participants performing well above chance. Note that Kim (in red) and all the direct-recruited friends and family of Kim (in blue) are performing near ceiling.

the modality-specific regions of her brain when using these metaphors, but whether she can use them at all without having previous direct sensory experiences.

To examine Kim's use of tactile metaphors, we present one emblematic discussion in which Kim told a story of her experience with a personal care attendant. In this conversation, provided below in a slightly abridged format to remove some back and forth among Kim, her mother, and the researchers with elisions indicated by [...], Kim described an attempt to get a spill off her pants with a paper towel that resulted in the paper towel pilling and leaving fragments behind. This story was unprompted, but the researchers pressed Kim for her understanding of what a tactile word like *gritty* means. This passage is equally noteworthy for Kim's spontaneous use of tactile metaphor as for her descriptions of the concrete tactile sensations themselves. Bolded text is added by the authors to emphasize metaphorical and concrete use of tactile language.

> *Kim:* We were at work one day, and in the morning before [the personal care attendant] had gotten there I noticed there was something on my shirt. And so my mom, or people, had told me previously that if you like wet like a paper towel and like rub it on your pants or whatever, it could help to get like stains out. So I had gone in the bathroom and I'd done that and I wet a paper towel and like tried to use [it to remove] the stain.
> So when she was there at lunchtime and I noticed there was a lot of like what I thought were like white flakes on my pants. So I asked her if she could like get it off. And she couldn't get it off and she was **having a hard time** and I was like– I didn't get why. And she was like, "Oh well it's real gritty." And I was like, "What do you mean it's gritty?" She's like, "Well you know **the little pieces are like hard** and I can't get it off your pants because the paper towel shredded and it became like–". And I was like, "I have no idea what you mean." I'm like, "**Gritty? You mean like rocks?**"

Here, Kim spontaneously uses the same tactile adjective (*hard*) in both the concrete source domain ("the little pieces are hard") and the abstract target domain ("having a hard time"), demonstrating her ability to produce both appropriately. Kim's use of a high-frequency tactile word like *hard* is perhaps not unexpected, but we see her question the attendant's use of a low frequency word, *gritty*, not understanding the term in this context.[4] We then asked her specifically about her understanding of the word *gritty*:

> *Researcher:* Do you know– could you ever describe a person as being gritty?
> *Kim:* Um. I don't know does it mean– would it be like if they're like kinda like from the streets and they're kinda like out there- they're kinda like a **little rough around the edges** that would be like a gritty person.

Here, Kim not only demonstrates her understanding of the metaphorical use of the tactile adjective *gritty* but also uses another tactile adjective (*rough*) metaphorically to describe the word in question. She thus demonstrates a reasonable understanding of the uses of both, despite her initial doubts. When asked if she would actually use *gritty* herself in this way, Kim indicates a preference for the concrete source meaning only, and provides some meta-commentary about how she conceptualizes tactile expressions:

> *Researcher:* Would you ever use that? Or would you just under[stand] it if someone used it? Do you know?
> *Kim:* I probably would understand it, I don't think I would use it. I mean to me, when I think "grit" I think like rocks. So, I would probably only use it in the sense of like it's gritty or like grits the food, I mean I know **grits the food obviously must be gritty because it's in the word** so–
> *Kim's mother:* Yeah, but grits aren't gritty.
> *Kim:* Well, when it's in the word, how could it not be gritty?! [...] Well, then to me, this is how I think about words. I think pretty literally about words, especially words about, like you know, sensation and things like that. [...] A lot of times words like we're talking about "gritty" or like "soft" or "hard" or, like I'm trying to think of examples, like "coarse". **My definitions come strictly from what other people have told me**, so that's where I'm getting it from.

Note that Kim claims that she uses words in their literal, or source domain, meaning, although we have just seen her use *hard* and *rough* metaphorically. Kim, like most individuals, holds beliefs about her language that may not align with her actual usage. Yet, even if Kim reports thinking about tactile expressions literally, she is still able to use and comprehend them in their metaphorical extensions, as evidenced by her own spontaneous speech. In short, the fact that she can and does use tactile metaphors supersedes any intuitions that she may have to the contrary. In addition, Kim expresses that her knowledge of these tactile words comes through linguistic rather than physical experiences. Thus, her tactile conceptualizations appear to be linguistically based, which leads her to the assumption that grits must be gritty because they share the same root. She argues against her mother's claim to the contrary on linguistic grounds as the words are homophonous and etymologically related.[5] But Kim notably does not invoke experiential knowledge to argue with her mother that raw grits are in fact gritty. It is cooked grits that are not, and Kim does not have the sensory experiences to back that up. Again, it is possible that Kim's intuitions about her conceptualizations of tactile terms do not align with her linguistic knowledge, but, in this case, her behavior backs up her claim: she makes a linguistic rather than a sensory argument.

While this passage is concerned with a single low-frequency tactile adjective, it provides an interesting case study on the understanding and use of sensory expressions without the relevant sensory perception. It highlights that Kim relies on linguistic experience to understand tactile expressions when she has not had the requisite sensory experiences.

## 5. Discussion

Our brief survey of idiomatic expressions asked if Kim, who has never experienced somatosensation or taste, is able to comprehend tactile, taste, and body metaphors despite having no direct sensory knowledge of the source domain itself, like a *rough* surface or a *sweet* dessert. If Kim's comprehension of tactile metaphors were impaired by the fact that she has never experienced the relevant somatosensations (*roughness, softness, warmth*, etc.), then she would have had significantly more difficulty (and thus less accuracy) selecting the correct tactile expression than controls and her friends and family. But the results clearly demonstrate that Kim has a full understanding of these words and expressions despite never having perceived the concrete sensations themselves. The same is true for both taste and body part metaphors, where Kim has very different sensory experiences with these domains than controls. Taken in conjunction with the findings of Lacey et al. (2012), this study demonstrates that while our past sensations may be recruited in the perception and processing of sensory metaphors, such recruitment is not necessary to accurately comprehend sensory metaphors.

Crucially, our analysis of spontaneous speech shows that Kim does use tactile words metaphorically without hesitation or conscious awareness. As Kim can use these expressions freely, the passage in Section 4.2 demonstrates that metaphors using a somatosensory source domain can spontaneously be used and understood without directly embodying, or activating, those sensations. But moreover, it demonstrates that these metaphors can be used without a complete or confident understanding of

4 The frequency of *hard* is 307.84 instances/million and *gritty* just 0.45 instances/million, according to the Subtlex database compiled from American English subtitles (Brysbaert and New, 2009).

5 The word *grit* "sand", "gravel" is from Old English *gréot*, Old Germanic **greuto$^m$* with attestations from the 5th century; *gritty* (<*grit* + *-y*) is first attested in the 16th century. The food term *grits* has the same Germanic root, but subsequently diverged, and comes from the Old English *grytt*; it has been attested since the 8th century. While the food term grits has historically referred to any coarse-milled grains, In the US, it refers exclusively to coarse cornmeal which is cooked into a thick porridge. The two forms of grit have mutually influenced each other over time to converge on a single form (OED online, 2020).

the concrete sensory definitions themselves. Kim may have doubts about whether a table is rough or smooth and rely on visual interrogation of the surface and information conveyed to her linguistically by her friends and family, but she has no difficulty describing a person as "rough around the edges." Thus, in much the same way as a blind or colorblind individual can use and understand an expression like "green with envy" or "in a blue mood," Kim can understand and use tactile expressions without having experienced the source domain directly.

## 6. Conclusion

As this study shows, Kim's use and understanding of tactile words cannot come through somatosensation; she may rely on visual interpretation of a surface, but she also crucially depends on knowledge acquired linguistically. Her understanding of the metaphorical use of tactile phrases also depends not just on introspection but also linguistic input. It is not surprising that she can understand and produce tactile words in language because that is how she has acquired them. Kim is so highly educated and has had such broad exposure to literary traditions that it would be surprising if the inverse were true. Separate testing of her lexical knowledge of tactile adjectives shows that she can appropriately define all the terms provided to her. For words like *rough*, she can define and use them in both the source sensory domain and the metaphorical domain, even if she cannot know for certain whether the physical object in question is rough to the touch. The linguistic knowledge can only take her so far because she still has gaps in her experiential knowledge, which highlights her different views from her mother for a low-frequency word like *gritty*.

Kim's understanding of tactile words in both their concrete source and metaphorical target meanings complicates the proposal of primary metaphors, by which the target domain is understood through implicit association with the source domain (Lakoff and Johnson, 1980). For tactile expressions, the source domain is concrete and experienced directly through haptic touch and the target domain is abstract and experienced through introspection. Thus, the target domain can only be derived through the source domain. However, for Kim, this cannot be the case as she clearly has no direct sensory experience. For her, the sensory domain is not concrete but equally as abstract as the target domain. Therefore, it need not be the case that she understands abstract concepts like *hard*-as-*difficult* through association with physicality, since it would involve understanding the abstract through the abstract. This raises the question of whether a tactile metaphor like "had a rough day" is even a metaphor for Kim instead of simply a separate lexical entry for a word like "rough." What does Kim gain by understanding the abstract through the abstract? Does Kim use sensory metaphors that she has no direct experience with simply because of their standardness and frequency in language? Or does appealing to texture, which she can experience visually and linguistically, still intensify the cognitive and expressive meaning beyond their semantic denotations?

The present findings further challenge stronger claims for the embodied metaphor where the associations between the source and target domains require a recruitment of the sensory system and a simulation of past sensations (Barsalou, 1999). Kim is fully able to process and use tactile metaphors without ever having experienced tactile sensations such that she could later simulate them to understand the metaphorical extension. Simply put, it cannot be the case that somatosensory experiences are required to process tactile metaphors as Kim is clearly able to do so. That is not to say, however, that somatosensory information is never used in the processing and use of tactile metaphors, as Lacey et al. (2012) show that individuals who have access to somatosensory input use it; rather Kim shows that these metaphors can be understood without it. Similar findings have been observed for other sensory domains. The ability of congenitally blind individuals to understand visual metaphors has been established (Minervino et al., 2018) and metaphors that utilize an auditory source domain are commonly attested across sign languages (Zeshan and Palfreyman, 2019). For example, the sign for *news* involves a listening gesture in Indian Sign Language and Polish Sign Language. Just as hearing and vision are not necessary to process metaphors that rely on those senses, somatosensation is not necessary to process tactile metaphors. It is perhaps the uniqueness of Kim's condition of never having experienced haptic touch or proprioception that allowed researchers to make stronger claims for the role of somatosensation in the embodiment metaphor than for vision and audition.

In the same vein, these findings challenge strong claims for embodied cognition, by which all cognition, not just metaphorical language, relies on the recruitment of the body's sensory systems. Kim demonstrates that somatosensation cannot be any more required for abstract thought than vision and audition are. These strong proposals for embodied cognition that foreground proprioceptive experiences of one's body and tactile experiences with the world in which one lives may stem from the fact that it is difficult for many researchers to even conceptualize the different relationship that someone like Kim has with her body and the rareness of conditions like hers. Yet Kim does exist and, despite her different sensory experiences with both her body and the world around her, is as capable of abstract thought and metaphorical language as the rest of us.

## Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

## Ethics statement

The studies involving human participants were reviewed and approved by University of Chicago Social and Behavioral Sciences Institutional Review Board. The patients/participants provided their written informed consent to participate in this study. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

## Author contributions

JP, LG, and PM contributed to the design and edited the manuscript. JP performed the research, conducted the analysis, and wrote the initial draft. All authors contributed to the article and approved the submitted version.

## Funding

This research was supported a grant, the language of Kim, from the Neubauer Collegium for Culture and Society at the University of Chicago. Additional funding and support provided by the Division of the Humanities at the University of Chicago.

## Acknowledgments

Thank you to Sara Hockett, Giovanna Hooton, and Ruby Otavka for transcribing our many recordings. We would also like to thank Kim and her family for their collaboration.

## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

## Publisher's note



## Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fcomm.2023.1144018/full#supplementary-material

## References

Barsalou, L. W. (1999). Perceptions of perceptual symbols. *Behav. Brain Sci.* 22, 637–660. doi: 10.1017/S0140525X99532147

Barsalou, L. W., Simmons, W. K., Barbey, A. K., and Wilson, C. D. (2003). Grounding conceptual knowledge in modality-specific systems. *Trends Cogn. Sci.* 7, 84–91. doi: 10.1016/S1364-6613(02)00029-3

Barsalou, L. W., and Wiemer-Hastings, K. (2005). *Situating Abstract Concepts*. Cambridge: Cambridge University Press.

Bates, D., Mächler, M., Bolker, B., and Walker, S. (2015). Fitting linear mixed-effects models using lme4. *J. Stast. Software* 67, 1–48. doi: 10.18637/jss.v067.i01

Brysbaert, M., and New, B. (2009). Moving beyond Kučera and francis: a critical evaluation of current word frequency norms and the introduction of a new and improved word frequency measure for American English. *Behav. Res. Methods* 41, 977–990. doi: 10.3758/BRM.41.4.977

Casasanto, D., and Gijssels, T. (2015). What makes a metaphor an embodied metaphor? *Linguist. Vanguard* 1, 327–337. doi: 10.1515/lingvan-2014-1015

Cole, J. (1991). *Pride and a Daily Marathon*. Cambridge: MA: MIT Press,.

Cole, J. (2016). *Losing Touch: A Man Without His Body*. Oxford: Oxford University Press.

Häfner, M. (2013). When body and mind are talking. *Exp. Psychol.* 60, 255–259. doi: 10.1027/1618-3169/a000194

Iran-Nejad, A., Ortony, A., and Rittenhouse, R. K. (1981). The comprehension of metaphorical uses of english by deaf children. *J. Speech Lang. Hear. Res.* 24, 551–556. doi: 10.1044/jshr.2404.551

Kilteni, K., Groten, R., and Slater, M. (2012). The sense of embodiment in virtual reality. *Presence* 21, 373–387. doi: 10.1162/PRES_a_00124

Lacey, S., Stilla, R., and Sathian, K. (2012). Metaphorically feeling: comprehending textural metaphors activates somatosensory cortex. *Brain. Lang.* 120, 416–421. doi: 10.1016/j.bandl.2011.12.016

Lakoff, G. (2014). Mapping the brain's metaphor circuitry: metaphorical thought in everyday reason. *Front. Hum. Neurosci.* 8, 958. doi: 10.3389/fnhum.2014.00958

Lakoff, G., and Johnson, M. (1980). *Metaphors We Live By*. Chicago: University of Chicago Press.

Lakoff, G., and Johnson, M. (1999). *Philosophy in the Flesh: The Embodied Mind and Its Challenge to Western Thought*. Chicago: University of Chicago Press.

Landau, M. J., Meier, B., and Keefer, L. A. (2010). A metaphor-enriched social cognition. *Psychol. Bull.* 136, 1045–1067. doi: 10.1037/a0020970

Minervino, R. A., Martín, A., Tavernini, L. M., and Trench, M. (2018). The understanding of visual metaphors by the congenitally blind. *Front. Psychol.* 9, 1242. doi: 10.3389/fpsyg.2018.01242

OED online (2020). "grit, n.1," in *Oxford English Dictionary*. (Oxford: Oxford University Press).

R Core Team (2015). *R: A Language and Environment for Statistical Computing*. Vienna: R Foundation for Statistical Computing.

Wilson, A. D., and Golonka, S. (2013). Embodied cognition is not what you think it is. *Front. Psychol.* 4, 58. doi: 10.3389/fpsyg.2013.00058

Wilson, M. (2008). "How did we get from there to here? an evolutionary perspective on embodied cognition," in *Handbook of Cognitive Science, Perspectives on Cognitive Science*, eds P. Calvo, and A. Gomila (San Diego, CA: Elsevier), 373–393.

Zeshan, U., and Palfreyman, N. (2019). "Sensory perception metaphors in sign languages," in *Perception Metaphors* (Amsterdam: John Benjamins), 275–301.

frontiers | Frontiers in Psychology

TYPE Original Research
PUBLISHED 12 May 2023
DOI 10.3389/fpsyg.2023.1154442

Check for updates

OPEN ACCESS

EDITED BY
Laura M. Morett,
University of Alabama,
United States

REVIEWED BY
Ma Lijun,
Guangzhou University of Chinese Medicine,
China
Chengyu Guo,
Hunan University,
China
Zilong Xie,
Florida State University,
United States

*CORRESPONDENCE
Manuel de Vega
✉ mdevega@ull.edu.es

RECEIVED 30 January 2023
ACCEPTED 21 April 2023
PUBLISHED 12 May 2023

CITATION
Gu B, Liu B, Beltrán D and de Vega M (2023) ERP evidence for emotion-specific congruency effects between sentences and new words with disgust and sadness connotations. *Front. Psychol.* 14:1154442.
doi: 10.3389/fpsyg.2023.1154442



# ERP evidence for emotion-specific congruency effects between sentences and new words with disgust and sadness connotations

Beixian Gu[1,2], Bo Liu[2,3], David Beltrán[2,4] and Manuel de Vega[2]*

[1]Institute for Language and Cognition, School of Foreign Languages, Dalian University of Technology, Dalian, China, [2]Instituto Universitario de Neurociencia (IUNE), Universidad de La Laguna, La Laguna, Spain, [3]School of Foreign Languages, Dalian Maritime University, Dalian, China, [4]Psychology Department, Universidad Nacional de Educación a Distancia (UNED), Madrid, Spain

**Introduction:** The present study investigated how new words with acquired connotations of disgust and sadness, both negatively valenced but distinctive emotions, modulate the brain dynamics in the context of emotional sentences.

**Methods:** Participants completed a learning session in which pseudowords were repeatedly paired with faces expressing disgust and sadness. An event-related potential (ERP) session followed the next day, in which participants received the learned pseudowords (herein, new words) combined with sentences and were asked to make emotional congruency judgment.

**Results:** Sad new words elicited larger negative waveform than disgusting new words in the 146–228ms time window, and emotionally congruent trials showed larger positive waveform than emotionally incongruent trials in the 304–462ms time window. Moreover, the source localization in the latter suggested that congruent trials elicited larger current densities than incongruent trials in a number of emotion-related brain structures (e.g., the orbitofrontal cortex and cingulate gyrus) and language-related brain structures (e.g., the temporal lobe and the lingual gyrus).

**Discussion:** These results suggested that faces are an effective source for the acquisition of words' emotional connotations, and such acquired connotations can generate semantic and emotional congruency effects in sentential contexts.

KEYWORDS

**disgust, sadness, pseudowords, sentences, ERPs**

## Introduction

Language is an important vehicle to express one's feelings and denote the emotionality of certain objects and events in people's daily lives. During early language acquisition, children initially learn words, the smaller linguistic units, and then gradually develop their language abilities to combine words to form larger units, namely, sentences (Lightfoot, 2010). Such a general pattern also occurs with emotional language, that is, many words have an emotional valence but they are also integrated into sentences and discourses that can be governed by principles of emotional coherence (Moreno and Vázquez, 2011; Delaney-Busch and Kuperberg, 2013; Moreno and Rivera, 2014). However, the neurocognitive activities that occur when acquiring emotional connotations for words and how such connotations function in sentential contexts have been barely investigated. The present study aimed to fill that gap by measuring the brain dynamics of processing new words whose emotional connotations were acquired through an associative learning paradigm, in emotional sentential contexts. On top of that, the present study went beyond a gross categorization of "positive" and "negative," which does not reflect the various emotions contained in words. For example, "piss" and "loneliness" are both "negative" words yet related to different emotions. Therefore, two specific emotions of disgust and sadness were selected in the present study to further tap into the various emotional nuances involved in daily verbal and written communication.

Traditionally, the role of emotion in language processing has been examined from the two dimensions of valence and arousal (Bradley and Lang, 2000). Alternatively, a discrete emotion model has been proposed, which presents more refined categorizations of emotions than merely classifying them as positive and negative valence (Ekman, 1992). In this sense, a series of studies were carried out to probe into the impact of discrete emotions on written word processing (Briesemeister et al., 2011, 2014; Silva et al., 2012; Ferré et al., 2017). For example, Briesemeister et al. (2014) reported that happy words modulated the N1 component, while general positive words affected the N400-like component, reflecting thereby a sequential processing of emotional connotation of words with discrete emotions being the basis for subsequent dimensional analysis. Such a discrete emotion effect can be interpreted through the contextual-learning hypothesis, which argues that emotion effects are based on a person's relevant real-life experience that can be traced back to a person's childhood (Barrett et al., 2007). Therefore, investigating the processing of words' acquired emotional connotations from a discrete dimension could contribute to a better understanding of emotional word acquisition.

Based on this, disgust and sadness were selected as the emotions of interest in this study, which are among the basic emotions proposed by Ekman (1992). The two emotions are highly distinctive from each other, since disgust is usually triggered by external physical aversive stimuli, thus is highly relevant to human's well-being (Rozin and Haidt, 2013) whereas sadness is more passive, internally-generated, and related to the loss of valuable goals or significant others (Kreibig et al., 2007; Lench et al., 2011). Disgust is usually accompanied by a series of typical psychophysiological responses such as nausea, reduced heart rate, amplified skin conductance, and decreased respiratory rate (Ritz et al., 2005; Stark et al., 2005). Moreover, neuroimaging studies of both brain lesion patients (Calder et al., 2000; Cantone et al., 2019) and healthy participants (Phillips et al., 1997; Wicker et al., 2003; Wright et al., 2004; Schienle et al., 2017; Viol et al., 2019) indicated that the anterior insula is the main brain structure involved in multi-modal disgust information processing. On the other hand, sadness was found to result in increased diastolic blood pressure (Sinha et al., 1992; Krumhansl, 1997) and nonspecific skin conductance (Frazier et al., 2004) and decreased pulse transit time to the ear and finger skin temperature (Gross and Levenson, 1997; Krumhansl, 1997; Kunzmann and Grühn, 2005; Kreibig et al., 2007). Moreover, converging neuroimaging study results suggested that the anterior cingulate cortex is related to processing and mediating sad experiences (Niida and Mimura, 2017; Ramirez-Mahaluf et al., 2018; Webb et al., 2018). Other negatively valenced emotions in the basic emotions such as anger and fear were ruled out for overlapping with disgust as they also tend to be triggered by threatening stimuli (Spielberger and Reheiser, 2010) despite showing different early attention modulation (Zhang et al., 2017).

An important feature of human language is that people can integrate various lexical units into a larger sentence unit (Hagoort, 2005; Hagoort and Indefrey, 2014). A series of anticipative and predictive processes take place when sentence comprehension is performed (Vosse and Kempen, 2000) both at syntactic and semantic levels. N400 is an indicator of the difficulty of integrating words into preceding contexts and the predictability of following words in unfolding sentences (Baggio and Hagoort, 2011; Kutas and Federmeier, 2011; Szewczyk and Schriefers, 2018). The N400 effects are reflected at both the semantic level and emotional level when emotional factors are involved in the sentence. Moreno and Vázquez (2011) reported reduced N400 amplitudes for highly expected negative outcomes than for highly expected positive outcomes using a passive reading paradigm while Moreno and Rivera (2014) found enhanced post-N400 frontal positivity amplitudes for unexpected positive outcomes in comparison with unexpected negative ones, indicating a bias toward possible negative results than positive ones. The N400 effects were also shown in more complex contextual setups. León et al. (2010) manipulated the emotional consistency between a story and a sentence describing the emotionality of the story and found that inconsistent emotions elicited larger N400 than consistent emotions. Positive and negative words elicited smaller N400 than neutral words following an emotional two-sentences context regardless of congruency (Delaney-Busch and Kuperberg, 2013) as well as when embedded in a pair of question and answer (Wang et al., 2013).

In addition to N400, some early ERP components have been reported to be sensitive to emotional context of words. Specifically, N1 and P2 were found to be larger for inconsistent emotions compared to consistent emotions (León et al., 2010); there was also evidence that N1 was enlarged by unexpected endings in positive-biased sentences compared to negative-biased sentences and P2 was larger for expected endings than for unexpected ones (Moreno and Rivera, 2014). Also in the early time window, Bayer et al. (2017) reported larger early posterior negativity (EPN) for negative critical words compared with positive and neutral ones in high- and low-relevance contexts. Finally, the N170 is another common component, which is usually induced by emotional words (Zhang et al., 2014) and emotional faces (Hinojosa et al., 2015), and the late positive complex (LPC) is enhanced for emotional words in sentential contexts (Delaney-Busch and Kuperberg, 2013).

In terms of the functional neuroanatomy of contextual processing of emotional words, it is difficult to disentangle activations of single word processing from those of sentence processing (Hinojosa et al., 2020). However, Mellem et al. (2016) attempted to investigate the brain structures involved in emotional sentence processing by comparing sentences with emotional–social content with meaningless sentences in a silent reading paradigm and found that the anterior superior temporal gyrus was specifically activated by emotional sentences. Moreover, Lai et al. (2015) reported activations in emotion-related brain areas such as the amygdala and insula and language-related areas such as the inferior frontal gyrus and middle temporal gyrus during the processing of sentences implying negative connotations.

The purpose of the present ERP study was twofold. Firstly, to the best of our knowledge, it explored for the first time whether new words with emotional connotations modulate brain dynamics based on their consistency with the sentential context; secondly, it investigated whether two negative but distinctive learned emotional connotations of disgust and sadness differently affect the brain dynamics of new words in sentential context. To these aims, the study was divided into a learning session and an ERP recording session. In the learning session, an associative learning paradigm used in our previous studies (Gu et al., 2021, 2022) was adopted for participants to acquire disgusting and sad connotations for pseudowords through repeatedly pairing them with emotional faces. Then the ERP session was carried out on the next day, in which all the pseudowords with acquired emotional connotations (herein new words) were paired with disgusting and sad sentences. Participants were instructed to determine the congruency between the sentence and the new words. Our hypotheses are as follows:

(1) Sad new words will elicit larger EPN amplitudes than disgusting new words based on our previous study (Gu et al., 2022).
(2) Incongruent sentence-new words pairs will enhance N400 compared to congruent ones as reviewed above.
(3) Regarding brain sources for these effects, we expect specific emotion-related sources for disgusting and sad new words; specifically, larger activation in the insula for disgusting new words (Schienle et al., 2017; Cantone et al., 2019; Viol et al., 2019) and in the anterior cingulate cortex for sad new words (Niida and Mimura, 2017; Ramirez-Mahaluf et al., 2018; Webb et al., 2018).
(4) Furthermore, given congruent sentence-new words pairs could be more deeply processed than incongruent sentence-new word pairs, we expect more robust activations in both emotion-related and language-related regions for the former than for the latter (Lai et al., 2015; Mellem et al., 2016).

# Materials and methods

## Participants

Twenty-nine Spanish college students (4 males), native speakers of Spanish, right-handed, without history of psychiatric or neurological disorders, and within an age range of 20 to 22 years old were recruited as participants for the experiment. All participants participated in the experiment voluntarily, received course credit for the learning session and money (5 euros) for the ERP recording session as reward, and provided informed consent. One participant was excluded due to excessive artifacts in the ERP data and four participants were excluded due to low response accuracies during the ERP recording session. The Research Ethics Committee of the University of La Laguna approved this study, and the experiment was conducted according to the principles expressed in the Declaration of Helsinki.

## Material

Twenty pseudowords were composed for the learning session. These pseudowords were 8–9 letters long and divided into two groups that starting with "al" and "ro" respectively. Thirty faces with disgusting and sad expressions were selected from KDEF stimuli database (Lundqvist et al., 1998). The faces selected were as follows: disgust: F02, F03, F09, F12, F13, F22, F27, F35, M12, M14, M18, M22, M24, M25, and M31; sadness: F05, F09, F11, F13, F14, F20, F22, F31, M05, M11, M13, M14, M25, M31, and M35. The hit rates of intended emotions and arousal values of the selected faces retrieved from the database documents (Karolinska Directed Emotional Faces (KDEF), 1998) are shown in Table 1. There was no significant difference in hit rates, $t(14) = 0.429$, $p = 0.674$, or arousal values, $t(14) = 1.520$, $p = 0.151$, between the two emotions. For all faces, non-facial areas (e.g., hair) were removed by applying an ellipsoidal mask. The faces were presented against a black background and with the size of 11.5 cm high by 8.5 cm wide, which equals a visual angle of 9.40° (vertical) × 6.95° (horizontal) at 70-cm viewing distance.

Other than the faces, 110 sentences expressing disgust and sadness (55 each) were composed. Two groups of students of the same college population who did not participate in the final experiment completed questionnaires to rate the emotions expressed by the sentences (39 students) and arousal values (32 students). Regarding emotion expressed, participants were instructed to first select the emotion (anger, disgust, happiness, neutral, or sadness) corresponding to the one connoted by the sentence and then to rate how confidence do they feel about their choice on a 5-point scale (1-a little sure, 5-completely sure). As for arousal, a different group of participants were instructed to rate the value in another questionnaire on a 5-point scale (1-very peaceful, 5-very exciting). No significant difference was found in terms of hit rates, $t(54) = 1.319$, $p = 0.199$, confidence scores $t(54) = 1.037$, $p = 0.305$, or arousal values, $t(54) = 0.417$, $p = 0.683$. Details of the ratings were shown in Table 2. Overall, the length of sad sentences (10.06) was longer than that of disgusting sentences (8.28).

## Learning session

Following the procedures implemented by Gu et al. (2022), the learning session consisted of a training phase, an evaluation phase, and a generalization phase. During the training phase, each trial began with a fixation cross at the center of the screen for 1,000 ms, followed by a sole presentation of the face of 1,000 ms, and then the pseudoword presented in Times New Roman font and size 50 on top of the face for 5,000 ms. There were in total three training blocks in the training phase. In the first block, there were four face—pseudoword pairs and in the second and third blocks, there were three. Each pair within the training block was repeated six times, which resulted in 48, 36, and 36 trials in each of the three blocks, respectively. The pairing between faces and pseudowords was counterbalanced across participants. After each training block, there was a pseudoword selection test in which

**TABLE 1** Means of the hit rates of intended emotions (percentage) and arousal scores of the KDEF faces used in the experiment retrieved from the KDEF database.

| | HIT rates (%) | Arousal |
|---|---|---|
| Emotion | | |
| Disgust | 92.08 (9.0) | 3.65 (0.4) |
| Sadness | 91.66 (7.0) | 3.41 (0.4) |
| Overall | 91.87 (8.0) | 3.53 (0.4) |

Standard deviations were shown in the parenthesis.

TABLE 2 Means and standard deviations of the hit rates of emotions expressed (percentage), choice confidence scores, and arousal of the sentences used in the experiment collected through normative studies.

| | HIT rates (%) | Choice confidence scores | Arousal |
|---|---|---|---|
| Emotion | | | |
| Disgust | 89.70 (8.0) | 4.71 (0.3) | 4.32 (0.4) |
| Sadness | 86.81 (9.0) | 4.66 (0.3) | 4.25 (0.7) |
| Overall | 88.26 (9.0) | 4.67 (0.3) | 4.29 (0.6) |

participants were instructed to select which of two presented pseudowords matched the face presented. Each selection trial began with a fixation cross at the center of the screen for 1,000 ms, followed by one of the faces presented in the training block for 1,000 ms, and then two pseudowords from the same training block appeared at the lower-left corner of the screen for 5,000 ms in Time New Roman font and size 18. Participants made their selections by pressing “1” on the keyboard for the pseudoword on the left and “2” for the one on the right (not the keypad) with their left hands. There were 30 test trials in total, 10 after each learning block.

After participants completed all three training blocks and pseudoword selection tests, they proceeded to the evaluation phase, consisting of a face-pseudoword matching test. There were 20 trials in this phase and the presentation sequence was as follows: a fixation cross at the center of the screen for 1,000 ms—a face from the previous three learning blocks for 1,000 ms—a pseudoword from the previous three learning blocks on top of the face along with two options of “correct” and “incorrect” for 5,000 ms at the lower-left corner of the screen. Like in the pseudoword selection test, participants were instructed to make their selections by pressing “1” on the keyboard for “correct” and “2” for “incorrect.” The fonts and sizes of the pseudowords and “correct” and “incorrect” options were identical to those in the pseudoword selection test.

Finally, there was a generalization phase, which included two tests. The purpose of these two tests was to probe whether participants have acquired the emotions, rather than specific faces, during the training phase. The first test in this phase was a within-modality generalization test. The presentation sequence of the 10 trials was the same as the pseudoword selection test only the faces were replaced with a new set of faces that also express either disgust or sadness. Participants were instructed to select the pseudoword that best describes the emotion expressed by the new face among the two options by pressing “1” or “2” on the keyboard just like in the pseudoword selection test. The second test was a cross-modality generalization test. In this test, sentences expressing disgust (e.g., Un perro se mea en tu pierna / A dog pees on your leg) or sadness (e.g., Tus padres se divorciaron / Your parents divorced) were introduced as probe materials. There were 10 trials in this test and the sentences used here never appeared in the ERP recording session. Each trial began with a fixation cross for 1,000 ms, followed by a sentence at the center of the screen for 1,000 ms in Times New Roman font and size 30, and then two pseudowords from the previous learning session were presented at the lower-left corner of the screen until participants made a response. Participants made their selections in the same way as previous, pressing “1” or “2” on the keyboard. Participants received immediate feedback after response in all the tests throughout the three phases indicating whether their selections were correct or not. The Figure 1 illustrates the three phases, depicting the last frame of the trials.

## ERP recording session

Participants came to the ERP recording session on the next day after completing the learning session. Upon arrival, participants first completed a refreshing session in which they went through all four tests in the preceding learning session. Participants had to reach at least 85% accuracy to be qualified for the ERP session. Such a design enabled us to investigate the effect of acquired emotional connotations rather than short-term memory and excluded the impact of tiredness due to long experimental duration. Next, they were seated comfortably in a chair in a sound-attenuated room. Experimental trials were presented on a computer screen using E-Prime 2.0 at approximately 80 cm from the participants. During the ERP recording session, participants used a joystick for responses. Each trial started with a fixation cross presented at the center of the screen for 1,000 ms, followed by a 500 ms blank screen. Next, a sentence was presented at the center of the screen in Times New Roman font and size 20 and a green arrow appeared under the sentence after 2,000 ms. At this moment, participants could press “2” on the joystick autonomously to proceed if they finished reading the sentence. A fixation cross was presented again at the center of the screen for a random interval between 1,200 and 2,000 ms and then the new word for 1,000 ms (Times New Roman fonts, size 50). Then the word “¿Congruente?” (Congruent?) along with two options of “Sí” (Yes) and “No” were presented in Times New Roman font and size 20, and the participants judged whether the emotional connotations between the sentence and the pseudoword were congruent. Participants were instructed to press “5” and “6” on the joystick to respond. The mapping between joystick buttons and options was counterbalanced across participants. For 20% of the experimental trials, there was an additional emotion probe test followed the congruency test with the sentence “¿Cuál es la emoción de la frase que acabas de leer?” (What is the emotion of the sentence you just read?) presented at the center of the screen to ensure that the participants were reading the sentence stimuli carefully. Under the sentence, there were two options of “Asco” (Disgust) and “Tristeza” (Sadness). Participants were instructed to select by pressing “5” or “6” on the joystick. Once again, the mapping between the buttons and options was counterbalanced across participants. Each experimental trial ended with a blank screen for 500 ms and then continue to the next one. There were two blocks of 100 sentences in the experimental session. Sentences followed by a disgusting pseudoword in block 1 were followed by a sad pseudoword in block 2, and vice versa. See Figure 2 for an example of experimental trials.

# EEG recording and analysis

Electroencephalography (EEG) and electrooculography (EOG) data were recorded with Ag/AgCl electrodes mounted in elastic Quick-caps (Compumedics). EOG data were recorded from two bipolar channels: one from two electrodes placed at the outer canthus of each eye and the other from two electrodes above and below the left eye. EEG data were recorded from 60 electrodes arranged in accordance with the standard 10–20 system with additional electrodes

10.3389/fpsyg.2023.1154442

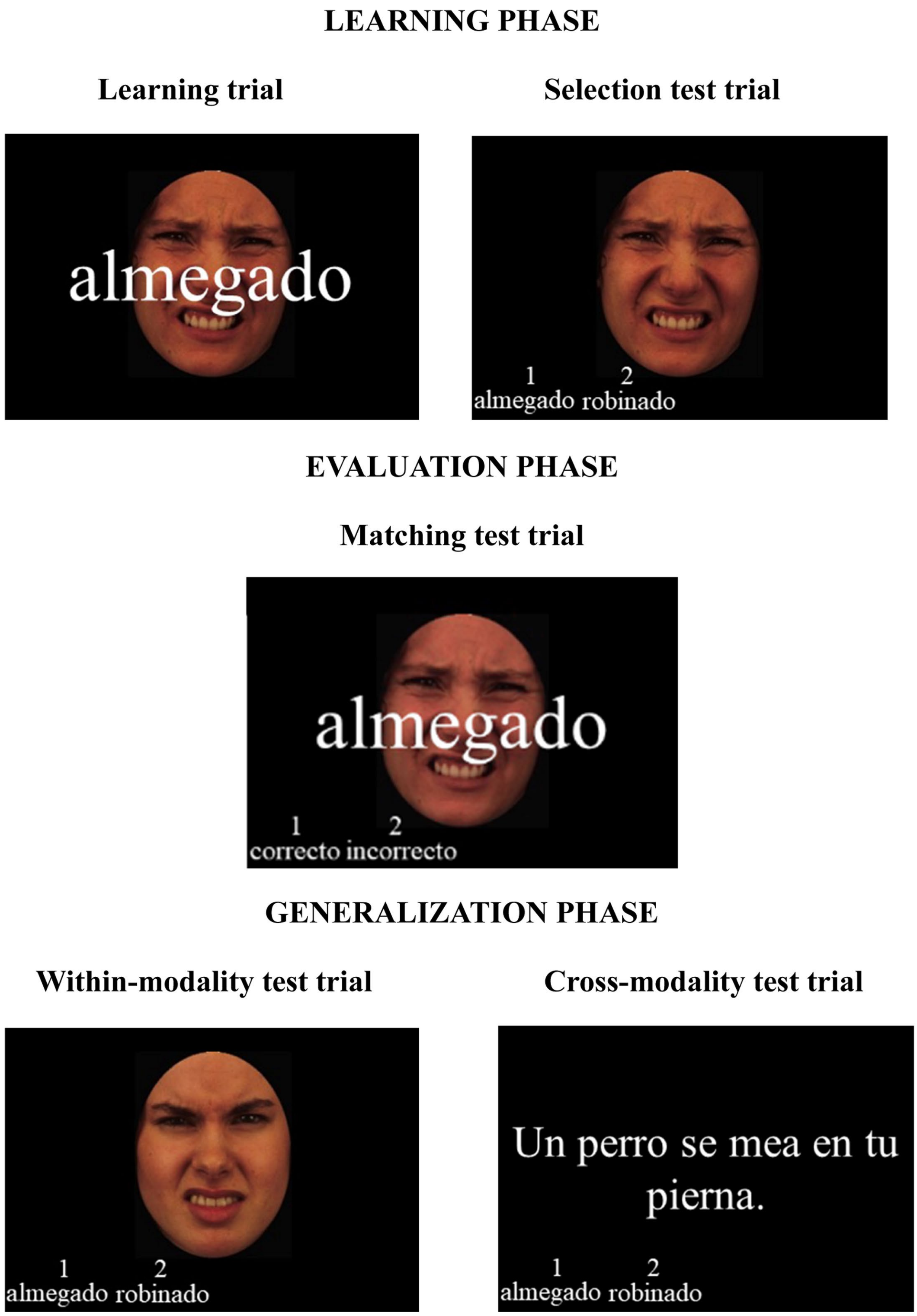


FIGURE 1
Learning session. Illustration of the last frame of trials employed in the learning phase, the evaluation phase, and the generalization phase. The procedures are explained in the text and in Gu et al. (2022). The English translation of the sentence in the figure is "A dog pisses on your leg". The faces used were extracted from the KDEF stimuli database (Lundqvist et al., 1998).

placed on the left and right mastoids (M1 & M2). All electrodes were re-referenced offline to the left and right mastoids. EEG and EOG signals were amplified at 500 Hz sampling rate using Synamp2 amplifier (Neuroscan; Compumedics), with high- and low-pass filters set at 0.05 and 50 Hz, respectively. The impedances of the electrodes were kept at under 5 kΩ. The ERP recordings were time-locked to the onset of each pseudoword and ERP analysis was applied to an epoch extending from 200 ms before to 1,000 ms after the pseudoword onset.

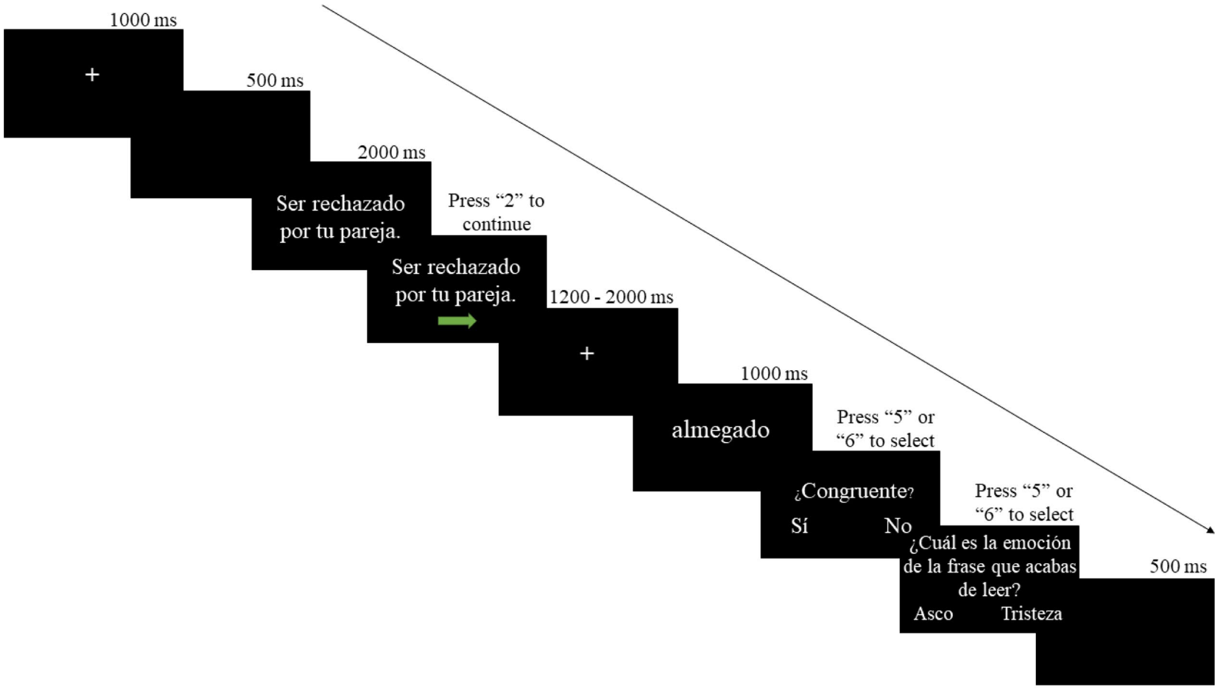


FIGURE 2
Outline of an experimental trial in the ERP recording session. The English translation of the sentence in the figure is "Being rejected by your partner" and the question is "What is the emotion of the sentence you just read?"

EEG preprocessing and analysis were performed with Brainstorm (Gramfort et al., 2010). Drifting, ocular, and motor artifacts in experimental trials were rejected by visual inspections before analysis. Eye blinks and movements were removed by applying the Independent Component Analysis (ICA; Lee, 1998). Finally, trials with EEG voltages exceeding 70 μV measured from peak to peak at any channel were removed (12%).

After preprocessing, the ERP data were computed and analyzed using Brainstorm. Baseline was set at 200 ms before stimuli onset. ERP waveforms were obtained by averaging baseline-corrected EEG segments. The obtained ERP waveforms were then statistically analyzed using the cluster-based random permutation method implemented in Fieldtrip (Maris and Oostenveld, 2007), which conducts multiple spatiotemporal comparisons by identifying clusters of significant differences between conditions (sample points in close spatial and temporal proximity) over the whole ERP segment (32 sample points: 500 time points, from 200 ms prior to and 1,000 ms after pseudoword onset, and 64 channels) so as to find components and time windows of interest. Given that only pair-wise comparisons are applicable to this method, experimental conditions were collapsed based on the main effects of emotion (disgust & sadness) and congruency (congruent & incongruent). To further explore the interaction effect, the pair-wise comparison was done between the differences of the two congruency conditions of each emotion (disgust-congruent minus disgust-incongruent & sadness-congruent minus sadness incongruent). ROIs were created for sets of neighboring solution points showing significant differences ($p < 0.05$) and 2*2 (disgust & sadness * congruent & incongruent)" here to further demonstrate how the ANOVAs were performed using the mean absolute values of current densities in those ROIs and time windows.

## Source localization analysis

Source localization was carried out using Brainstorm and EEG data were co-registered with a standard anatomical template (ICBM152) and boundary element head models were constructed with OpenMEEG (Pascual-Marqui, 2002). Source activities were estimated for each condition using sLORETA (Pascual-Marqui, 2002) with unconstrained source orientations. Differences between every two conditions were calculated for each participant and ROIs were created accordingly for sets of neighboring solution points (no less than 30) showing significant differences ($p < 0.01$). Mean absolute values of the current densities of the ROIs were then exported for running pairwise t-tests as in the EEG data analysis.

## Results

### Behavioral results

#### Learning session

Participants' learning effects were demonstrated through the two tests in the generalization phase since they could best reflect the acquisition of emotional connotations for the pseudowords.

The mean response accuracy for disgusting and sad trials in the two tests was shown in Table 3. There was no significant difference regarding response accuracy of the two types of trials in both the within-modality ($t(23) = 0.514$, $p = 0.612$) and the cross-modality [$t(23) = 2.000$, $p = 0.057$] generalization tests.

TABLE 3 Means and standard deviations of response accuracy (percentage of correct choices) in the within- and the cross-modality generalization tests.

| | Within-modality (%) | Cross-modality (%) |
|---|---|---|
| Emotion | | |
| Disgust | 89.17 (12.0) | 95.83(8.0) |
| Sadness | 86.67 (22.0) | 89.17(16.0) |
| Overall | 87.92 (17.0) | 92.50(12.0) |

## ERP recording session

The mean response accuracies for the congruency and emotion choice tasks in the ERP recording session were 96.85% (SD = 3.67%) and 97.71% (SD = 5.10%) respectively, indicating that the participants have fully understood the experimental instructions and paid attention to the stimuli throughout the experimental process.

## ERP results

The main effects of emotion and congruency were analyzed separately. The waveforms of the four experimental conditions were presented in Figure 3A. For the emotion analyses, congruent and incongruent trials were collapsed and the cluster-based random permutation method was adopted to locate significant clusters in the time window of 0–1,000 ms by comparing between disgusting trials and sad trials. For the congruency analyses, the two emotion conditions were collapsed and congruent and incongruent trials were compared. For the interaction analyses, the differences of the two congruency conditions of each emotion were compared. With such an approach, two clusters were identified that reflect the main effect of emotion and the main effect of congruency respectively, with the former extending from 146–228 ms, coincident with a N1/P2 complex (Figure 3B), and the latter from 304–462 ms, coincident with partially overlapped P3 and N400 components (Figure 3C). Meanwhile, no significant effect was spotted in the interaction analyses.

### The main effect of emotion (146–228ms)

The waveform and topography of the main effect of emotion are illustrated in Figure 3. Sad new words elicited more negative amplitudes than disgusting new words in the central-parietal area in the 146–228 ms time window, $t(23) = 2.904$, $p = 0.008$. Repeated ANOVA analyses revealed an interaction effect of emotion*congruency, $F(1, 23) = 8.377$, $p = 0.008$, $\eta^2_p = 0.267$, with sad congruent trials eliciting larger negative amplitudes than disgusting congruent trials, $t(23) = 3.094$, $p = 0.02$.

### The main effect of congruency (304–462ms)

The waveform and topography of the main effect of congruency are illustrated in Figure 3. Congruent trials elicited larger positive amplitude than incongruent trials in the central-parietal area in the 304–462 time window, $t(23) = 4.872$, $p < 0.001$. Repeated ANOVA analyses revealed a main effect of emotion, $F(1, 23) = 7.621$, $p = 0.011$, $\eta^2_p = 0.249$, and a main effect of congruency, $F(1, 23) = 23.764$, $p < 0.001$, $\eta^2_p = 0.508$, with sad congruent trials eliciting larger positive amplitudes than sad incongruent trials, $t(23) = 4.123$, $p < 0.001$, and disgusting incongruent trials, $t(23) = 5.465$, $p < 0.001$, and disgusting congruent trials eliciting larger positive amplitudes than disgusting incongruent trials, $t(23) = 2.847$, $p = 0.039$.

## Source localization

The source localization did not reveal any converging result for the main effect of emotion but four clusters were identified for the main effect of congruency. Congruent trials elicited larger current densities than incongruent trials in the four significant clusters, that is the lateral orbitofrontal cortex & insular cortex & rostral middle frontal gyrus, $t(23) = 4.772$, $p < 0.001$, the left inferior temporal lobe & parahippocampal gyrus & lingual gyrus, $t(23) = 3.801$, $p < 0.001$, the rostral anterior cingulate cortex & medial orbitofrontal cortex & lateral orbitofrontal cortex, $t(23) = 4.292$, $p < 0.001$, and the right superior temporal gyrus & middle temporal gyrus & inferior temporal gyrus, $t(23) = 4.158$, $p < 0.001$. See Figure 4 for details.

## Discussion

The present study examined how acquired disgusting and sad connotations affect written word processing under sentential contexts. Participants acquired the two emotional connotations for new words by pairing pseudowords with emotional faces in a learning session and the high accuracies in responding to the tests indicated that the acquisition was successful. In the ERP recording session on the next day, participants were presented with sentential contexts expressing either disgusting or sad events followed by one of the new words learned in the previous session. The instruction to participants was to judge the emotional congruency between the context and the new word. The results revealed several main facts. Firstly, sad new words elicited larger negativity than disgusting new words in the early time window, coincident with N1/P2 components complex, indicating that the emotional learning succeeded to show differential modulation of a brain signature between new words with two discrete negative emotions. Secondly, new words that were emotionally congruent with the sentence induced larger positive-going waveform than those that were emotionally incongruent with the sentence in a later time window (304–462 ms), coincident with a N400 and P3 components. Thirdly, the source localization for this congruency effect revealed activations mainly in fronto-medial and temporal brain structures, which further demonstrates successful emotional connotation acquisition for the new words and a congruency effect of emotion.

## Behavioral and ERP results

These results were possible because the methodology used in the learning session (see also Gu et al., 2021, 2022). Participants achieved high response accuracy in the within- and cross-modality tests, which suggests that rather than merely associating the new words with specific faces, they acquired the corresponding emotions expressed by those faces and were able to apply the new words to refer to new materials. We intentionally used a categorical design of new words (first two letters being "al" and "ro") to reduce the learning difficulty as the learning session was relatively short. Such a design was

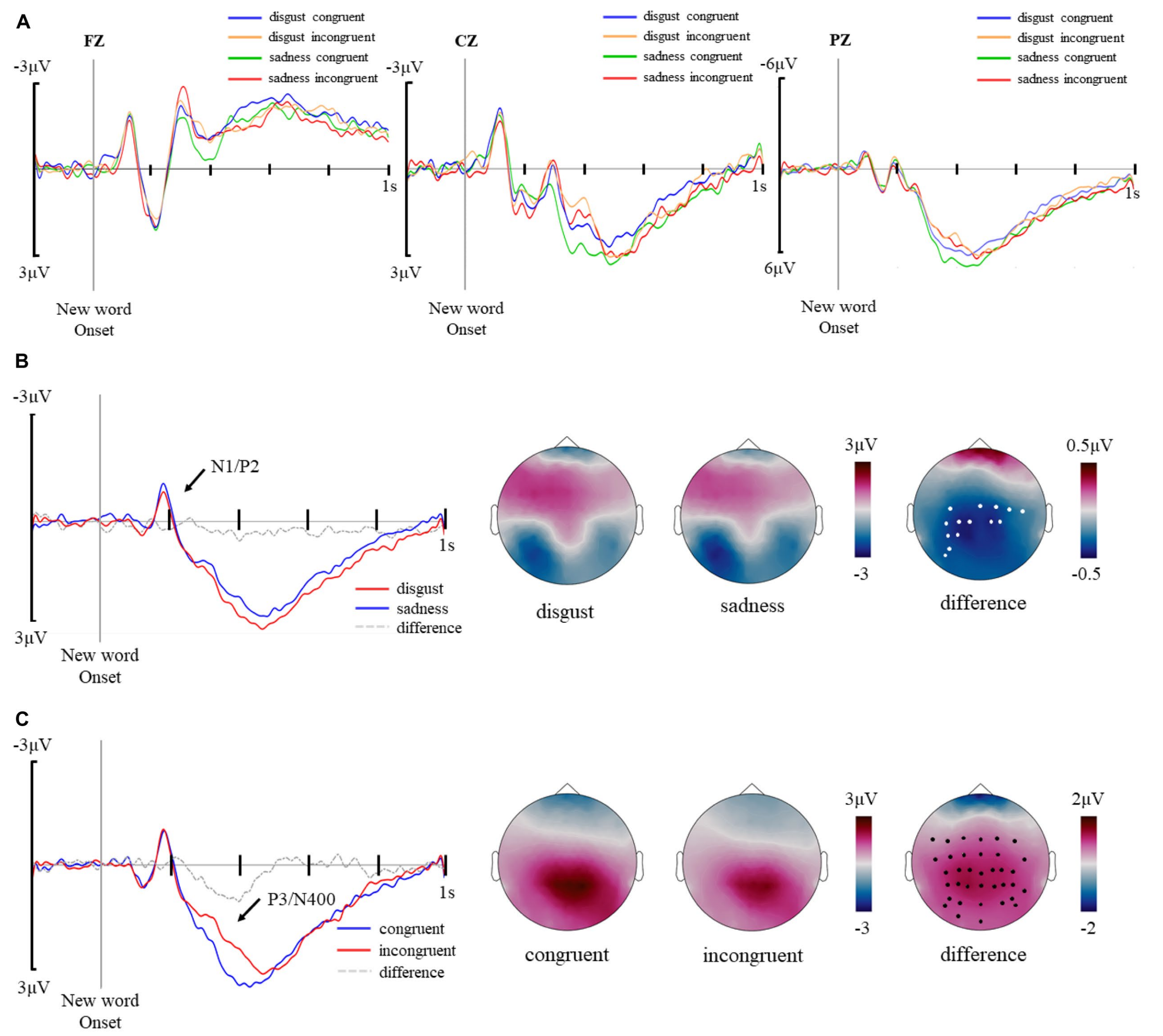


FIGURE 3
**(A)** Average waveforms of disgust congruent, disgust incongruent, sad congruent, and sad incongruent trials in a cluster of representative electrodes (FZ, CZ, PZ). **(B)** The main effect of emotion. Average waveforms of disgusting new words and sad new words in a cluster of electrodes showing significant differences (C3, CP5, CP3, CP1, P5, P3, PO5, PO7, CZ, C2, C4, C6, CP2, and CP4) and topographical distributions of the central-parietal negativity for disgusting and sad new words, and for their difference. Electrodes showing significant differences were marked with white dots. **(C)** The main effect of congruency. Average waveforms of congruent trials and incongruent trials in an extensive cluster, which includes fronto-central and parietal electrodes showing significant differences (FC5, FC3, FC1, FCZ, FC2, FC4, C5, C3, C1, CZ, C2, C6, CP5, CP3, CP1, CPZ, CP2, CP4, CP6, P5, P3, P1, PZ, P2, P4, P6, P8, PO7, PO5, PO3, POZ, PO4, PO6, PO8, O1, and OZ) and topographical distributions of the central-parietal positivity for congruent trials, incongruent trials, and differences between the two types of trials. Electrodes showing significant differences were marked with black dots.

employed in our previous study as well (Gu et al., 2021, 2022). The possibility that participants only pay attention to the first two letters could be ruled out since evidence suggests that lexical processing is not conducted in a letter-by-letter fashion (Shallice and Saffran, 1986). Meanwhile, such a design emulates the semantic structure of real emotional words that are often organized in morphological sets with the same root (e.g., disgust, disgusting, disgusted).

ERP data analysis revealed a main effect of emotion between 146 and 228 ms, represented by larger centro-parietal negativity elicited by sad new words than disgusting new words combined with a positivity distributed in the frontal-central area, which resembles the N1/P2 complex (Begleiter et al., 1979; Scott et al., 2009). Such early components were reported in previous studies focusing on emotion and words to be reflecting the effect of emotion on early lexical access (Sereno et al., 1998; Sereno and Rayner, 2003; Hofmann et al., 2009) and attention allocation (Kanske and Kotz, 2007; Gu et al., 2022). More importantly, such early components suggest different processing patterns of specific emotions (Thomas et al., 2007; Mattavelli et al., 2016). The pattern discovered here is contrary to our previous study investigating individual emotional new word processing (Gu et al., 2022), in which disgusting new words elicited larger EPN amplitudes than sad new words. The difference could be attributed to the influence of emotional sentential contexts that either reduce the attentional resource costs or decoding difficulty of disgusting new words, whose connotations were acquired through faces (Suzuki and Akiyama, 2013; Leleu et al., 2015). In addition, ERP components were highly

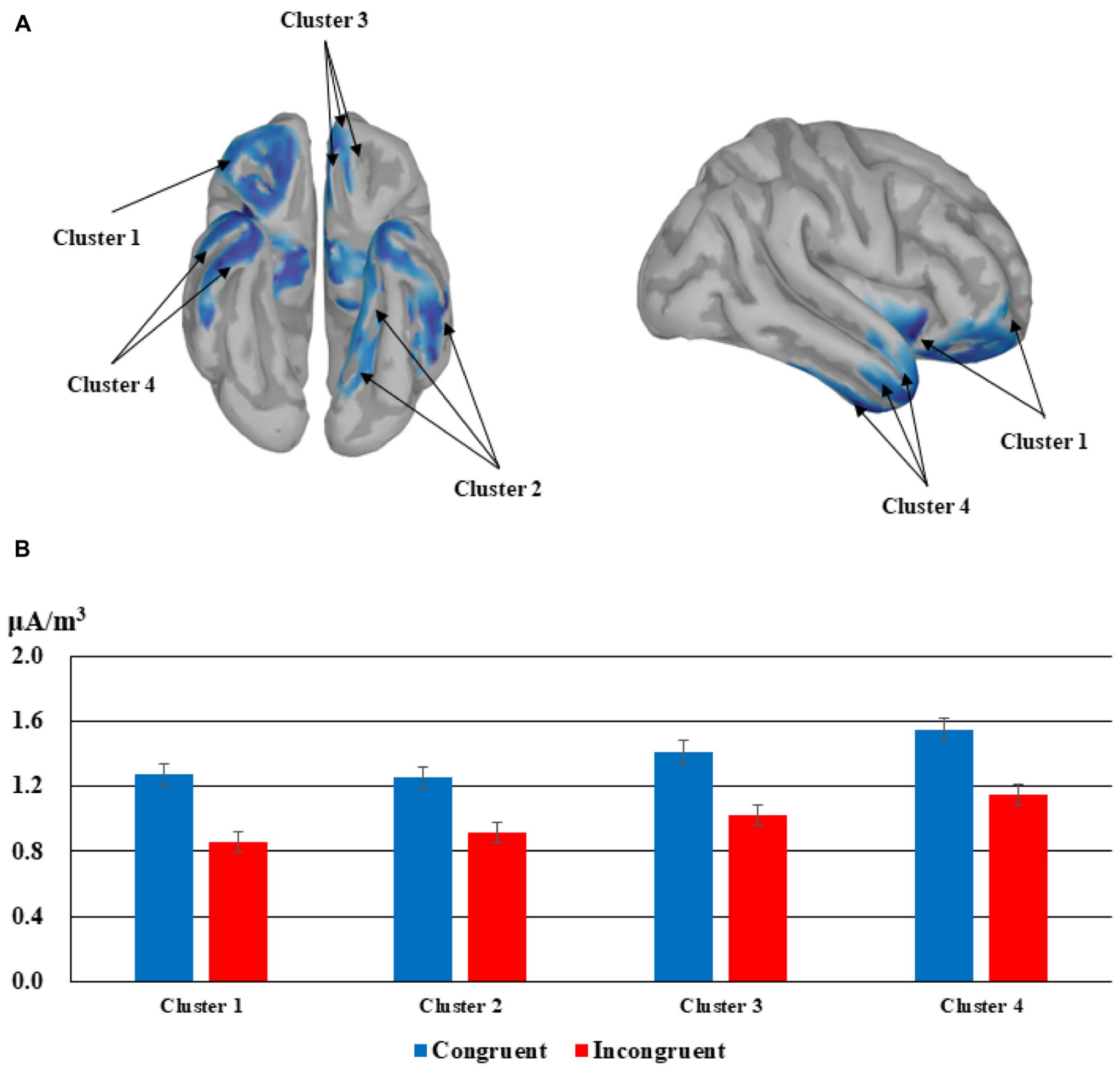


FIGURE 4
Source localization for the congruency effects corresponding to the ERPs in the time window of 304–462ms. **(A)** The cortices demonstrating significant effects in four clusters (Cluster 1: lateral orbitofrontal cortex & insular cortex & rostral middle frontal gyrus; Cluster 2: the left inferior temporal lobe & parahippocampal gyrus & lingual gyrus; Cluster 3: the rostral anterior cingulate cortex & medial orbitofrontal cortex & lateral orbitofrontal cortex; Cluster 4: the right superior temporal gyrus & middle temporal gyrus & inferior temporal gyrus). **(B)** Mean current densities for congruent trials and incongruent trials in the four clusters.

sensitive to different experimental designs and materials, for example, Scott et al. reported enlarged N1 amplitudes for isolated negative words than for positive words (2009) while Moreno and Rivera found a more positive-biased N1 in their study involving sentential contexts (2014).

The main effect of congruency was shown through a positive/negative complex from 304 to 462 ms, which was similar to the P3/N400 complex given its time window and scalp distribution (Chwilla et al., 1995). According to previous studies, P3 could be closely related to decision-making (O'Connell et al., 2012; Kelly and O'Connell, 2013; Twomey et al., 2015) as well as event categorization (Kok, 2001; Polich, 2007) processes, which are in line with the characteristics of the task used in our ERP recording session, where the participants were instructed to determine the emotional congruency between the new word and the preceding context. Other than that, the complex could be interpreted as a semantic N400 effect that is commonly reported in processing emotional words in contexts (for review, see Hinojosa et al., 2020). The waveform was more negative-going for incongruent trials than for congruent trials, which reflects higher integration difficulties and/or lower anticipation possibilities for emotionally incongruent new words (Baggio and Hagoort, 2011; Kutas and Federmeier, 2011; Szewczyk and Schriefers, 2018). The N400 effect thus reflected the successful acquisition of emotional connotation through emotional faces in the learning session. However, such an interpretation should be viewed with caution as it was difficult to disentangle the N400-like negativity from the P3-like positivity, which overlap in the same time window. Nevertheless, the P3/N400 complex spotted here was induced by the emotional congruency at the sentence level rather than pure associative pairing between faces and new words.

### Source localization results

The role of emotion in the congruency judgment process was further verified through source localization results. Congruent trials induced larger current densities in four different ROIs related to emotion and language processing than incongruent trials during the 304–462 ms time window. The first group of structures includes the lateral orbitofrontal cortex, the insular cortex, and rostral middle frontal gyrus, which were reported to be related to emotion regulation (Gross, 2002; Hooker and Knight, 2010), disgust processing (Calder et al., 2000; Krolak-Salmon et al., 2003; Wright et al., 2004), and emotion generation (Waugh et al., 2010, 2014; Roy et al., 2012), respectively. Next, two word recognition related structures, left inferior temporal lobe (Sharp et al., 2004; Antonucci et al., 2008; Trimmel et al., 2018) and lingual gyrus (Mechelh et al., 2000; Xiao et al., 2005; Ghosh et al., 2010), were activated more for congruent trials than for incongruent ones, and the same pattern applies to parahippocampal gyrus, a structure involved in emotion identification and regulation (Almeida et al., 2009; Zhu et al., 2019). In the third ROI, the rostral anterior cingulate cortex is the neural locus for sad information processing as suggested recently (Niida and Mimura, 2017; Ramirez-Mahaluf et al., 2018; Webb et al., 2018). Similarly, the orbitofrontal cortex was reported to be related to depression and emotion regulation (Rolls et al., 2020), despite the medial section is more closely associated to negative emotions than the lateral section (Northoff et al., 2000). The temporal lobe in the fourth ROI is another brain structure demonstrated to be critical to emotion processing (Adolphs, 2002; Monti and Meletti, 2015). Specifically, the superior temporal gyrus is involved in emotion perception of facial stimuli (Bigler et al., 2007; Radua et al., 2010), the middle temporal gyrus is connected with face recognition (Pourtois et al., 2005) and word meaning retrieval (Acheson and Hagoort, 2013), and the inferior temporal gyrus is in support of word recognition (Nobre et al., 1994). To sum up, the above activation patterns suggested that firstly, the emotional connotation acquisition for the new words was successful and effective, particularly reflected through the larger activations in the insula and anterior cingulate cortex; secondly, the congruency effect was emotional as new words that are emotionally congruent with the preceding contexts induced larger current densities in emotion- and word recognition-related regions.

### Implications and possible future research directions

One of the novelty in the present experimental design was employing emotional faces rather than emotional scenes commonly used in previous studies (Fritsch and Kuchinke, 2013; Kuchinke et al., 2015), as associative contexts in the learning session. This method succeeded in showing that disgusting new words and sad new words were processed differently, as reflected the modulation of the N1/P2 complex in the early time window. Moreover, this study revealed that emotionally constraining contexts influence the processing of incoming emotional information (Hinojosa et al., 2020), even recently acquired as was the case here. Importantly, this study provided evidence from a discrete emotion model, ruling out the impact of arousal as that of the associative contexts and experimental contexts was matched. Finally, this study presented clues relevant for second language (L2) acquisition of words emotional connotations. It suggests that pairing L2 words with facial expressions (of teachers and/or students) could be a simple and efficient method to induce emotional semantics of L2 in classroom learning. Furthermore, it supports the idea that embodied representations of emotional words contribute to reinforce meaning (Pulvermüller, 2013).

Meanwhile, future studies could conduct similar investigations on a more gender-balanced participant group to compare the learning and processing of words' emotional connotations between males and females, since gender has been reported to affect the ERP amplitudes (Yang et al., 2016) and latency (Toufan et al., 2021) as well as emotional cognition (Lin et al., 2021). In addition, neutrality could be introduced as a research baseline to further demonstrate the differential processing of words' acquired emotional connotations in sentential contexts.

## Conclusion

The current study presents evidence of how words' acquired disgusting and sad connotations are processed in emotionally congruent and incongruent sentential contexts. ERP results suggested that sad new words elicited larger negativity compared with disgusting new words, which demonstrates unique brain temporal dynamics for processing the two discrete emotional connotations acquired through emotional faces in emotional contexts. Meanwhile, an emotional congruency effect was revealed by enhanced positivity for emotionally congruent trials than incongruent trials. In addition, the congruency effect was accompanied by larger activations in emotion regulation and processing-related brain structures for congruent trials, which verifies the emotion acquisition effect and highlights the role of emotion in the congruency judgment process. In conclusion, the present study adds relevant evidence in the field of emotional words processing by demonstrating the brain dynamics during the processing of words' acquired emotional connotation as well as their sensitivity to sentential context.

## Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

## Ethics statement

The studies involving human participants were reviewed and approved by The Research Ethics Committee of the University of La Laguna. The patients/participants provided their written informed consent to participate in this study.

## Author contributions

BG: experiment design and conduction, data processing, and paper writing. BL: experiment design and conduction and data processing. DB: experiment design, data processing, and paper writing guidance. MV: experiment design and paper writing guidance. All authors contributed to the article and approved the submitted version.

## Funding

European Regional Development Fund (Grant RTI2018-098730-B-I00): EEG equipment and facilities, and participants' rewards. The National Social Science Fund of China (22CYY019): Open access publication fees. The Fundamental Research Funds for the Central Universities (DUT21RC(3)094): Information retrieval and data processing equipment procurement. The Research Funds for the School of International Education at Dalian University of Technology (SIE21RYB12): Information retrieval and data processing equipment procurement.


## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

## Publisher's note



## Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2023.1154442/full#supplementary-material

## References


Acheson, D. J., and Hagoort, P. (2013). Stimulating the brain's language network: syntactic ambiguity resolution after TMS to the inferior frontal gyrus and middle temporal gyrus. *J. Cogn. Neurosci.* 25, 1664–1677. doi: 10.1162/jocn_a_00430

Adolphs, R. (2002). Neural systems for recognizing emotion. *Curr. Opin. Neurobiol.* 12, 169–177. doi: 10.1016/S0959-4388(02)00301-X

Almeida, J. R. C., Mechelli, A., Hassel, S., Versace, A., Kupfer, D. J., and Phillips, M. L. (2009). Abnormally increased effective connectivity between parahippocampal gyrus and ventromedial prefrontal regions during emotion labeling in bipolar disorder. *Psychiatry Res. Neuroimaging* 174, 195–201. doi: 10.1016/J.PSCYCHRESNS.2009.04.015

Antonucci, S., Beeson, P., Labiner, D., and Rapcsak, S. (2008). Lexical retrieval and semantic knowledge in patients with left inferior temporal lobe lesions. *Aphasiology* 22, 281–304. doi: 10.1080/02687030701294491

Baggio, G., and Hagoort, P. (2011). The balance between memory and unification in semantics: a dynamic account of the N400. *Lang. Cogn. Process.* 26, 1338–1367. doi: 10.1080/01690965.2010.542671

Barrett, L. F., Lindquist, K. A., and Gendron, M. (2007). Language as context for the perception of emotion. *Trends Cogn. Sci.* 11, 327–332. doi: 10.1016/J.TICS.2007.06.003

Bayer, M., Ruthmann, K., and Schacht, A. (2017). The impact of personal relevance on emotion processing: evidence from event-related potentials and pupillary responses. *Soc. Cogn. Affect. Neurosci.* 12, 1470–1479. doi: 10.1093/scan/nsx075

Begleiter, H., Porjesz, B., and Garozzo, R. (1979). Visual evoked potentials and affective ratings of semantic stimuli. *Evoked Brain Potentials Behav.*, 127–141. doi: 10.1007/978-1-4684-3462-0_5

Bigler, E. D., Mortensen, S., Neeley, E. S., Ozonoff, S., Krasny, L., Johnson, M., et al. (2007). Superior temporal gyrus, language function, and autism. *Dev. Neuropsychol.* 31, 217–238. doi: 10.1080/87565640701190841

Bradley, M. M., and Lang, P. J. (2000). "Measuring emotion: behavior, feeling, and physiology" in *Cognitive neuroscience of emotion*. eds. R. D. Lane and L. Nadel (NY: Oxford University Press), 242–276. https://psycnet.apa.org/record/2000-08961-010

Briesemeister, B. B., Kuchinke, L., and Jacobs, A. M. (2011). Discrete emotion effects on lexical decision response times. *PLoS One* 6:e23743. doi: 10.1371/JOURNAL.PONE.0023743

Briesemeister, B. B., Kuchinke, L., and Jacobs, A. M. (2014). Emotion word recognition: discrete information effects first, continuous later? *Brain Res.* 1564, 62–71. doi: 10.1016/j.brainres.2014.03.045

Calder, A. J., Keane, J., Manes, F., Antoun, N., and Young, A. W. (2000). Impaired recognition and experience of disgust following brain injury. *Nat. Neurosci.* 3, 1077–1078. doi: 10.1038/80586

Cantone, M., Lanza, G., Bella, R., Pennisi, G., Santalucia, P., Bramanti, P., et al. (2019). Fear and disgust: case report of two uncommon emotional disturbances evoked by visual disperceptions after a right temporal-insular stroke. *BMC Neurol.* 19:193. doi: 10.1186/s12883-019-1417-0

Chwilla, D. J., Brown, C. M., and Hagoort, P. (1995). The N400 as a function of the level of processing. *Psychophysiology* 32, 274–285. doi: 10.1111/j.1469-8986.1995.tb02956.x

Delaney-Busch, N., and Kuperberg, G. (2013). Friendly drug-dealers and terrifying puppies: affective primacy can attenuate the N400 effect in emotional discourse contexts. *Cogn. Affect. Behav. Neurosci.* 13, 473–490. doi: 10.3758/s13415-013-0159-5

Ekman, P. (1992). An argument for basic emotions. *Cognit. Emot.* 6, 169–200. doi: 10.1080/02699939208411068

Ferré, P., Haro, J., and Hinojosa, J. A. (2017). Be aware of the rifle but do not forget the stench: differential effects of fear and disgust on lexical processing and memory. *Cognit. Emot.* 32, 796–811. doi: 10.1080/02699931.2017.1356700

Frazier, T. W., Strauss, M. E., and Steinhauer, S. R. (2004). Respiratory sinus arrhythmia as an index of emotional response in young adults. *Psychophysiology* 41, 75–83. doi: 10.1046/j.1469-8986.2003.00131.x

Fritsch, N., and Kuchinke, L. (2013). Acquired affective associations induce emotion effects in word recognition: an ERP study. *Brain Lang.* 124, 75–83. doi: 10.1016/j.bandl.2012.12.001

Ghosh, S., Basu, A., Kumaran, S. S., and Khushu, S. (2010). Functional mapping of language networks in the normal brain using a word-association task. *Indian J. Radiol. Imag.* 20, 182–187. doi: 10.4103/0971-3026.69352/BIB

Gramfort, A., Papadopoulo, T., Olivi, E., and Clerc, M. (2010). OpenMEEG: Opensource software for quasistatic bioelectromagnetics. *Biomed. Eng. Online* 9:45. doi: 10.1186/1475-925X-9-45

Gross, J. J. (2002). Emotion regulation: Affective, cognitive, and social consequences. *J. Psychophysiol.* 39, 281–291. doi: 10.1017/S0048577201393198

Gross, J. J., and Levenson, R. W. (1997). Hiding feelings: the acute effects of inhibiting negative and positive emotion. *J. Abnorm. Psychol.* 106, 95–103. doi: 10.1037/0021-843X.106.1.95

Gu, B., Liu, B., Wang, H., Beltrán, D., and De Vega, M. (2021). Learning new words' emotional meanings in the contexts of faces and sentences. *Psicológica* 42, 57–84. doi: 10.2478/psicolj-2021-0004

Gu, B., Liu, B., Wang, H., de Vega, M., and Beltrán, D. (2022). ERP signatures of pseudowords' acquired emotional connotations of disgust and sadness. *Language, Cognition Neurosci.* 1–17. doi: 10.1080/23273798.2022.2099914

Hagoort, P. (2005). On Broca, brain, and binding: a new framework. *Trends Cogn. Sci.* 9, 416–423. doi: 10.1016/J.TICS.2005.07.004

Hagoort, P., and Indefrey, P. (2014). The neurobiology of language beyond single words. *Annu. Rev. Neurosci.* 37, 347–362. doi: 10.1146/annurev-neuro-071013-013847

Hinojosa, J. A., Mercado, F., and Carretié, L. (2015). N170 sensitivity to facial expression: a meta-analysis. *Neurosci. Biobehav. Rev.* 55, 498–509. doi: 10.1016/J.NEUBIOREV.2015.06.002

Hinojosa, J. A., Moreno, E. M., and Ferré, P. (2020). Affective neurolinguistics: towards a framework for reconciling language and emotion. *Lang. Cogn. Neurosci.* 35, 813–839. doi: 10.1080/23273798.2019.1620957

Hofmann, M. J., Kuchinke, L., Tamm, S., Võ, M. L. H., and Jacobs, A. M. (2009). Affective processing within 1/10th of a second: high arousal is necessary for early facilitative processing of negative but not positive words. *Cogn. Affect. Behav. Neurosci.* 9, 389–397. doi: 10.3758/9.4.389

Hooker, C. I., and Knight, R. T. (2010). "The role of lateral orbitofrontal cortex in the inhibitory control of emotion" in *The orbitofrontal cortex* (London: Oxford University Press), 1–22.

Kanske, P., and Kotz, S. A. (2007). Concreteness in emotional words: ERP evidence from a hemifield study. *Brain Res.* 1148, 138–148. doi: 10.1016/j.brainres.2007.02.044

Karolinska Directed Emotional Faces (KDEF). (1998) Documents—Department of Experimental Clinical and Health Psychology—Ghent University. Retrieved April 8, 2020. Available from: https://www.ugent.be/pp/ekgp/en/research/research-groups/panlab/kdef.

Kelly, S. P., and O'Connell, R. G. (2013). Internal and external influences on the rate of sensory evidence accumulation in the human brain. *J. Neurosci.* 33, 19434–19441. doi: 10.1523/JNEUROSCI.3355-13.2013

Kok, A. (2001). On the utility of P3 amplitude as a measure of processing capacity. *Psychophysiology* 38, 557–577. doi: 10.1017/S0048577201990559

Kreibig, S. D., Wilhelm, F. H., Roth, W. T., and Gross, J. J. (2007). Cardiovascular, electrodermal, and respiratory response patterns to fear- and sadness-inducing films. *Psychophysiology* 44, 787–806. doi: 10.1111/j.1469-8986.2007.00550.x

Krolak-Salmon, P., Hénaff, M. A., Isnard, J., Tallon-Baudry, C., Guénot, M., Vighetto, A., et al. (2003). An attention modulated response to disgust in human ventral anterior insula. *Ann. Neurol.* 53, 446–453. doi: 10.1002/ana.10502

Krumhansl, C. L. (1997). An exploratory study of musical emotions and psychophysiology. *Can. J. Exp. Psychol.* 51, 336–353. doi: 10.1037/1196-1961.51.4.336

Kuchinke, L., Fritsch, N., and Müller, C. J. (2015). Evaluative conditioning of positive and negative valence affects P1 and N1 in verbal processing. *Brain Res.* 1624, 405–413. doi: 10.1016/j.brainres.2015.07.059

Kunzmann, U., and Grühn, D. (2005). Age differences in emotional reactivity: the sample case of sadness. *Psychol. Aging* 20, 47–59. doi: 10.1037/0882-7974.20.1.47

Kutas, M., and Federmeier, K. D. (2011). Thirty years and counting: finding meaning in the N400 component of the event-related brain potential (ERP). *Annu. Rev. Psychol.* 62, 621–647. doi: 10.1146/annurev.psych.093008.131123

Lai, V. T., Willems, R. M., and Hagoort, P. (2015). Feel between the lines: implied emotion in sentence comprehension. *J. Cogn. Neurosci.* 27, 1528–1541. doi: 10.1162/JOCN_A_00798

Lee, T.-W. (1998). *Independent component analysis*. In Independent Component Analysis. Springer

Leleu, A., Godard, O., Dollion, N., Durand, K., Schaal, B., and Baudouin, J. Y. (2015). Contextual odors modulate the visual processing of emotional facial expressions: an ERP study. *Neuropsychologia* 77, 366–379. doi: 10.1016/j.neuropsychologia.2015.09.014

Lench, H. C., Flores, S. A., and Bench, S. W. (2011). Discrete emotions predict changes in cognition, judgment, experience, behavior, and physiology: a meta-analysis of experimental emotion elicitations. *Psychol. Bull.* 137, 834–855. doi: 10.1037/a0024244

León, I., Díaz, J. M., de Vega, M., and Hernández, J. A. (2010). Discourse-based emotional consistency modulates early and middle components of event-related potentials. *Emotion* 10, 863–873. doi: 10.1037/A0019983

Lightfoot, D. (2010). Language acquisition and language change. *Wiley Interdiscip. Rev. Cogn. Sci.* 1, 677–684. doi: 10.1002/wcs.39

Lin, Y., Ding, H., and Zhang, Y. (2021). Gender differences in identifying facial, prosodic, and semantic emotions show category-and channel-specific effects mediated by encoder's gender. *J. Speech Lang. Hear. Res.* 64, 2941–2955. doi: 10.1044/2021_JSLHR-20-00553

Lundqvist, D., Flykt, A., and Öhman, A. (1998). *The Karolinska directed emotional faces—KDEF*. CD ROM from Department of Clinical Neuroscience, Psychology Section, Karolinska Institutet.

Maris, E., and Oostenveld, R. (2007). Nonparametric statistical testing of EEG- and MEG-data. *J. Neurosci. Methods* 164, 177–190. doi: 10.1016/j.jneumeth.2007.03.024

Mattavelli, G., Rosanova, M., Casali, A. G., Papagno, C., and Romero Lauro, L. J. (2016). Timing of emotion representation in right and left occipital region: evidence from combined TMS-EEG. *Brain Cogn.* 106, 13–22. doi: 10.1016/j.bandc.2016.04.009

Mechelh, A., Humphreys, G. W., Mayall, K., Olson, A., and Price, C. J. (2000). Differential effects of word length and visual contrast in the fusiform and lingual gyri during reading. *Proc. R. Soc. B Biol. Sci.* 267, 1909–1913. doi: 10.1098/rspb.2000.1229

Mellem, M. S., Jasmin, K. M., Peng, C., and Martin, A. (2016). Sentence processing in anterior superior temporal cortex shows a social-emotional bias. *Neuropsychologia* 89, 217–224. doi: 10.1016/j.neuropsychologia.2016.06.019

Monti, G., and Meletti, S. (2015). Emotion recognition in temporal lobe epilepsy: a systematic review. *Neurosci. Biobehav. Rev.* 55, 280–293. doi: 10.1016/J.NEUBIOREV.2015.05.009

Moreno, E. M., and Rivera, I. C. (2014). Setbacks, pleasant surprises and the simply unexpected: brainwave responses in a language comprehension task. *Soc. Cogn. Affect. Neurosci.* 9, 991–999. doi: 10.1093/scan/nst066

Moreno, E. M., and Vázquez, C. (2011). Will the glass be half full or half empty? Brain potentials and emotional expectations. *Biol. Psychol.* 88, 131–140. doi: 10.1016/j.biopsycho.2011.07.003

Niida, R., and Mimura, M. (2017). The center of sadness, pain, and recognition. *Brain Nerve* 69, 417–426. doi: 10.11477/mf.1416200759

Nobre, A. C., Allison, T., and McCarthy, G. (1994). Word recognition in the human inferior temporal lobe. *Nature* 372, 260–263. doi: 10.1038/372260a0

Northoff, G., Richter, A., Gessner, M., Schlagenhauf, F., Fell, J., Baumgart, F., et al. (2000). Functional dissociation between medial and lateral prefrontal cortical spatiotemporal activation in negative and positive emotions: a combined fMRI/MEG study. *Cereb. Cortex* 10, 93–107. doi: 10.1093/cercor/10.1.93

O'Connell, R. G., Dockree, P. M., and Kelly, S. P. (2012). A supramodal accumulation-to-bound signal that determines perceptual decisions in humans. *Nat. Neurosci.* 15, 1729–1735. doi: 10.1038/nn.3248

Pascual-Marqui, R. D. (2002). Standardized low-resolution brain electromagnetic tomography (sLORETA): technical details. *Methods Find. Exp. Clin. Pharmacol.* 24, 5–12.

Phillips, M. L., Young, A. W., Senior, C., Brammer, M., Andrew, C., Calder, A. J., et al. (1997). A specific neural substrate for perceiving facial expressions of disgust. *Nature* 389, 495–498. doi: 10.1038/39051

Polich, J. (2007). Updating P300: an integrative theory of P3a and P3b. *Clin. Neurophysiol.* 118, 2128–2148. doi: 10.1016/j.clinph.2007.04.019

Pourtois, G., de Gelder, B., Bol, A., and Crommelinck, M. (2005). Perception of facial expressions and voices and of their combination in the human brain. *Cortex* 41, 49–59. doi: 10.1016/S0010-9452(08)70177-1

Pulvermüller, F. (2013). How neurons make meaning: brain mechanisms for embodied and abstract-symbolic semantics. *Trends Cogn. Sci.* 17, 458–470. doi: 10.1016/J.TICS.2013.06.004

Radua, J., Phillips, M. L., Russell, T., Lawrence, N., Marshall, N., Kalidindi, S., et al. (2010). Neural response to specific components of fearful faces in healthy and schizophrenic adults. *NeuroImage* 49, 939–946. doi: 10.1016/j.neuroimage.2009.08.030

Ramirez-Mahaluf, J. P., Perramon, J., Otal, B., Villoslada, P., and Compte, A. (2018). Subgenual anterior cingulate cortex controls sadness-induced modulations of cognitive and emotional network hubs. *Sci. Rep.* 8:8566. doi: 10.1038/s41598-018-26317-4

Ritz, T., Thöns, M., Fahrenkrug, S., and Dahme, B. (2005). Airways, respiration, and respiratory sinus arrhythmia during picture viewing. *Psychophysiology* 0, 050826083451001–050826083451??? doi: 10.1111/j.1469-8986.2005.00312.x

Rolls, E. T., Cheng, W., and Feng, J. (2020). The orbitofrontal cortex: reward, emotion and depression. Brain. *Communications* 2:fcaa196. doi: 10.1093/braincomms/fcaa196

Roy, M., Shohamy, D., and Wager, T. D. (2012). Ventromedial prefrontal-subcortical systems and the generation of affective meaning. *Trends Cogn. Sci.* 16, 147–156. doi: 10.1016/J.TICS.2012.01.005

Rozin, P., and Haidt, J. (2013). The domains of disgust and their origins: Contrasting biological and cultural evolutionary accounts. *Trends Cogn. Sci.* 17, 367–368. doi: 10.1016/j.tics.2013.06.001

Schienle, A., Übel, S., and Wabnegger, A. (2017). When opposites lead to the same: a direct comparison of explicit and implicit disgust regulation via fMRI. *Soc. Cogn. Affect. Neurosci.* 12, 445–451. doi: 10.1093/scan/nsw144

Scott, G. G., O'Donnell, P. J., Leuthold, H., and Sereno, S. C. (2009). Early emotion word processing: evidence from event-related potentials. *Biol. Psychol.* 80, 95–104. doi: 10.1016/J.BIOPSYCHO.2008.03.010

Sereno, S. C., and Rayner, K. (2003). Measuring word recognition in reading: eye movements and event-related potentials. *Trends Cogn. Sci.* 7, 489–493. doi: 10.1016/j.tics.2003.09.010

Sereno, S. C., Rayner, K., and Posner, M. I. (1998). Establishing a time-line of word recognition: evidence from eye movements and event-related potentials. *Neuroreport* 9, 2195–2200. doi: 10.1097/00001756-199807130-00009

Shallice, T., and Saffran, E. (1986). Lexical processing in the absence of explicit word identification: evidence from a letter-by-letter reader. *Cogn. Neuropsychol.* 3, 429–458. doi: 10.1080/02643298608252030

Sharp, D. J., Scott, S. K., and Wise, R. J. S. (2004). Retrieving meaning after temporal lobe infarction: the role of the basal language area. *Ann. Neurol.* 56, 836–846. doi: 10.1002/ana.20294

Silva, C., Montant, M., Ponz, A., and Ziegler, J. C. (2012). Emotions in reading: disgust, empathy and the contextual learning hypothesis. *Cognition* 125, 333–338. doi: 10.1016/J.COGNITION.2012.07.013

Sinha, R., Lovallo, W. R., and Parsons, O. A. (1992). Cardiovascular differentiation of emotions. *Psychosom. Med.* 54, 422–435. doi: 10.1097/00006842-199207000-00005

Spielberger, C. D., and Reheiser, E. C. (2010). "The nature and measurement of anger" in *International handbook of anger* (New York: Springer), 403–412. doi: 10.1007/978-0-387-89676-2_23

Stark, R., Walter, B., Schienle, A., and Vaitl, D. (2005). Psychophysiological correlates of disgust and disgust sensitivity. *J. Psychophysiol.* 19, 50–60. doi: 10.1027/0269-8803.19.1.50

Suzuki, A., and Akiyama, H. (2013). Cognitive aging explains age-related differences in face-based recognition of basic emotions except for anger and disgust. *Aging Neuropsychol. Cognit.* 20, 253–270. doi: 10.1080/13825585.2012.692761

Szewczyk, J. M., and Schriefers, H. (2018). The N400 as an index of lexical preactivation and its implications for prediction in language comprehension. *Language, Cognition Neurosci.* 33, 665–686. doi: 10.1080/23273798.2017.1401101

Thomas, S. J., Johnstone, S. J., and Gonsalvez, C. J. (2007). Event-related potentials during an emotional Stroop task. *Int. J. Psychophysiol.* 63, 221–231. doi: 10.1016/j.ijpsycho.2006.10.002

Toufan, R., Aghamolaei, M., and Ashayeri, H. (2021). Differential effects of gender on mismatch negativity to violations of simple and pattern acoustic regularities. *Brain Behav.* 11:e2248. doi: 10.1002/brb3.2248

Trimmel, K., Van Graan, A. L., Caciagli, L., Haag, A., Koepp, M. J., Thompson, P. J., et al. (2018). Left temporal lobe language network connectivity in temporal lobe epilepsy. *Brain* 141, 2406–2418. doi: 10.1093/brain/awy164

Twomey, D. M., Murphy, P. R., Kelly, S. P., and O'Connell, R. G. (2015). The classic P300 encodes a build-to-threshold decision variable. *Eur. J. Neurosci.* 42, 1636–1643. doi: 10.1111/ejn.12936

Viol, K., Aas, B., Kastinger, A., Kronbichler, M., Schöller, H. J., Reiter, E.-M., et al. (2019). Erroneously disgusted: fMRI study supports disgust-related neural reuse in obsessive-compulsive disorder (OCD). *Front. Behav. Neurosci.* 13:81. doi: 10.3389/fnbeh.2019.00081

Vosse, T., and Kempen, G. (2000). Syntactic structure assembly in human parsing: a computational model based on competitive inhibition and a lexicalist grammar. *Cognition* 75, 105–143. doi: 10.1016/S0010-0277(00)00063-9

Wang, L., Bastiaansen, M., Yang, Y., and Hagoort, P. (2013). ERP evidence on the interaction between information structure and emotional salience of words. *Cogn. Affect. Behav. Neurosci.* 13, 297–310. doi: 10.3758/s13415-012-0146-2

Waugh, C. E., Hamilton, J. P., and Gotlib, I. H. (2010). The neural temporal dynamics of the intensity of emotional experience. *NeuroImage* 49, 1699–1707. doi: 10.1016/J.NEUROIMAGE.2009.10.006

Waugh, C. E., Lemus, M. G., and Gotlib, I. H. (2014). The role of the medial frontal cortex in the maintenance of emotional states. *Soc. Cogn. Affect. Neurosci.* 9, 2001–2009. doi: 10.1093/SCAN/NSU011

Webb, C. A., Olson, E. A., Killgore, W. D. S., Pizzagalli, D. A., Rauch, S. L., and Rosso, I. M. (2018). Rostral anterior cingulate cortex morphology predicts treatment response to internet-based cognitive behavioral therapy for depression. *Biol. Psychiatry: Cognitive Neurosci. Neuroimag.* 3, 255–262. doi: 10.1016/j.bpsc.2017.08.005

Wicker, B., Keysers, C., Plailly, J., Royet, J. P., Gallese, V., and Rizzolatti, G. (2003). Both of us disgusted in my insula: the common neural basis of seeing and feeling disgust. *Neuron* 40, 655–664. doi: 10.1016/S0896-6273(03)00679-2

Wright, P., He, G., Shapira, N. A., Goodman, W. K., and Liu, Y. (2004). Disgust and the insula: fMRI responses to pictures of mutilation and contamination. *Neuroreport* 15, 2347–2351. doi: 10.1097/00001756-200410250-00009

Xiao, Z., Zhang, J. X., Wang, X., Wu, R., Hu, X., Weng, X., et al. (2005). Differential activity in left inferior frontal gyrus for pseudowords and real words: an event-related fMRI study on auditory lexical decision. *Hum. Brain Mapp.* 25, 212–221. doi: 10.1002/HBM.20105

Yang, X., Yu, Y., Chen, L., Sun, H., Qiao, Z., Qiu, X., et al. (2016). Gender differences in pre-attentive change detection for visual but not auditory stimuli. *Clin. Neurophysiol.* 127, 431–441. doi: 10.1016/j.clinph.2015.05.013

Zhang, D., He, W., Wang, T., Luo, W., Zhu, X., Gu, R., et al. (2014). Three stages of emotional word processing: an ERP study with rapid serial visual presentation. *Soc. Cogn. Affect. Neurosci.* 9, 1897–1903. doi: 10.1093/scan/nst188

Zhang, D., Liu, Y., Wang, L., Ai, H., and Luo, Y. (2017). Mechanisms for attentional modulation by threatening emotions of fear, anger, and disgust. *Cogn. Affect. Behav. Neurosci.* 17, 198–210. doi: 10.3758/s13415-016-0473-9

Zhu, Y., Gao, H., Tong, L., Li, Z. L., Wang, L., Zhang, C., et al. (2019). Emotion regulation of hippocampus using real-time fMRI neurofeedback in healthy human. *Front. Hum. Neurosci.* 13:242. doi: 10.3389/fnhum.2019.00242

frontiers | Frontiers in Psychology

TYPE Original Research
PUBLISHED 16 May 2023
DOI 10.3389/fpsyg.2023.1131387



OPEN ACCESS

EDITED BY
Yan Jing Wu,
Ningbo University, China

REVIEWED BY
Xiaoguang Li,
Anhui Polytechnic University, China
Feng Gu,
Sichuan University, China
Tongquan Zhou,
Southeast University, China

*CORRESPONDENCE
Huili Wang
✉ wanghl@zucc.edu.cn

RECEIVED 25 December 2022
ACCEPTED 20 April 2023
PUBLISHED 16 May 2023

CITATION
Cao S, Yue F, Zheng S, Fu Y, Huang J and Wang H (2023) Matching different-structured advertising pictorial metaphors with verbalization forms: incongruity-based evoked response potentials evidence.
*Front. Psychol.* 14:1131387.
doi: 10.3389/fpsyg.2023.1131387



# Matching different-structured advertising pictorial metaphors with verbalization forms: incongruity-based evoked response potentials evidence

Shuo Cao[1], Fang Yue[1], Shihui Zheng[2], Yang Fu[3], Jing Huang[1] and Huili Wang[4]*

[1]School of Foreign Languages, Dalian University of Technology, Dalian, China, [2]Faculty of Management and Economics, Dalian University of Technology, Dalian, China, [3]Instituto de Neurociencia IUNE, Facultad de Psicología, Universidad de La Laguna, San Cristóbal de La Laguna, Spain, [4]School of Foreign Languages, Hangzhou City University, Hangzhou, China

Many studies emphasize the need of verbally representing pictorial metaphors, but few have empirically investigated whether and how the particular verbalization form match different types of pictorial metaphors. Using evoked response potentials (ERP), a 3 (pictorial structure: fusion, juxtaposition, literal image)×2 [verbalization form: A是(is) B, A像(is like) B] within-group experiment was conducted among 36 participants. ERPs were time-locked to the onset of the verb [是/像(is/is like)] of the metaphor sentence that follows a pictorial metaphor to detect the verbo-pictorial incongruity in metaphor comprehension. The incongruity-based ERP analysis showed that pictorial metaphors, when verbalized in two forms, all induced frontal N1 effect, regardless of pictorial structures, only with a larger N1 amplitude for literal images in "A是(is) B." A central stronger P2 was observed in "A像(is like) B" for three structures. Despite a general elicitation of posterior P3 in all conditions, a larger P3 was found for juxtapositions verbalized in "A像(is like) B" and for literal images verbalized in "A是(is) B." There was no significant difference between two verbalization forms for fusion-structured pictorial metaphors. These findings suggest: (1) verbo-pictorial metaphors could induce incongruity-based attention; (2) higher verbo-pictorial semantic congruity and relatedness, indexed by stronger P2 and P3, confirmed "A像(is like) B" to be the more effective verbalization form in representing pictorial metaphors, specifically for juxtaposition-structured pictorial metaphors; (3) for non-metaphor advertising pictures, verbal metaphor showed an interference effect. The study not only reveals the neuro-cognitive mechanism of processing verbo-pictorial metaphors, but also offers neural reference for the design of effective multi-modal metaphor by finding an optimal match between PMs and verbalization forms.

KEYWORDS

**pictorial metaphors, visual structure, verbalization, incongruity, ERP**

## 1. Introduction

Visual metaphors are visual manifestations of cognitive metaphors where concepts are represented in images (Lakoff and Johnson, 2008). As an indirect persuasion popular in advertising, pictorial metaphors (hereafter as PM) imply advertising appeals in an implicit manner, as a PM usually combines two dissimilar objects for viewers to discover the subtle connections. In the PM comprehension, the contextual verbal clues play an important role

(Phillips and McQuarrie, 2004; Forceville and Urios-Aparisi, 2009; Bergkvist et al., 2012).

On the cognitive processing of verbo-pictorial metaphors, visual structures of PM, concerned with the visual position and relationship of one thing to another, have an important influence. Considering differed processing complexity, a few typologies to the classification of visual metaphors were proposed (Forceville, 1996; Phillips and McQuarrie, 2004; Gkiouzepas and Hogg, 2011; Peterson, 2019). Typically, Phillips and McQuarrie (2004) classification includes fusion, juxtaposition and replacement. This typology, consistent with Forceville' classification (hybrid metaphor, pictorial simile and context metaphor), has been widely used in empirical metaphor studies (Indurkhya and Ojha, 2013; van Mulken et al., 2014; Ojha et al., 2017; Ryoo et al., 2021). For the three structures, a gradient of complexity was previously presupposed and confirmed, with the lowest for juxtaposition and the highest for replacement. Fusions are graded as of moderate complexity. In a juxtaposition-structure PM, the source and target are visually equated, being presented side by side in a juxtaposition. As for fusion-structure, the source and target are combined to merge into one, so that viewers need to make some efforts to break down the two elements for comprehending the meaning intended by the PM. The most complex one is replacement-structure that has one domain absent. Viewers need to identify the missing element based on the information indicated by the present domain, verbal messages and context of the advertisement, which consumes excessive processing effort and usually exceeds cognitive resources that viewers have available (McQuarrie and Mick, 1999; Brennan and Bahn, 2006).

In addition to the visual structure of PMs, the effect study of verbalized manifestation on PM comprehension is also determined by the necessity of translating PMs into language. As put by Ojha et al. (2017), comprehension of visual metaphors required the involvement of language resources and in many cases, verbalization is necessary. In practice, PMs are also often presented with verbal messages in the headline to illustrate PMs (Mothersbaugh et al., 2002). Researchers and advertising designers all believe that metaphors, whether verbal or visual, are primarily multi-modal, which requires the allocation and integration of information from different modalities to resolve the inter-domain incongruity created by a metaphor to make sense of its implied meaning. In a multi-modal metaphor, pictorial and verbal elements interact in a dynamic way (Leigh, 1994; McQuarrie and Phillips, 2005; van Mulken et al., 2014). Different from verbal metaphors, in PM there are not such linearity or grammatical rules as the explicit copula "is" or "like," which renders difficulty for viewers in distinguishing target domains from source domains due to the uncertainty of conceptual mapping (Forceville, 2008). Some studies explored the positive effect of verbal elements on the PM comprehension (Phillips, 2000; Ang and Lim, 2006; Bergkvist et al., 2012; Lagerwerf et al., 2012). When verbal elements were added to PMs, it would be easier for PMs to be understood because the verbal cues were provided to reduce the required processing complexity for ad comprehension by strengthening the connections between two visual elements in PMs (Lagerwerf et al., 2012). Phillips (2000) proposed that an implicit headline was desirable to increase the level of comprehension of the advertising metaphors, which in turn elicited a positive effect on ad liking. Whereas an explicit headline produced increased comprehension but decreased ad liking by reducing consumers' pleasure in interpreting the message of the ad. As Ang and Lim (2006) claimed, the effect of verbal metaphors is dynamic, depending on product type (symbolic products vs. utilitarian products), picture type (metaphor vs. non-metaphor) and headline type (metaphor vs. non-metaphor). As such, due to the complicated and divergent findings, verbalized PM calls for a further study.

Based on the previous studies, verbalization of PMs can be realized by several syntactic forms. Forceville (1996) maintained that different forms of verbalization reflect different ways we experience metaphors. Despite various grammatical structures for metaphorical sentences, Lakoff and Johnson (2008) suggested that all metaphorical expressions derive from the conceptual paradigmatic form "A is B." This combination of linearity and syntactic rules allows for an easy distinguishing between the target domain and the source domain and for a clear identification of the features mapped from source to target. However, the career of metaphor theory (Bowdle and Gentner, 2005) proposed different syntactic structures ("A is B" and "A is like B") for the manifestation of metaphorical thinking via an empirical study that investigated the preferred processing route of verbal metaphors. They designed their experiment based on what is known as grammatical concordance (Gibb and Wales, 1990; Gregory and Mergler, 1990), believing that there is a link between form and function in figurative language and that the form follows function. Specifically, the metaphor form (A is B) leads to categorizing the target domain as a member of a specific category named by the source domain so that one can understand one concept in terms of another; in contrast, the simile form (A is like B) facilitates comparing the target domain with the source domain. Therefore, metaphor processing is modulated by conventionality, that is, the form "A is B" fits conventional metaphors best, which uses a categorization-based processing, whereas "A is like B" fits novel metaphors best, which adopts a comparison-based processing. As such, it is clear again that different verbal metaphors are represented in different syntactic forms and recruits different processing mechanisms. Following the similar research stream, Forceville (1996) analyzed linguistic representation of pictorial metaphors in *Pictorial Metaphor in Advertising*, confirming the hypothesis that different-structured PMs can be verbalized by different syntactic forms. He identified the verbalization form "A is B" for MP1s (replacement-structured PM) and MP2s (fusion-structured PM), and the form "A is like B" for PM (juxtaposition-structured PM). Teng and Sun (2002) also contended that visual construction of juxtaposition visually expressed the comparison relation (i.e., A is like B), whereas visual constructions of fusion and replacement visually represented the metaphorical categorization relations (i.e., A is B). These initiative studies laid a solid foundation for the present study in terms of verbalization classification of PMs and of the relationship between verbalization form and corresponding processing mechanism.

In terms of methodology, to the best of our knowledge, experiments using evoked response potential remain less to explore the specific neural mechanism underlying the processing of verbo-pictorial metaphors. Compared with behavioral experiments, the ERP technique can measure cognitive processing without behavioral response in real time. Human's mental activity originates from the brain, and every change of mental state has a corresponding brain cell activity, which reflects the electrophysiological changes of the cognitive task in the brain. Therefore, due to its high temporal resolution, ERP studies offer a possibility to uncover the time-course of cognitive mechanism underlying PM comprehension. When a picture violates a semantic context, the event-related potential (ERP) is negative compared with that evoked by a picture that fits into the context (Barrett and Rugg, 1990; Pratarelli, 1994; McPherson and Holcomb, 1999). That is, when the picture does not match with the sentence that intends to verbalize it, some ERP components indicating incongruity will be immediately detected. And we can analyze this incongruity and its extent to find the effective verbalization form for PMs.

In the neurocognitive studies of metaphors, ERP components, such as N400 and P600, have been widely investigated for verbal stimuli (Kutas and Hillyard, 1980). It is believed that they reflect different stages of cognitive processing of metaphor comprehension, with N400 reflecting the detection of semantic incongruity (Pynte et al., 1996; Balconi and Amenta, 2010; Kutas and Federmeier, 2011), and P600 marking the late concept matching and semantic integration processing (Van Herten et al., 2005). In addition, early components of ERP, which mainly refer to the potential changes within 200 ms of stimulus onset, can be observed especially when the visual pathway is involved. In the present study, we would focus on some early ERP components, including N1, P2 and P3, so as to discover their initial functional contributions to PM comprehension.

The incongruity-sensitive visual N1 is elicited by visual stimuli and significantly affected by attention (Vogel and Luck, 2000). As an index of a discrimination process within the focus of attention, it is related to filter mechanisms involved in triggering of attention (Boutros et al., 2004; Kisley et al., 2004). In the present experiment, different-structured PMs would attract the attention of participants to varied extent. Accordingly, N1 would be detected in the initial processing stage.

P200, an early component related to visual-spatial processing (O'Donnell et al., 1997; Song et al., 2007; Niu et al., 2008; Tlauka et al., 2009), is reported to be influenced by the contextual predictability, i.e., the efficient semantic features are pre-activated and extracted more rapidly from expected items than from unexpected items. And this contextual predictability could be interpreted as the congruity of the preceding materials with the following stimuli. The more consistent the semantic information, the larger the P2 amplitude. In an experiment by Federmeier and Kutas (2002) who compared sentences ended with contextually expected pictures and those with contextually unexpected pictures. They found larger P2 amplitude in response to expected items. As such, it is hypothesized in the present study that P2 should be detected when the verbo-pictorial matching process is perceived as congruent.

P3, another marker of (in)congruity processing, is found to be associated with a series of cognitive activities in terms of its amplitude, latency, and scalp topography (Pritchard, 1981; Picton, 1992). P3 could be elicited in experimental paradigms, like S1–S2 paradigm (Ma et al., 2008). Changes in P3 are influenced by factors like attention (Mangun and Hillyard, 1990), memory load (Brookhuis et al., 1981), and familiarity of stimuli (Rugg and Doyle, 1992). Ma et al. (2008) proved that P3 can be evoked by category similarity in their experiment of brand extension, in which participants were instructed to decide the suitability between the original brand in S1 and the extension product in S2. The higher similarity and coherence between the brand and the product led to an activation of more neural resources in the brain cortex with a larger P3 amplitude evoked. Therefore, P3 reflects the similarity-based categorical processing.

P3 is widely used to examine similarity (versus incongruity). For example, in an experiment of schematic face conducted by Azizian et al. (2006), stimuli higher in perceptual similarity to targets produced larger P3 than did other stimuli with few similar features. This experiment demonstrated that the P3 amplitude was an effective neural indicator of perceptual similarity between target and non-target stimuli. Watson et al. (2005) further examined the effect of conceptual similarity on the P3 amplitude through an oddball paradigm composed of print words and their conceptually related pictures. Most notably, on the basis of P3 as a similarity indicator, many experiments extended the findings that P3 was observable in semantic priming, which indexed the semantic relatedness between primes and targets. The sensitivity of P3 to semantic priming has been demonstrated not only in mono-modal studies, such as verbal modality (Hill et al., 2002) and pictorial modality (McPherson and Holcomb, 1999), but also in multi-modal studies using pictures and words as stimuli (Watson et al., 2005). The more semantically related between primes and targets, the larger the P3 amplitude. The present study involves the matching between PMs and verbalization forms. When the verbalization form can convey the message of the picture, the similar conceptual representation would be activated due to the high degree of semantic relatedness. Therefore, we hypothesize that the P3 would be observed reflecting similarity and semantic relatedness.

Based on the above literature review, this study, providing electrophysiological evidence, aims to identify effective verbalization forms in representing PMs by examining how the particular verbalization forms match with different-structured PMs. ERP data are recorded while participants view an advertising picture and a following sentence presented word by word. The task is to decide whether the sentence is appropriate or not to describe the picture. Since the extant ERP studies show that N1, P2, and P3 components index some aspects of semantic processing of both verbal and visual stimuli, we would expect these neural components to be observed in the verbo-pictorial matching process for metaphors. And changes of their amplitudes would be indicative of matching extent between verbalization forms and PMs. We hypothesize that enhanced P2, P3 and decreased N1 would be elicited when PMs are matched with effective verbalization forms.

This cognitive study of verbal and pictorial stimuli in advertising is of great significance, because the typical observation time for advertising is 2 s in an editorial context (Pieters and Wedel, 2004). Instead of depending on the conventional self-report or surveys on ad attitudes, establishing the neural changes with a brief exposure to advertising visual stimuli can contribute to the development of both the cognitive study and advertising research of multi-modal metaphors.

## 2. Materials and methods

### 2.1. Participants

Thirty-seven students from Dalian University of Technology participated in the ERP Experiment (24 men, 13 women; average age: 24.2; range: 20–30). All participants were native Chinese speakers with normal or corrected-to-normal vision. They were all right-handed and had no color blindness or color weakness, no history of mental illness or other brain diseases. Informed about the design of the study, all participants gave their written consent for participation before the experiment and received remuneration after the experiment. One

10.3389/fpsyg.2023.1131387

participant's data was excluded for excessive recording artifacts. The experiment was examined and approved by the Biological and Medical Ethics Committee of the Dalian University of Technology.

## 2.2. Stimuli

The stimulus pool included 90 pictures and 180 corresponding Chinese sentences (Table 1 shows representative examples). The pictures fell into three conditions: fusion structure (hereafter as FS), juxtaposition structure (hereafter as JS), and literal structure (hereafter as LS), with 30 pictures in each condition. The source domain and the target domain of each set of three visual structures were the same. The present experiment did not take replacement-structured PM into account considering its complexity in the visual context, the excessive processing load and its scarcity in practical advertising. Instead, literal images that show the product directly (i.e., just images of the advertised objects) are considered, as non-metaphor pictures combined with metaphor headlines are often seen in advertising. The non-metaphor pictures can also be used as a baseline for the condition comparison.

Since the participants in the experiment were all college students, the advertising pictures included the best-selling products of low-involvement, that was, the advertised products in the pictures were what college students could afford and often purchased, including food and electronic devices. In these advertising PMs, trademarks, slogans, and brand names were removed to avoid the impact of reading. As for verbalization form, there were two: "A是(is) B" and "A像(is like) B." The stimuli were selected based on four pretests.

Initially, 100 fusion-structured adverting PMs were pretested for the selection of appropriate experiment pictures. As familiarity has a modulating influence on the metaphor processing (Blasko and Connine, 1993; Giora and Fein, 1999; Giora, 2003; Blasko and Kazmerski, 2006; Schmidt and Seger, 2009; Mcquire et al., 2017), 70 university students at Dalian University of Technology, China, who did not participate in the later ERP experiment, were invited to rate their familiarity with PM, on a five-point Likert scale ranging from 1 (the least familiar) to 5 (the most familiar) in a preliminary test. Twenty-four highly familiar pictures were removed.

In the second pretest, a naming test (Forceville, 2002) was employed for the identification of the source and target items in PMs. A new group of 10 undergraduates participated in the naming, on a scale from 1 (the least consistent) to 5 (the most consistent). Sixteen pictures of low consistency were deleted.

In addition, a questionnaire was designed and delivered to 45 students to confirm which was the theme (target domain) of the pictures (Forceville, 2002) for the metaphorical expression: A (target domain) 是/像(is/is like) B (source domain). A sentence was presented below each picture, indicating "This is an advertisement for XXX." The answers were presented in a five-point Likert scale ranging from 1 (do not agree at all) to 5 (agree completely). To avoid redundant cognitive processing, the source and target items in the sentences were named in the same lexical length of Chinese characters.

The fourth is a sentence comprehension test (Tang et al., 2017) conducted to test whether or not the metaphorical sentences could be comprehended, on a five-point Likert scale from 1 (strongly non-comprehensible) to 5 (strongly comprehensible). This questionnaire was delivered to another group of 32 students. Sentences of low comprehensibility were deleted.

Finally, 41 pictures were retained and processed by Adobe Photoshop 13.0 to create the corresponding JS and LS with the same source and target domain. Thirty were used in the formal experiment and another 11 were used in the practice trials. All the pictures had the same luminance, shade and size and the Chinese characters were Song typeface with the same font size.

**TABLE 1** Examples of stimuli used in the experiment.

| Visual structures | Metaphor pictures | Sentences |
|---|---|---|
| FS |  | 蛋糕是玫瑰。<br>(Cake is rose.) |
| | | 蛋糕像玫瑰。<br>(Cake is like rose.) |
| JS |  | 蛋糕是玫瑰。<br>(Cake is rose.) |
| | | 蛋糕像玫瑰。<br>(Cake is like rose.) |
| LS |  | 蛋糕是玫瑰。<br>(Cake is rose.) |
| | | 蛋糕像玫瑰。<br>(Cake is like rose.) |

## 2.3. Procedure

A 3 (pictorial structure: FS, JS, LS) × 2 [verbalization form: A是(is) B, A像(is like) B] within-group experiment was conducted. In total, there were 180 trials, divided into 3 blocks with 60 trials in each. All the stimuli were presented in the center of the screen with white background in a quasi-random order.

As illustrated in Figure 1, the picture was presented first and then the sentence was presented word by word. The stimuli on each trial were presented in the following time sequence: fixation cross (800 ms), metaphor picture (2,000 ms), blank (200–500 ms), subject (source domain; 1,000 ms), blank (200–500 ms), linking verb [是/像(is/is like) 600 ms], blank (200–500 ms), predicative (target domain, 1,000 ms), and question mark (3,000 ms). At the sight of the question mark, participants needed to make their judgments about whether the sentence was appropriate to describe the picture, by pressing a corresponding key. For counterbalance, half of participants pressed F (appropriate) or J (inappropriate) and the other half of participants pressed J (appropriate) or F (inappropriate). Response period was limited to 3,000 ms and was followed by a 1,000 ms interval. The participants conducted a brief exercise before the experiment.

## 2.4. Electroencephalogram data recording and processing

The participants were seated at a distance of 0.8 m from the screen in a silent room with soft lighting. The tasks were run and data were

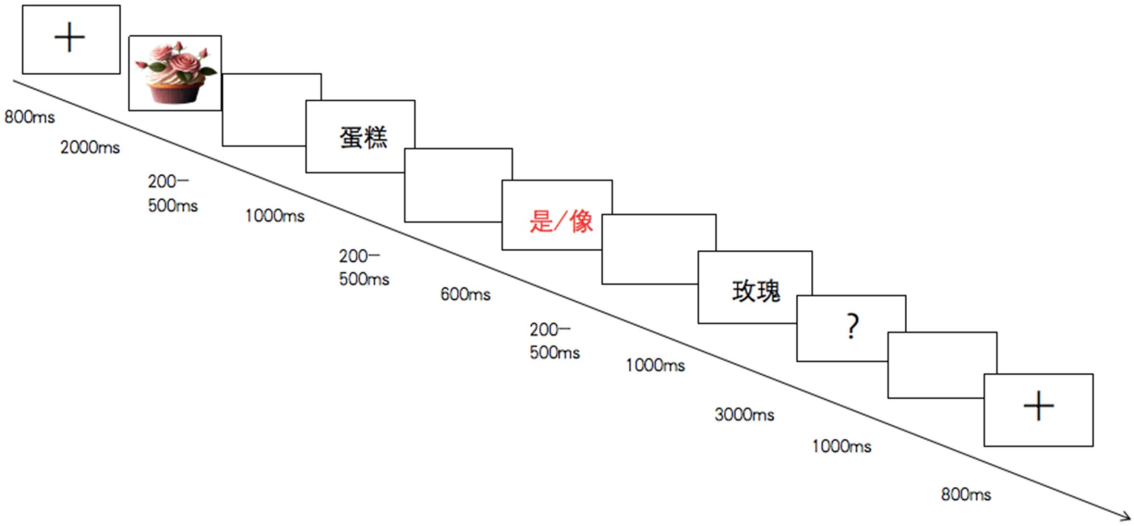


FIGURE 1
Experimental procedure.

collected using E-Prime 2.0 (Psychology Software Tools, Sharpsburg, MD). ERPs were time-locked to the onset of the verb [是/像(is/is like)] of the sentence and were obtained by stimulus-locked averaging of the EEG recorded in each condition. Electroencephalogram data were continuously recorded via an electrode cap with 64 Ag/AgCl electrodes, using the international 10/20 system. A 64-channel BrainAmp EEG amplifier (Brain Products, Germany) and the recording software (BrainVision Video Recorder) were used. Electrode impedance was maintained below 10 kΩ in the experiment. EEG was analyzed with Python using the MNE-Python toolbox. The EEG was digitally filtered using FIR filter-based filtering at 0.1–30 Hz band pass. Epochs were 1,000 ms in length with a 200 ms pre-stimulus baseline. ICA was performed after the extraction of the epoch to correct the ocular artifacts. The ground electrode was placed on the forehead and FCz was used as recording reference. Data were re-referenced offline to the average of the two mastoid electrodes.

## 2.5. Statistical analysis

First, the threshold-free cluster-enhancement (TFCE) technique (the exploratory analysis) was used for the analysis of ERP signals to define the region of interest (ROI) and channels by considering all spatial–temporal points. This technique was purely data-driven and took all data of each channel and any time point into account while strictly controlling for multiple comparisons (Mensen and Khatami, 2013). Based on the TFCE results, frontally distributed five electrodes (F3, F1, Fz, F2, and F4) were selected for the analysis of N1 component (100–130 ms); centrally distributed six electrodes (FC3, FCz, FC4, C3, Cz, and C4) for the analysis of P2 component between 180 and 300 ms; six posterior electrodes (P3, Pz, P4, PO3, POz, and PO4) were selected for the analysis of P3 component (330–430 ms). In the next place, we conducted confirmatory analysis (lmer function, package lme4) including the factors pictorial structure and verbalization form as fixed-terms. Significance *p*-values and Type III F-statistics for main effects and interactions for continuous variables (ERP amplitude) were calculated using Satterthwaite approximations to denominator degrees of freedom as implemented in the lme4 (Bates et al., 2014). Planned comparisons and β estimates were calculated using function emmeans as implemented in the package emmeans.

# 3. Results

## 3.1. Behavioral results

The behavioral data were recorded, including the button-press reaction time and the selection frequency of each verbalization form for PM of the same structure. Noticeably, we only recorded the reaction time of the trials in which the sentence was judged to be appropriate for describing the picture.

As can be seen from Figure 2, for three structures of PM, the form "A像(is like) B" is selected more compared to the form "A是(is) B." And the paired-samples *t*-test further demonstrated that there was a significant difference in selection frequency between two verbalization forms for three structures of advertising pictures ($t = -6.518$, $p < 0.001$ for FS; $t = -7.976$, $p < 0.001$ for JS; $t = -5.402$, $p < 0.001$ for LS). For FS and JS, the reaction time of "A像(is like) B" is shorter than that of "A是(is) B" ($t = 2.868$, $p = 0.007$ for FS; $t = 4.165$, $p < 0.001$ for JS). But there was no significant difference between two verbalization forms for LS ($t = -0.179$, $p = 0.855$).

## 3.2. Evoked response potentials results

The grand averaged ERP waveform generated by the two verbalization forms ["A是(is) B," and "A像(is like) B"] for three structures of PM at a frontal group (F3, Fz, F4), a central group (C3, Cz, C4) and a posterior group (P3, Pz, P4) were plotted in Figures 3–5. Visual inspection from TFCE showed the significant difference between two verbalization forms at P2 component for FS in Figure 3. P2 and P3 exhibited significant difference between two forms for JS in

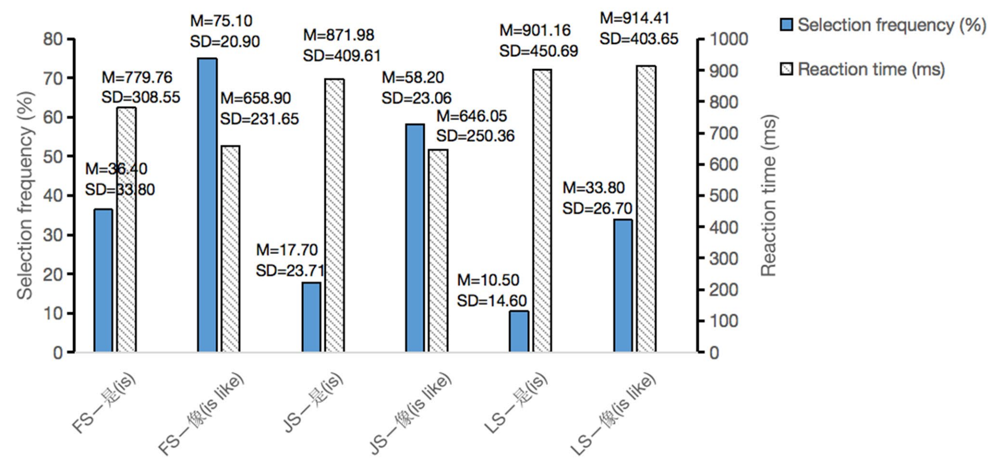


FIGURE 2
Behavior results.

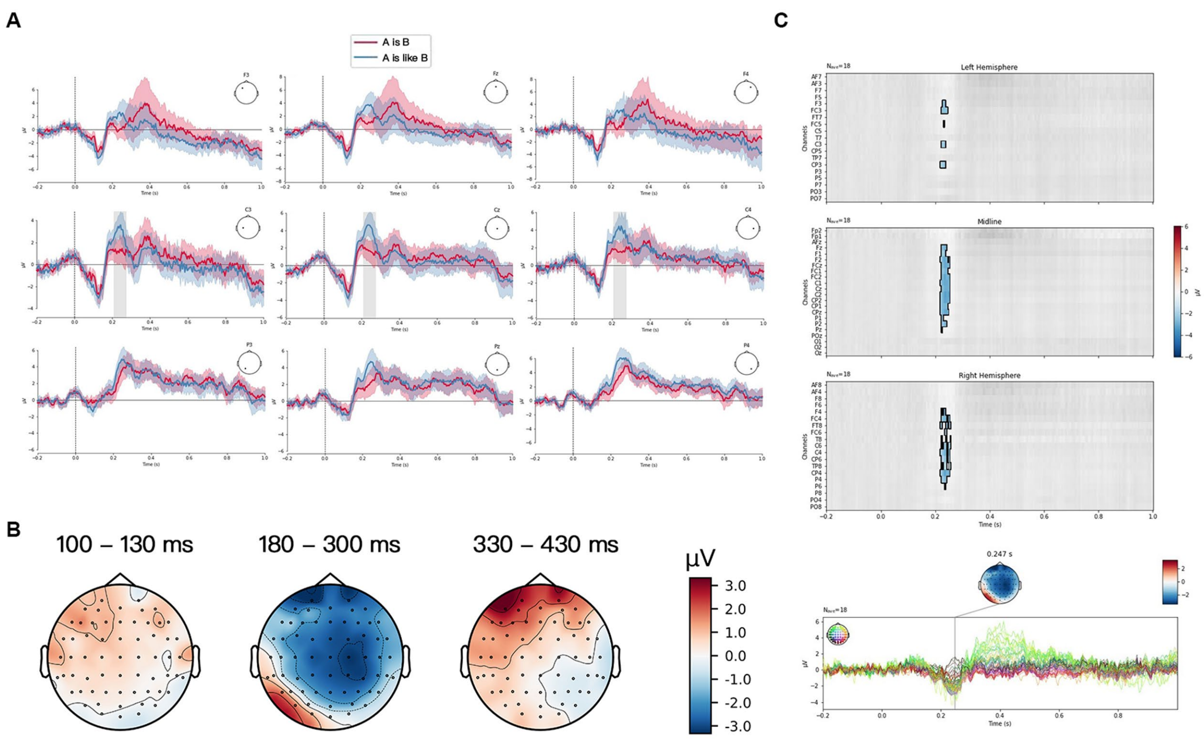


FIGURE 3
Fusion structure (FS) condition. **(A)** Grand average ERP waveform elicited by "A是(is) B" (red) and "A像(is like) B" (blue) from frontal scalps (F3, Fz, F4), central scalps (C3, Cz, C4) and parietal scalps (P3, Pz, P4). Negative voltage is plotted upwards. **(B)** Scalp distributions of the N1 (100–130 ms), P2 (180–300 ms) and P3 (330–430 ms) based on the difference waves between "A是(is) B" and "A像(is like) B." **(C)** ERP data analyzed by TFCE.

Figure 4. And there was significant difference at N1, P2, and P3 components for LS in Figure 5. The topographies of each ERP effect, obtained by subtracting "A像(is like) B" from "A是(is) B" ["A是(is) B"—"A像(is like) B"] from three time frames (100–130 ms, 180–300 ms, 330–430 ms) were also displayed. For FS (see Figure 3), "A像(is like) B" elicited larger P2 than "A是(is) B," frontally and centrally distributed. For JS (see Figure 4), "A像(is like) B" elicited larger P2 and P3 than "A是(is) B," frontally distributed. For LS (see Figure 5), "A像(is like) B" elicited larger N1 than "A是(is) B" almost in the whole brain; "A像(is like) B" elicited larger P2 than "A是(is) B," frontally distributed; "A是(is) B" elicited larger P2 than "A像(is like) B," focal in the frontal sites.

Table 2 showed the significant difference between the grand averaged ERP waveform generated by the two verbalization forms ["A是(is) B," and "A像(is like) B"] for three structures of PM. The results of N1 (100–130 ms) indicated the significant main effects of verbalization form [$F(1, 180) = 4.9547$, $p < 0.05$] and pictorial structure [$F(2, 180) = 7.2407$, $p < 0.001$]. The interaction effect between

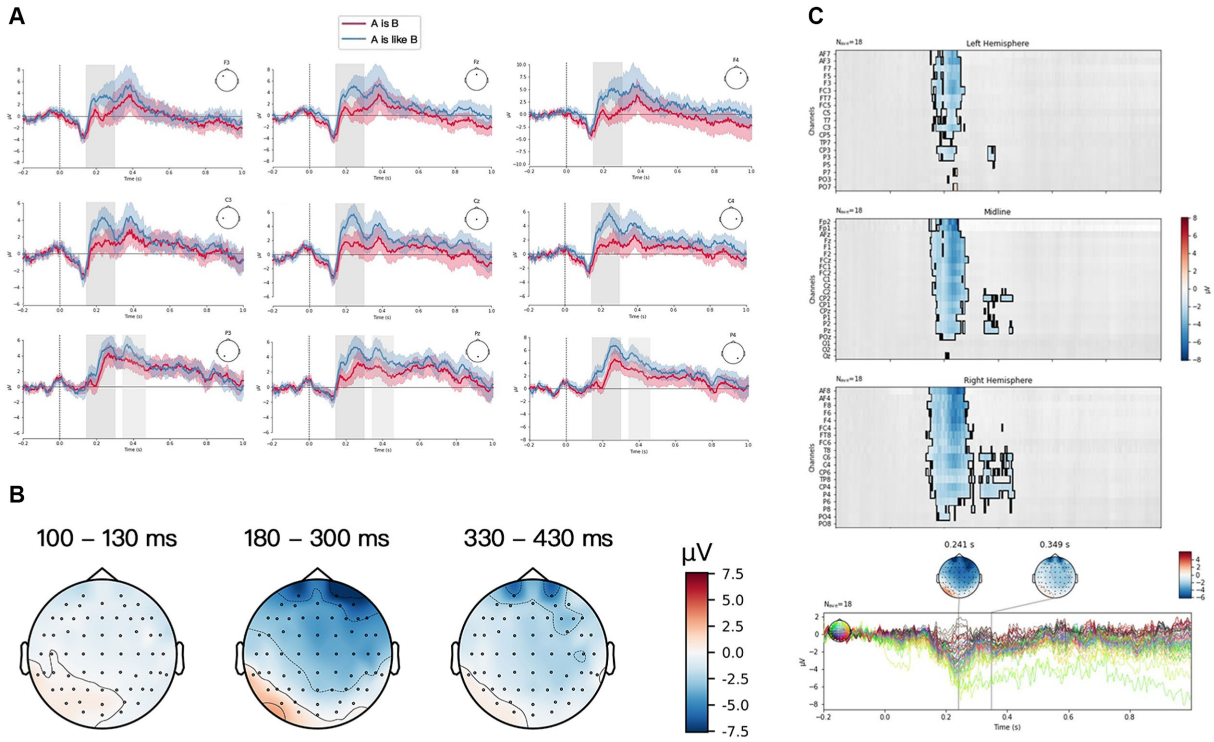


FIGURE 4
Juxtaposition structure (JS) condition. **(A)** Grand average ERP waveform elicited by "A是(is) B" (red) and "A像(is like) B" (blue) from frontal scalps (F3, Fz, F4), central scalps (C3, Cz, C4) and parietal scalps (P3, Pz, P4). Negative voltage is plotted upwards. **(B)** Scalp distributions of the N1 (100–130 ms), P2 (180–300 ms) and P3 (330–430 ms) based on the difference waves between "A是(is) B" and "A像(is like) B." **(C)** ERP data analyzed by TFCE.

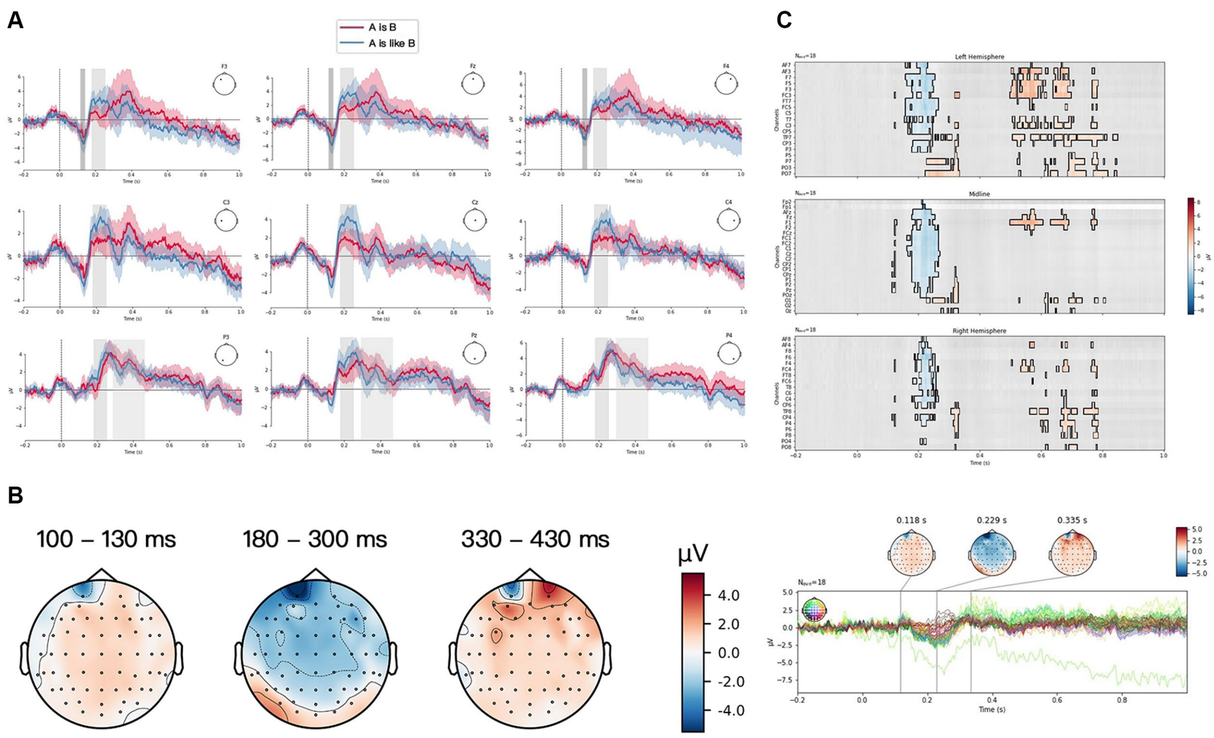


FIGURE 5
Literal structure (LS) condition. **(A)** Grand average ERP waveform elicited by "A是(is) B" (red) and "A像(is like) B" (blue) from frontal scalps (F3, Fz, F4), central scalps (C3, Cz, C4) and parietal scalps (P3, Pz, P4). Negative voltage is plotted upwards. **(B)** Scalp distributions of the N1 (100–130 ms), P2 (180–300 ms) and P3 (330–430 ms) based on the difference waves between "A是(is) B" and "A像(is like) B." **(C)** ERP data analyzed by TFCE.

TABLE 2 Evoked response potentials (ERP) results.

| | N1 (100–130ms) | P2 (180–300ms) | P3 (330–430ms) |
|---|---|---|---|
| FS: 是(is) vs 像(is like) | $\beta = -0.099$; | $\beta = 1.464$; | $\beta = 0.218$; |
| | SD = 0.397; | SD = 0.376; | SD = 0.484; |
| | $z = -0.250$; | $z = 3.893$; | $z = 0.451$ |
| | $p = 0.803$ | $p < 0.001$ | $p = 0.652$ |
| JS: 是(is) vs 像(is like) | $\beta = 0.803$; | $\beta = 2.986$; | $\beta = 1.166$; |
| | SD = 0.397; | SD = 0.376; | SD = 0.484; |
| | $z = 0.766$; | $z = 7.939$; | $z = 2.410$; |
| | $p = 0.691$ | $p < 0.001$ | $p = 0.032$ |
| LS: 是(is) vs 像(is like) | $\beta = -1.735$; | $\beta = 1.248$; | $\beta = -1.923$; |
| | SD = 0.397; | SD = 0.376; | SD = 0.484; |
| | $z = -4.372$; | $z = 3.317$; | $z = -3.974$; |
| | $p < 0.001$ | $p < 0.001$ | $p < 0.001$ |

verbalization form and pictorial structure did reach significant [$F$ (2, 180) = 7.4031, $p < 0.001$]. N1 generated in the form "A像(is like) B" was significantly larger than that of "A是(is) B" for LS ($\beta = -1.735$, SD = 0.397, $z = -4.372$, $p < 0.001$), whereas no such difference was observed for FS and JS ($z = -0.250$, $p > 0.80$ for FS; $z = 0.766$, $p > 0.69$ for JS).

For P2 (180–300 ms) analysis, the results showed that only main effect of verbalization form was significant [$F$ (1, 180) = 76.5053, $p < 0.001$]. The effect of pictorial structure was not significant [$F$ (2, 180) = 1.7863, $p > 0.17$], whereas the interaction effect between verbalization form and pictorial structure was significant [$F$ (2, 180) = 6.3434, $p = 0.002 < 0.05$]. A larger P2 amplitude was observed in the form "A像(is like) B" than that in the form "A是(is) B" ($\beta = 1.464$, SD = 0.376, $z = 3.893$, $p < 0.001$ for FS; $\beta = 2.986$, SD = 0.376, $z = 7.939$, $p < 0.001$ for JS; $\beta = 1.248$, SD = 0.376, $z = 3.317$, $p < 0.001$ for LS).

The results of P3 (330–430 ms) reflected that the interaction effect did reach significant [$F$ (2, 180) = 10.694, $p < 0.001$], despite an insignificant main effect of verbalization form [$F$ (1, 180) = 0.4131, $p > 0.52$] and pictorial structure [$F$ (2, 180) = 2.341, $p > 0.009$]. Follow-up analysis by contrasting two conditions demonstrated that P3 had no significant effect on the two verbalization forms for FS ($z = 0.451$, $p > 0.65$), whereas for JS, "A像(is like) B" elicited significantly larger P3 amplitude than "A是(is) B" ($\beta = 1.166$, SD = 0.484, $z = 2.410$, $p = 0.032 < 0.05$). And for LS, "A是(is) B" elicited significantly a larger P3 amplitude than "A像(is like) B" ($\beta = -1.923$, SD = 0.484, $z = -3.974$, $p < 0.001$).

## 4. Discussion

This ERP study investigates the processing of PMs when they are verbalized in different metaphorical expressions, to seek the optimal match between PMs and verbalization forms for the design and application of multi-modal metaphors. A 3 (pictorial structure: FS, JS, LS) × 2 [verbalization form: A是(is) B, A像(is like) B] within-group experiment was conducted among 36 participants to collect behavioral (button-press reaction time and selection frequency), and neural (evoked potentials) data.

Analyzing behavioral performance, the study found that for three structures of advertising PMs, the verbalization form "A像(is like) B" was selected more for illustrating the PMs, compared with the verbalization form "A是(is) B." On the premise that we recorded the reaction time of the trials in which the sentence was judged to be appropriate for describing the picture, the reaction time of "A是(is) B" for FS and JS was longer. This implies that matching three different-structured advertising PMs with "A是(is) B" was relatively difficult to be comprehended for its recruiting more cognitive effort. In comparison, "A像(is like) B" was easier and more expressive as a verbalization form representing FS and JS PMs. However, there was no significant difference between two verbalization forms for LS. It may reflect certain degree of processing difficulty when LS were verbalized with these two syntactic expressions (which would be discussed in detail later with ERP results).

As for ERP components, the early component N1 and its amplitude change were found in this study. The matching of two verbalization forms with each type of PMs all induced N1 effect, indicating that this initial response observed in the early window was caused by visual stimuli of the experimental pictures with different visual structures. This finding was in line with the previous one (Cao et al., 2018) that both metaphor and literal pictures could elicit N1 due to the perceptual stimulation of the shape of experimental pictures. But for LS, there was significant difference between two verbalization forms. The form "A像(is like) B," in the judgment task of verbo-pictorial match, evoked a larger amplitude of N1 than "A是(is) B," indicating that more recognition of incongruity occurred in the processing of "A像(is like) B." Interestingly, for FS and JS, significant difference was not revealed between two verbalization forms. It may be attributed to the effect of different visual structures of PMs. In the condition of LS, participants could quickly identify the pictured product (target domain) before making the verbo-pictorial matching. While in the condition of FS and JS, the presence of both source domain and target domain made it hard for participants to distinguish them in the short-initial time window, only eliciting the perceptual activation of the picture instead.

Among three structures of PMs, a larger amplitude of P2 was found in "A像(is like) B" than in "A是(is) B." Previous psycholinguistic studies (Duffy et al., 1989; Hess et al., 1995) found words that were predictable in a sentence context (contextually congruent and semantically associated words) provided greater facilitation than the words that occurred out of context or in incongruent contexts. Electrophysiological results (Biederman and Cooper, 1991) supported these findings, reflected by an enhanced P2 in contextually congruent and semantically associated matching conditions. The similar findings were also found by Federmeier and Kutas (2002), who pointed out that the upcoming pictures could be facilitated by a preceding semantically-related sentences. The more consistent and expected the semantic information, the stronger the P2 effect. In the present experiment, when participants saw the picture and the following sentence "A像(is like) B," more semantically-related and congruent features were extracted to construct a conceptual mapping between the visual and verbal stimuli. As such, "A像(is like) B," due to its larger semantic congruity with the PMs, was assumed to be a more effective verbalization form in representing PMs in general.

However, a question remains unclear, i.e., why was "A像(is like) B" the expected syntactic pattern over "A是(is) B"? We believe it is related to their different cognitive semantic features. The syntactic form of "A是(is) B" by nature is one manifestation of Noun Metaphor (Shu, 2002). This type of metaphor is more flexible to be used and also more difficult to be recognized due to the lack of necessary cognitive context, that is, literally provided semantic content alone is not sufficient for establishing a cross-domain mapping. For example, we do not use the ambiguous metaphorical expressions like "Heart is a strawberry" or "Coke is a rocket" in everyday speech, because they were too semantically impenetrable or too difficult to be interpreted without context. The interaction theory of metaphor (Richards, 1965) revealed that the meaning of metaphor came from the interaction of various features of two conceptual domains, including feature selection, emphasis and suppression. It emphasized the process of creating similarity between two concepts in metaphor comprehension. Su et al. (2016) also claimed that metaphor is a process that creates similarity between source domain and target domain in cases where such similarity does not already exist. Whereas "A像(is like) B," especially with the auxiliary "像(is like)," exactly primes a processing of comparing the target domain with the source domain. As evidenced by Li (1999) and Zhao (2001), in the process of grammaticalization, "像(is like)" has gradually lost its original meaning and become an auxiliary word, which was used to explicitly signal the similarity relation. Therefore, as the terms of the similitude were explicit, the form "A像(is like)B" was more accessible than "A是(is) B."

In addition, our results showed that both verbalization forms elicited P3 for three structures of PMs. The previous studies reported that P3 amplitude is evoked in case of perceived similarity and semantic relatedness (Picton, 1992; Ma et al., 2008). The higher similarity and semantic relatedness, the stronger P3. There was a significant difference between two verbalization forms for JS and LS in terms of P3 amplitude. The form "A像(is like) B" induced a larger P3 amplitude than the form "A是(is) B" did for JS, whereas for LS, the form "A是(is) B" exhibited stronger P3 than "A像(is like) B." But there was no significant difference between two forms for FS PM. These results suggested that the feature matching between JS and the verbalization form "A像(is like) B" was more effective, and the same went for the matching between LS and "A是(is) B." There were more attribute congruity and semantic relatedness for the matching of JS with the form "A像(is like) B" and for LS with the form "A是(is) B" as well. According to these results, it can be concluded that "A像(is like) B" is more effective in representing JS, and "A是(is) B" is more effective for LS. This finding, to some extent, was consistent with the hypothesis proposed by Teng and Sun (2002) that visual construction of juxtaposition expressed the simile relation (i.e., comparison) because displaying two domains beside each other tipped toward similarity-based simile relation, whereas visual templates of one domain was apt to convey the metaphorical relation (i.e., categorization) which mainly results from the transformational effect by blending two different concepts, which enabled viewers to see a concept in terms of another.

So far, two points still need to be noted. The first one was that why we obtained diverging findings about the effective verbalization form for LS as reflected, respectively, in N1, P2 and P3 time window. In the N1 time window, as literal images lacked one domain for conceptual processing of PM, the comparison-based processing route was interfered with. Therefore, the categorization processing [i.e., A是(is) B] occurred. In the P2 time window when the matching process started and was influenced by the contextual predictability, "A像(is like) B" became the dominant and expected. In the P3 time window, based on the feature matching and the deeper information processing, it was confirmed that the more effective form for LS was "A是(is) B." The second point was that P3 amplitude did not show significant difference between two verbalization forms for FS. We assume that this homogeneity results from the visual construction of FS. The size, the form and the degree to which the two items were fused were different in the experiment, even though four pretests had been carried out. Accordingly, the fusion complexity would have an effect on viewers' interpretation of PMs, which is likely to hinder the upcoming matching process. This factor of visual complexity should be further controlled in the future studies.

To sum up, the major finding of the present study is that, regardless of the visual structures, the processing of verbalized PM mainly involves the comparison mechanism. Specifically, for both FS and JS, the congruent verbalization form is consistently "A像(is like) B." Such a major finding can be explained by the career of metaphor theory (Bowdle and Gentner, 2005). This theory postulates that conventional metaphors lead to categorization processes, whereas novel metaphors tend to be processed in the comparison mechanism. And these two processing mechanisms can be represented by two grammatical concordances, "A是(is) B" (categorization) versus "A像(is like) B" (comparison). The advertising metaphor pictures are generally characterized by creativity and low familiarity to viewers. The experimental stimuli used in the current study were PMs of low familiarity. These novel verbo-pictorial information in the categorization mode (is) was highly difficult to comprehend, compared with conventional metaphors that participants are familiar with. Only with a similarity network between the source and the target domain, the comprehension of novel metaphors can be facilitated, that is, when novel metaphors appeared, the comparison processing was generated to access the meaning of novel metaphors because they cannot be categorized based on the prior experience. Accordingly, the comparison processing (is like), i.e., the similarity between the two concrete items in the picture, was more likely to be recognized with fast processing speed with less cognitive load. In contrast, for LS, when matched with verbalization forms, there was a switching of different processing mechanisms reflected by the time course of N1–P2–P3. Only one item (the product) was presented in the preceding LS picture, but two items were referred to in the sentence. At the sight of the sentence, participants, based on their memory retrieval, need to construct an image of the item that is not shown in the picture. In addition, the perception and recognition of PMs would be disturbed, as the mental construction of the absent item varied with each individual. Accordingly, the matching of LS with metaphorical sentences ["A是(is) B" and "A 像(is like) B"] would interfere with the cognitive activities of participants, which was also consistent with the behavioral result that there was no significant difference between two forms for LS. Neither form was effective to verbally represent LS.

## 5. Conclusion

The current research discovered the optimal verbalization form for pictorial metaphors by observing the neuro-cognitive responses in verbo-pictorial matching task. The form "A 像(is like) B" was cognitively preferred across three structures of advertising metaphors. The JS PM verbalized with "A像(is like) B" was the optimal scheme for the design and application of verbo-pictorial metaphor. LS pictures paired with metaphorical sentences would cause the most difficult semantic recognition. Therefore, verbal metaphors are not recommended to be integrated with non-metaphor advertising pictures.

The study not only identifies the early processing mechanism of PMs, but also reveals the verbo-pictorial interaction of metaphor processing. Practically, it provides neural reference for the design of effective multi-modal metaphor in advertising by finding an optimal match between PMs and verbalization forms. In addition to time-domain analysis the study has performed, the future study should employ the time-frequency analysis to study the brain oscillations, such as delta and theta activities, to explore their functional roles for verbo-pictorial metaphor comprehension. A larger sample of the population is also needed, as the participants in this experiment are all university students.

## Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

## Ethics statement

The studies involving human participants were reviewed and approved by Ethics Committee, Dalian University of Technology, China. The patients/participants provided their written informed consent to participate in this study.

## Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

## Funding

This work was supported by the National Social Science Foundation of China under Grant Number 19BYY088.

## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

## Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

## Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2023.1131387/full#supplementary-material

## References

Ang, S. H., and Lim, E. A. C. (2006). The influence of metaphors and product type on brand personality perceptions and attitudes. *J. Advert.* 35, 39–53. doi: 10.1080/00913367.2006.10639226

Azizian, A., Freitas, A. L., Watson, T. D., and Squires, N. K. (2006). Electrophysiological correlates of categorization: P300 amplitude as index of target similarity. *Biol. Psychol.* 71, 278–288. doi: 10.1016/j.biopsycho.2005.05.002

Balconi, M., and Amenta, S. (2010). "A fighter is a lion". Neuropsychological indexes in comprehending frozen metaphors. *J. Pragmat.* 42, 3246–3257. doi: 10.1016/j.pragma.2010.06.016

Barrett, S. E., and Rugg, M. D. (1990). Event-related potentials and the semantic matching of pictures. *Brain Cogn.* 14, 201–212. doi: 10.1016/0278-2626(90)90029-N

Bates, D., Mächler, M., Bolker, B., and Walker, S. (2014). Fitting linear mixed-effects models using lme4. *arXiv* [Epub ahead of preprint].

Bergkvist, L., Eiderbäck, D., and Palombo, M. (2012). The brand communication effects of using a headline to prompt the key benefit in ads with pictorial metaphors. *J. Advert.* 41, 67–76. doi: 10.2753/JOA0091-3367410205

Biederman, I., and Cooper, E. E. (1991). Object recognition and laterality: null effects. *Neuropsychologia* 29, 685–694. doi: 10.1016/0028-3932(91)90102-E

Blasko, D. G., and Connine, C. M. (1993). Effects of familiarity and aptness on metaphor processing. *J. Exp. Psychol. Learn. Mem. Cogn.* 19, 295–308. doi: 10.1037/0278-7393.19.2.295

Blasko, D. G., and Kazmerski, V. A. (2006). ERP correlates of individual differences in the comprehension of nonliteral language. *Metaphor. Symb.* 21, 267–284. doi: 10.1207/s15327868ms2104_4

Boutros, N. N., Korzyukov, O., Jansen, B., Feingold, A., and Bell, M. (2004). Sensory gating deficits during the mid-latency phase of information processing in medicated schizophrenic patients. *Psychiatry Res.* 126, 203–215. doi: 10.1016/j.psychres.2004.01.007

Bowdle, B. F., and Gentner, D. (2005). The career of metaphor. *Psychol. Rev.* 112, 193–216. doi: 10.1037/0033-295X.112.1.193

Brennan, I., and Bahn, K. D. (2006). Literal versus extended symbolic messages and advertising effectiveness: the moderating role of need for cognition. *Psychol. Mark.* 23, 273–295. doi: 10.1002/mar.20111

Brookhuis, K. A., Mulder, G., Mulder, L. J. M., Gloerich, A. B. M., Van Dellen, H. J., Van, D. M. J. J., et al. (1981). Late positive components and stimulus evaluation time. *Biol. Psychol.* 13, 107–123. doi: 10.1016/0301-0511(81)90030-2

Cao, S., Wang, Y., Chen, H., and Wang, H. (2018). The N1–N2–LPC pattern in processing advertising pictorial metaphors: an ERP study. *Front. Psychol.* 9, 1–13. doi: 10.3389/fpsyg.2018.02566

Duffy, S. A., Henderson, J. M., and Morris, R. K. (1989). Semantic facilitation of lexical access during sentence processing. *J. Exp. Psychol. Learn. Mem. Cognit.* 15, 791–801.

Federmeier, K. D., and Kutas, M. (2002). Picture the difference: electrophysiological investigations of picture processing in the two cerebral hemispheres. *Neuropsychologia* 40, 730–747. doi: 10.1016/S0028-3932(01)00193-2

Forceville, C. (1996). *Pictorial Metaphor in Advertising.* London: Routledge.

Forceville, C. (2002). The identification of target and source in pictorial metaphors. *J. Pragmat.* 34, 1–14. doi: 10.4324/9780203272305

Forceville, C. (2008). "Metaphor in pictures and multimodal representations" in *The Cambridge Handbook of Metaphor and Thought*. ed. W. G. Raymond (Cambridge: Cambridge University Press), 462–482.

Forceville, C., and Urios-Aparisi, E. (2009). *Multimodal Metaphor (Vol. 11)*, Berlin, New York: Walter de Gruyter.

Gibb, H., and Wales, R. (1990). Metaphor or simile: psychological determinants of the differential use of each sentence form. *Metaphor. Symb.* 5, 199–213. doi: 10.1207/s15327868ms0504_1

Giora, R. (2003). *On Our Mind. Salience, Context and Figurative Language*. New York, NY: Oxford University Press.

Giora, R., and Fein, O. (1999). On understanding familiar and less-familiar figurative language. *J. Pragmat.* 31, 1601–1618. doi: 10.1016/S0378-2166(99)00006-5

Gkiouzepas, L., and Hogg, M. K. (2011). Articulating a new framework for visual metaphors in advertising. *J. Advert.* 40, 103–120. doi: 10.2753/JOA0091-3367400107

Gregory, M. E., and Mergler, N. L. (1990). Metaphor comprehension: in search of literal truth, possible sense, and metaphoricity. *Metaphor. Symb.* 5, 151–173. doi: 10.1207/s15327868ms0503_2

Hess, D. J., Foss, D. J., and Carroll, P. (1995). Effects of global and local context on lexical processing during language comprehension. *J. Exp. Psychol. Gen.* 124, 62–82. doi: 10.1037/0096-3445.124.1.62

Hill, H., Strube, M., Roesch-Ely, D., and Weisbrod, M. (2002). Automatic vs. controlled processes in semantic priming-differentiation by event-related potentials. *Int. J. Psychophysiol.* 44, 197–218. doi: 10.1016/S0167-8760(01)00202-1

Indurkhya, B., and Ojha, A. (2013). An empirical study on the role of perceptual similarity in visual metaphors and creativity. *Journal of Creative Behavior*, 47(3), 233–253. doi: 10.1002/jocb.39

Kisley, M. A., Noecker, T. L., and Guinther, P. M. (2004). Comparison of sensory gating to mismatch negativity and self-reported perceptual phenomena in healthy adults. *Psychophysiology* 41, 604–612. doi: 10.1111/j.1469-8986.2004.00191.x

Kutas, M., and Federmeier, K. D. (2011). Thirty years and counting: finding meaning in the N400 component of the event related brain potential (ERP). *Annu. Rev. Psychol.* 62, 621–647. doi: 10.1146/annurev.psych.093008.131123

Kutas, M., and Hillyard, S. A. (1980). Event-related brain potentials to semantically inappropriate and surprisingly large words. *Biol. Psychol.* 11, 99–116. doi: 10.1016/0301-0511(80)90046-0

Lagerwerf, L., van Hooijdonk, C. M., and Korenberg, A. (2012). Processing visual rhetoric in advertisements: interpretations determined by verbal anchoring and visual structure. *J. Pragmat.* 44, 1836–1852. doi: 10.1016/j.pragma.2012.08.009

Lakoff, G., and Johnson, M. (2008). *Metaphors We Live By*, Chicago: University of Chicago Press.

Leigh, J. H. (1994). The use of figures of speech in print ad headlines. *J. Advert.* 23, 17–33. doi: 10.1080/00913367.1994.10673439

Li, X. (1999). "As the same as" and related sentence patterns. *Lang. Teach. Res.* 3, 85–96.

Ma, Q., Wang, X., Shu, L., and Dai, S. (2008). P300 and categorization in brand extension. *Neurosci. Lett.* 431, 57–61. doi: 10.1016/j.neulet.2007.11.022

Mangun, G. R., and Hillyard, S. A. (1990). Allocation of visual attention to spatial locations: tradeoff functions for event-related brain potentials and detection performance. *Percept. Psychophys.* 47, 532–550. doi: 10.3758/BF03203106

McPherson, W. B., and Holcomb, P. J. (1999). An electrophysiological investigation of semantic priming with pictures of real objects. *Psychophysiology* 36, 53–65. doi: 10.1017/S0048577299971196

McQuarrie, E. F., and Mick, D. G. (1999). Visual rhetoric in advertising: text-interpretive, experimental, and reader-response analyses. *J. Consum. Res.* 26, 37–54. doi: 10.1086/209549

McQuarrie, E. F., and Phillips, B. J. (2005). Indirect persuasion in advertising: how consumers process metaphors presented in pictures and words. *J. Advert.* 34, 7–20. doi: 10.1080/00913367.2005.10639188

Mcquire, M., Mccollum, L., and Chatterjee, A. (2017). Aptness and beauty in metaphor. *Lang. Cogn.* 9, 316–331. doi: 10.1017/langcog.2016.13

Mensen, A., and Khatami, R. (2013). Advanced EEG analysis using threshold-free cluster-enhancement and non-parametric statistics. *NeuroImage* 67, 111–118. doi: 10.1016/j.neuroimage.2012.10.027

Mothersbaugh, D. L., Huhmann, B. A., and Franke, G.R. (2002). Combinatory and separative effects of rhetorical figures on consumers' effort and focus in ad processing. *Journal of Consumer Research*, 28, 589–602. doi: 10.1086/338211

Niu, Y. N., Wei, J. H., and Luo, Y. J. (2008). Early ERP effects on the scaling of spatial attention in visual search. *Prog. Nat. Sci.* 18, 381–386. doi: 10.1016/j.pnsc.2007.12.002

O'Donnell, B. F., Swearer, J. M., Smith, L. T., Hokama, H., and McCarley, R. W. (1997). A topographic study of ERPs elicited by visual feature discrimination. *Brain Topogr.* 10, 133–143. doi: 10.1023/A:1022203811678

Ojha, A., Indurkhya, B., and Lee, M. (2017). "Is language necessary to interpret visual metaphors?" *in Metaphor in Communication, Science and Education*. eds. Ervas, F., Gola, E. and Rossi, M. (Berlin, Boston: De Gruyter Mouton), 61–76. doi: 10.1515/9783110549928-004

Peterson, M. O. (2019). Aspects of visual metaphor: an operational typology of visual rhetoric for research in advertising. *Int. J. Advert.* 38, 67–96. doi: 10.1080/02650487.2018.1447760

Phillips, B. J. (2000). The impact of verbal anchoring on consumer response to image ads. *J. Advert.* 29, 15–24. doi: 10.1080/00913367.2000.10673600

Phillips, B. J., and McQuarrie, E. F. (2004). Beyond visual metaphor: a new typology of visual rhetoric in advertising. *Mark. Theory* 4, 113–136. doi: 10.1177/1470593104044089

Picton, T. W. (1992). The P300 wave of the human event-related potential. *J. Clin. Neurophysiol.* 9, 456–479. doi: 10.1097/00004691-199210000-00002

Pieters, R., and Wedel, M. (2004). Attention capture and transfer in advertising: brand, pictorial, and text-size effects. *J. Mark.* 68, 36–50. doi: 10.1509/jmkg.68.2.36.27794

Pratarelli, M. E. (1994). Semantic processing of pictures and spoken words: evidence from event-related brain potentials. *Brain Cogn.* 24, 137–157. doi: 10.1006/brcg.1994.1008

Pritchard, W. S. (1981). Psychophysiology of P300. *Psychological Bulletin*, 89, 506–540. doi: 10.1037/0033-2909.89.3.506

Pynte, J., Besson, M., Robichon, F.-H., and Poli, J. (1996). The time-course of metaphor comprehension: An event-related potential study. *Memory & Cognition*, 24, 356–371. doi: 10.3758/BF03200810

Richards, I. A.. *The Philosophy of Rhetoric, A Galaxy Book*. New York, NY: Oxford University Press, (1965).

Rugg, M. D., and Doyle, M. C. (1992). Event-related potentials and recognition memory for low-and high-frequency words. *J. Cogn. Neurosci.* 4, 69–79. doi: 10.1162/jocn.1992.4.1.69

Ryoo, Y., Jeon, Y. A., and Sung, Y. (2021). Interpret me! The interplay between visual metaphors and verbal messages in advertising. *Int. J. Advert.* 40, 760–782. doi: 10.1080/02650487.2020.1781477

Schmidt, G. L., and Seger, C. A. (2009). Neural correlates of metaphor processing: the roles of figurativeness, familiarity and difficulty. *Brain Cognit.* 71, 375–386. doi: 10.1016/j.bandc.2009.06.001

Song, Y., Peng, D. L., Xiaolan, L. I., Zhang, Y., Kang, J., Zhe, Q. U., et al. (2007). Neural correlates of short-term perceptual learning in orientation discrimination indexed by event-related potentials. *Chin. Sci. Bull.* 52, 352–357. doi: 10.1007/s11434-007-0058-7

Shu, D. (2002). On the operating mechanism of metaphor. *Language Science*, 4, 11–18.

Su, C., Tian, J., and Chen, Y. (2016). Latent semantic similarity based interpretation of Chinese metaphors. *Eng. Appl. Artif. Intell.* 48, 188–203. doi: 10.1016/j.engappai.2015.10.014

Tang, X., Qi, S., Jia, X., Wang, B., and Ren, W. (2017). Comprehension of scientific metaphors: complementary processes revealed by ERP. *J. Neurolinguistics* 42, 12–22. doi: 10.1016/j.jneuroling.2016.11.003

Teng, N. Y., and Sun, S. (2002). Grouping, simile, and oxymoron in pictures: A design-based cognitive approach. *Metaphor and Symbol*, 17, 295–316. doi: 10.1207/S15327868MS1704_3

Tlauka, M., Clark, C. R., Liu, P., and Conway, M. (2009). Encoding modality and spatial memory retrieval. *Brain Cogn.* 70, 116–122. doi: 10.1016/j.bandc.2009.01.002

Van Herten, M., Kolk, H. H., and Chwilla, D. J. (2005). An ERP study of P600 effects elicited by semantic anomalies. *Cogn. Brain Res.* 22, 241–255. doi: 10.1016/j.cogbrainres.2004.09.002

Van Mulken, M., Van Hooft, A., and Nederstigt, U. (2014). Finding the tipping point: visual metaphor and conceptual complexity in advertising. *J. Advert.* 43, 333–343. doi: 10.1080/00913367.2014.920283

Vogel, E. K., and Luck, S. J. (2000). The visual N100 component as an index of a discrimination process. *Psychophysiology* 37, 190–203. doi: 10.1111/1469-8986.3720190

Watson, T. D., Azizian, A., Berry, S., and Squires, N. K. (2005). Event-related potentials as an index of similarity between words and pictures. *Psychophysiology* 42, 361–368. doi: 10.1111/j.1469-8986.2005.00295.x

Zhao, J. (2001). On the comparative category of Chinese. *J. Chin. Linguist.* 5, 1–16.

frontiers | Frontiers in Psychology

TYPE Original Research
PUBLISHED 30 June 2023
DOI 10.3389/fpsyg.2023.1175217



OPEN ACCESS

EDITED BY
Huili Wang,
Dalian University of Technology, China

REVIEWED BY
Tao Wang,
Qufu Normal University, China
Zhao Yao,
Xi'an Jiaotong University, China

*CORRESPONDENCE
Francesca Vitale
✉ frvitale@ull.edu.es

RECEIVED 27 February 2023
ACCEPTED 19 June 2023
PUBLISHED 30 June 2023

CITATION
Vitale F and de Vega M (2023) Disturbing the activity of the primary motor cortex by means of transcranial magnetic stimulation affects long term memory of sentences referred to manipulable objects.
*Front. Psychol.* 14:1175217.
doi: 10.3389/fpsyg.2023.1175217



# Disturbing the activity of the primary motor cortex by means of transcranial magnetic stimulation affects long term memory of sentences referred to manipulable objects

Francesca Vitale* and Manuel de Vega

Instituto Universitario de Neurociencia (IUNE), Universidad de La Laguna, La Laguna, Spain

**Introduction:** Previous studies on embodied meaning suggest that simulations in the motor cortex play a crucial role in the processing of action sentences. However, there is little evidence that embodied meaning have functional impact beyond working memory. This study examines how the neuromodulation of the motor cortex (M1) could affect the processing of action-related language, measuring participants' performance in a long-term memory task.

**Method:** Participants were submitted to two sessions in separate days, one with low-frequency repetitive transcranial magnetic stimulation (rTMS) and the other with sham rTMS. The pulses were delivered for 15 minutes over M1 or over V1, used as a control area. After each stimulation or sham period, the participants were asked to memorize a list of simple sentences, with a manual action verb or an attentional verb, followed in both cases by a noun referred to a manipulable object (e.g., to hang a cane vs. to observe a cane). Finally, they received the verbs as cues with instructions to recall the nouns.

**Results:** The results showed that low frequency rTMS on M1, compared to sham stimulation, significantly improved the performance in the memory task, for both types of sentences. No change in performance was found after the rTMS stimulation of V1.

**Discussion:** These results confirm that the perturbation on the motor system, affect the memory of manipulable object names in the context of sentences, providing further evidence of the role played by the sensorimotor system in the encoding and recall of concrete sentences of action.

KEYWORDS

**transcranial magnetic stimulation (TMS), language, memory, embodied cognition, motor system**

## Introduction

Which is the causal role of the motor cortex in long-term memory of language referred to manipulable objects? The embodied approach to language processes has devoted especial attention to the processing of action-related sentences, revealing that the motor cortex plays a role during their comprehension (Gallese and Lakoff, 2005; Barsalou, 2008; Fischer and Zwaan, 2008; García and Ibáñez, 2016). Thus, neuroimaging (Tettamanti et al., 2005; Raposo et al., 2009; de Vega et al., 2014), EEG (van Elk et al., 2010; Moreno et al., 2013, 2015), non-invasive brain stimulation (Oliveri et al., 2004; Gerfo et al., 2008; Papeo et al., 2009; Candidi et al., 2010; Repetto et al., 2013; Gianelli and Volta, 2014; Vukovic et al., 2017; Vitale et al., 2021), and brain patients studies (Bak et al., 2001; Desai et al., 2015; Birba et al., 2022) have provided extensive evidence that the motor and premotor cortex (PMC) are activated for action language, especially referred to hand actions, but not for abstract or attentional verbs. However, those studies generally show the intervention of the motor cortex during comprehension or its impact on the immediate recall of information.

The use of transcranial brain stimulation to perturb the activity of a brain region and observe changes in the performance of cognitive tasks could provide evidence for the causal role of the primary motor cortex (M1) in the comprehension of action language. Thus, in some studies participants receive 1-Hz rTMS offline on M1 before performing a semantic or morphological task with action and non-action words (Gerfo et al., 2008; Repetto et al., 2013). Given the inhibitory effect of low-frequency rTMS, performance was selectively impaired (slowing responses) for action words, both verbs and names. In the same vein, online high-frequency rTMS applied to M1 slowed down responses in a semantic judgment task for action related words (Vukovic et al., 2017) and increased the amplitude of the ERP component N400, which is a reliable index of semantic processing, in a hand-related words priming paradigm (Kuipers et al., 2013).

These studies are not entirely conclusive, however, because most of them tested the functional impact of M1 on performance in an immediate task, typically while the received action verb is still active in working memory. However, some behavioral (Dutriaux and Gyselinck, 2016; Dutriaux et al., 2018) and EEG studies (de Vega et al., 2021) on embodied meaning suggest that motor simulations play a crucial role in the long-term memory of nouns in the context of action verbs. These studies showed that holding the hands behind the back interferes with the memorization of manipulable object presented as pictures or as words, but does not affect recall of non-manipulable objects or words (Dutriaux and Gyselinck, 2016); the hands behind back posture also interfered with the memory of action sentences compared to attentional sentences (Dutriaux et al., 2018). In addition, an EEG study using the same memory paradigm, found suppression in fronto-central beta rhythm desynchronization, a brain signature of motor processes, when participants held the hands-behind-the-back posture, compared with the hands in front posture, but only during the processing of manual action sentences (de Vega et al., 2021). Taken together, all these findings suggest the key role of neural motor simulation as a functional aspect of memory for action language.

However, to our knowledge, there is only one study that examines the impact of M1 neuromodulation on long-term memory (Vitale et al., 2021). In that study the participants received in two separate sessions offline sham and active tDCS on M1. At the end of each session, they were given sentences referred to manipulable objects in the context of action verbs or attentional verbs, and after a distractive task, the participants were cued with the verbs and asked to recall the missing names. The results showed that after excitatory stimulation of M1 (anodal tDCS) memory performance selectively improved for names in the context of action verbs. The study clearly demonstrated a causal impact of M1 activity on long-term performance, beyond working memory. However, some limitations of the tDCS techniques should be notice. First, ordinary tDCS involves large electrodes that according to computational estimations produce diffuse electric fields in the brain, which means that other regions beyond the target M1 could be stimulated (Mikkonen et al., 2018, 2020); second, the tDCS induced electric fields varied considerably among individuals because of their individual cranial and brain anatomy (Laakso et al., 2019).

Most of the literature on action-related language focuses on the comparison between manual action verbs (e.g., write, clap), and non-action verbs (think, remember), reporting behavioral facilitation or interference on actions performed with the same effector (compatibility effects) for the former, suggesting that motor cortex activity is involved. Thus, behavioral studies have shown language-action compatibility effects (Shebani and Pulvermüller, 2013, 2018; Zhang et al., 2016). For instance, performing a complex rhythmic hands movement impairs working memory for hand-related words (e.g., clap), while rhythmic feet movements led to selectively impairs memory for foot-related words (e.g., kick) (Shebani and Pulvermüller, 2013, 2018). However, nouns of manipulable objects (pen, hammer) can be also considered action related words, given the implicit motor affordances of the referred objects, which may share neural processes with action verbs (Stanfield and Zwaan, 2001; Glenberg and Kaschak, 2002; Bub et al., 2018). For instance, a neuroimaging study demonstrated that naming manual actions and naming manipulable objects share neural activations in fronto-parietal networks that subserve hand action representation (Saccuman et al., 2006), and a study with single pulse TMS on hand-related M1 revealed that nouns of manipulable objects modulate corticospinal excitability (Gough et al., 2012). In addition, inhibitory neuromodulation on M1 increases reaction times in a concrete/abstract judgment task both for manual action verbs and manipulable object nouns (Gerfo et al., 2008). Finally, Parkinson's disease patients (PD) and controls were asked to give a bottom-pressing response to pictures or names of graspable and non-graspable objects. Whereas the controls showed interference for graspable objects/nouns (slower responses) indicating underlying motor processing, PD patients produced similar response times for graspable and non-graspable objects (Buccino et al., 2018). In sum, manipulable object names might trigger motor cortex activity and therefore could be sensitive to neuromodulation of M1.

The current research examined the role of the motor cortex on long term memory for action sentences, using the same materials and task demands as in Vitale et al. (2021) study; that is, participants initially read a set of sentences composed of manipulable object nouns presented in the context of either action or attentional verbs (learning phase); then, in the testing phase, they were asked to recall the object nouns that were associated with action or attentional verbs, using a cued recall procedure. However, unlike in Vitale et al., in this research we employed repetitive transcraneal magnetic stimulation (rTMS), which has better accuracy and focality than the tDCS used by those authors. This is an important decision, as the spatial precision of TMS is extremely high, especially when M1 is the target region, and TMS is combined with electromyography to obtain motor threshold (MT) for a single muscle. In contrast, tDCS is imprecise as it does not adapt to the individual anatomy of skulls and brains. Furthermore, the electric field induced by TMS is quite focal, while the electric field induced by tDCS is diffuse and other regions beyond the target can be stimulated (Mikkonen et al., 2018, 2020; Laakso et al., 2019). In one stimulation group, rTMS was applied on the target region M1 to directly test its functional role in language comprehension. To ensure full control conditions, all participants were tested in two sessions, one with active rTMS and the other with sham rTMS, which served as a baseline control session. In addition, a second control-stimulation group was introduced, in which the stimulation was administered on V1, which has no functional relationship with the task. Therefore, we expect that M1 stimulation will modulate long term memory performance, whereas V1 stimulation will not.

A low frequency (1 Hz) rTMS protocol was chosen in the experiment, which is often considered "inhibitory." So, rTMS might be expected to reduce the excitation of M1 and thus impair long-term memory for action language, indicating a functional relationship. However, the direction of the effects may be reversed in some circumstances, as some memory studies have reported enhanced recall for pictures and words after 1 Hz-rTMS in the DLPF cortex (Turriziani et al., 2012; Patel et al., 2020; van der Plas et al., 2021). Furthermore, offline inhibitory theta burst targeting PMC was shown to enhance the performance of action verbs in a subsequent lexical decision task (Willems et al., 2011). Although the task demand and target region stimulated here are different from those used in that study, it is possible that 1 Hz-rTMS over M1 could also improve performance for a long-term memory task. By contrast, the stimulation on V1 would not change performance, confirming the specific functional role of M1 on long-term memory of action related language. We selected V1 as the control region because it is a standard protocol used by previous studies (Boggio et al., 2008; Makoshi et al., 2011; Avenanti et al., 2012; Casula et al., 2014), and because it is a region not involved in the language processing network.

Finally, the modulation of performance could be constrained to the retrieval of object names learned in the context of action verbs, as previously reported after M1 stimulation (Vitale et al., 2021), or when the hands posture was manipulated (Dutriaux et al., 2018; de Vega et al., 2021). Another possibility is that the retrieval of names is modulated by M1 stimulation regardless of the type of verb in the learning context. This possibility derives from the fact that the names always referred to manipulable objects, which are action words with motor affordances (Gerfo et al., 2008; Dutriaux and Gyselinck, 2016).

# Material and method

## Participants

Sixty Spanish speaking students took part in the study (mean age ± SD: 19 ± 2). All the participants were right-handed, without visual or medical problems, or contraindication to TMS (Rossi et al., 2009, 2011; Rossini et al., 2015). The participants were randomly assigned to two different stimulation group: 30 participants (5 men, mean age ± SD: 19 ± 1) were assigned to the M1 group, where the TMS stimulation was applied over M1 and 30 (5 men, mean age ± SD: 19 ± 2) participants were included in the control group, in this case the target site of the stimulation was V1.

## Linguistic material

The material consisted of 30 action verbs, 30 attentional verbs and 120 manipulable objects combined to create to two set of 120 Spanish simple sentences, with "verb + article + noun" syntax. Within each set, each verb appeared twice, associated with a different object, which were only presented once. The material was organized in a way that if a noun was associated with a manual verb in set 1 (e.g., *colgar un bastón*/to hang a cane), then, in set 2, it was associated with an attentional verb (e.g., *observar un bastón*/to observe a cane) and vice versa. The material was the same used in a previous study (Vitale et al., 2021), and was considerably validated, ensuring that there are no differences in frequency, length and familiarity between the action and attentional verbs (see Table 1). The two types of verbs differed in concreteness, since the manual action verbs were judged as more concrete than the attentional verbs, reflecting the expected semantic differences between them.

Furthermore, we made sure that the sentences were semantically comparable for both sets (see Vitale et al., 2021 for a detailed description of the validation analysis). The results indicate that the number of verb-object co-occurrences for manual action sentences did not differ from the number of co-occurrences for attentional sentences (set 1: manual action = 31,762 ± 55,992, attentional = 78,917 ± 343,442; t118 = −1.05, $p = 0.30$; set 2: manual action = 88,682 ± 310,006, attentional = 115,036 ± 409,065; t118 = −0.40, $p = 0.69$).

## rTMS parameters and site localization

Low-frequency rTMS was applied through a figure-of-eight coil connected to a Magstim Rapid2 stimulator (Magstim, Whiteland, Dyfed, United Kingdom). In the M1 group, active stimulation was delivered over the hand representation in the left M1. The exact location was defined as the point where stimulation consistently evoked the largest motor-evoked potentials (MEPs) in the right first dorsal interosseous muscle (FDI). The intensity of stimulation was set at 80% of the resting motor threshold (rMT), defined as the minimal intensity of stimulator output that evoked MEPs with an amplitude of at least 50 µV in the FDI in a series of 10 stimuli (Rossini et al., 2015). With a frequency of 1 Hz, inhibitory rTMS was given in two separate blocks of 9-min stimulation, separated by 1-min break during which overheated stimulation coils were changed (see Figure 1A). In the active stimulation the coil was placed tangentially to the skull, with the handle orientated posteriorly at 45° angle from the midline, while, in the sham condition, the coil was placed vertically over left M1, oriented at 90° with respect to the scalp. The latter stimulation allows to replicate the auditory and somatosensory effect of real TMS, but without inducing any stimulation in the brain.

TABLE 1 Scores of psycholinguistic variables and statistics for manual action and attentional verbs.

| | Action | Attentional | *t* | *p*-level |
|---|---|---|---|---|
| Frequency | 23.83 ± 54.91 | 56.84 ± 93.87 | −1.66 | 0.10 |
| Length | 6.67 ± 1.37 | 7.27 ± 1.87 | −1.41 | 0.16 |
| Familiarity | 6.24 ± 0.52 | 5.97 ± 0.76 | 1.55 | 0.13 |
| Concreteness | 5.72 ± 0.51 | 4.28 ± 0.63 | 9.77 | <0.001** |

** denote a strong significant comparisons.

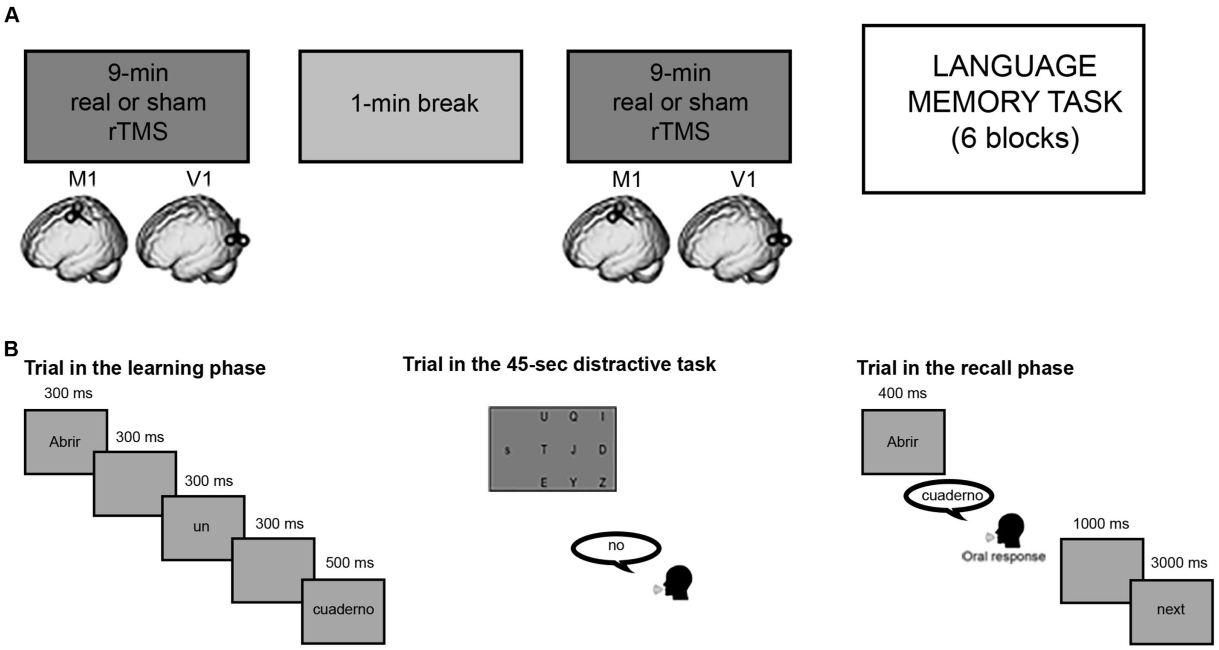


FIGURE 1
Experimental structure. **(A)** Representation of offline stimulation protocol before the behavioral task. **(B)** Language memory task structure: example of a trial in the learning phase (translation: to open/a/notebook), example of a trial in a distractive task, example of a trial in the recall phase.

In the control group, participants underwent the same experimental procedure of the M1 group, but in this case the locus of stimulation was V1, located 3 cm anterior and 1 cm lateral from the inion (Silvanto et al., 2007; Casula et al., 2014). The coil was held with the handle pointing upwards and the stimulation protocol was the same as in the M1 group, with the difference that the stimulation intensity was set at 60% of maximum stimulator output (Silvanto et al., 2005).

## Procedure

The experiment was programmed using Python software. In each stimulation group, all participants were tested in two different sessions, separated by at least 7 days. In the active session, real rTMS was delivered over the target region immediately before the participants performed the memory task, while, in the sham session, the task was preceded by sham stimulation. The order of the sessions was counterbalanced across participants.

The memory task consisted of 6 blocks for each session, for a total of 12 blocks. Each block consisted of a learning phase, followed by a distractive task and a final recall phase (Figure 1B). In the learning phase, participants were asked to memorize as many sentences as possible, as they would be required to recall them later. Each block in the learning phase always began with a filler sentence, not tested in the recall phase to avoid primacy effects, followed by 10 sentences (5 manual action and 5 attentional) appearing in random order. The sentences were presented word-by-word separated by a 2-s intertrial interval, which allowed minimizing mental rehearsal of the sentence that had just been read. Immediately after the learning phase, participants were submitted to a 45-s distractive task, consisting of perceptual letter-matching trials, in which they had to respond whether a target lower-case letter on one side of the screen, was among nine upper-case letters presented on another part of the screen (Dutriaux and Gyselinck, 2016; de Vega et al., 2021). This task was intended to avoid recency effects, as well as working memory strategies such as mental rehearsal or top-down semantic elaboration of learned sentences (e.g., Ye and Xiaolan, 2007; Rose et al., 2014). In the recall phase following the distractive task, participants were given the verbs of the previous sentences as memory cues and had to orally recall the object names associated with them. Responses were recorded and analyzed offline.

## Data analysis

Memory accuracy, calculated as the percentage of objects correctly recalled, was analyzed with a linear mixed model, using the lme4 package in R (Bates et al., 2015). Group (M1, V1), Type of Sentences (action, attentional) and Session (sham, active) were defined as fixed factors, while participants were accounted for as a random effect in the model. Post-hoc analysis were conducted using the false discovery rate (FDR) (Benjamini and Hochberg, 1995) to correct for multiple comparisons.

## Result

The linear mixed model showed a strong main effect of Type of Sentences ($F_{1,174}=29.56$; $p<0.0001$; $\eta p^2=0.15$), driven by a better memory for manual action sentences (34% ± 16%) relative to attentional sentences (28% ± 17%). As shown in Table 2, such difference

TABLE 2 Mean and standard deviation of memory accuracy for the action and attentional sentences, after receiving sham or active stimulation, in both M1 and V1 groups.

| | M1 stimulation | | V1 stimulation | |
|---|---|---|---|---|
| | Sham | Active | Sham | Active |
| Action sentences | 30% ± 14% | 35% ± 13% | 36% ± 21% | 35% ± 20% |
| Attentional sentences | 24% ± 15% | 30% ± 16% | 28% ± 20% | 29% ± 20% |

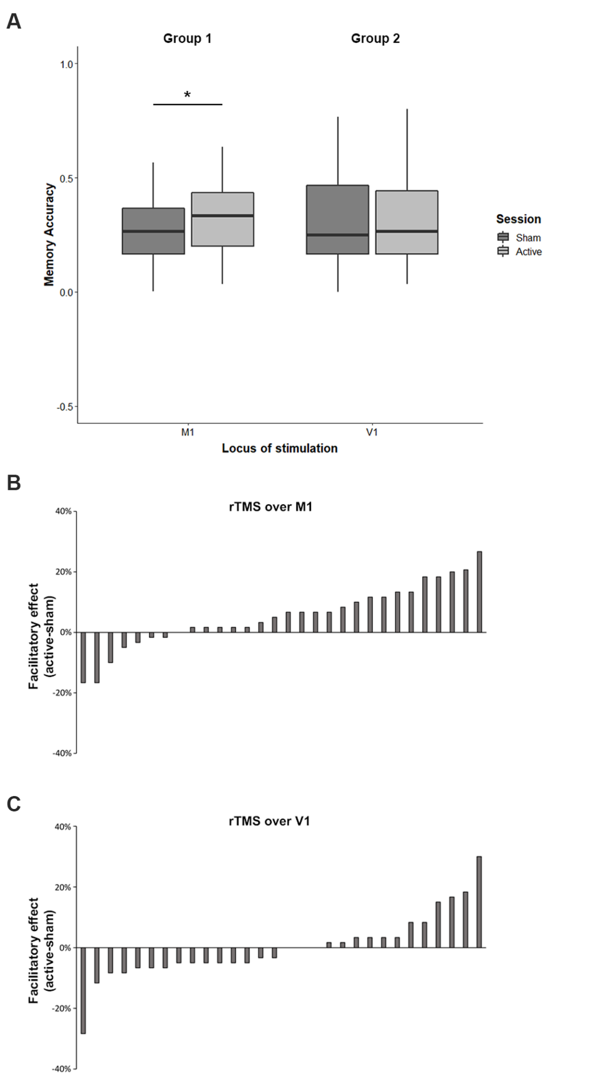


FIGURE 2
Effect of active stimulation on memory performance in M1 and V1 (left and right of the panel, respectively). Error bars indicate standard error of the mean (SEM). *$p$<0.05 **(A)**. Changes in recall across participants (difference between active and sham rTMS) in M1 **(B)** and in V1 **(C)**.

between type of sentences in the retrieval of manipulable object names appears in all the experimental conditions, independently of stimulation session (active or sham) and stimulation group (M1 or V1).

More importantly, the analysis revealed a significant Group x Session interaction ($F_{1,174}=4.70$; $p=0.03$; $\eta p^2=0.03$). As shown in Figure 2A, in the experimental group, whose target area was M1, recall of both sentences was significantly better after the active rTMS session (33% ± 13%) relative to sham session (27% ± 12%, $p=0.01$, Cohen's $d=0.47$). On the contrary, as we expected, in the control group, stimulating V1, no changes were found. That is, participants' performance did not improve when they received active rTMS over V1 (32% ± 19%) compared to the sham stimulation (32% ± 19%). Figure 2B shows the changes in recall, expressed as the difference in accuracy between active and sham stimulation in M1, across participants, where positive and negative values indicate improved and impaired performance, respectively. As can be seen, the facilitatory effects after rTMS on M1 were obtained in 23 participants out of 30. On the other hand, Figure 2C shows that the stimulation of V1 produced more variable results, with a more symmetric distribution centered at zero, with 15 participants showing impairment and 12 participants showing improvement in the recall of manipulable object.

## Discussion

This study demonstrated that focal neurostimulation of M1, by means of offline rTMS, modifies performance in a cue-recall task in which object names were retrieved in response to verb cues. Specifically, rTMS on the motor cortex improved recall for manipulable object names, learned in action verb and attentional verb contexts. The results were robust, and their validity was guaranteed by the strict control conditions of the experimental design. That is, there was a within-participants control, which consisted of testing performance in two sessions under active and sham stimulation, respectively. In addition, a control group was introduced, in which a non-motoric region (V1) was stimulated. Only active rTMS on M1 induced changes in recall, demonstrating a functional role of this region in memory for manipulable object names, and supporting the general idea that embodied representations play a causal role in long-term memory of sentences.

*The recall of objects names depends on the type of verb context.* Before commenting the impact of neuromodulation on memory, let us consider the main effect of verb: the names are always better recalled in action verb contexts than in attentional verb contexts, independently of the stimulation protocol, confirming previous results in the literature with similar materials and task demands as ours (Dutriaux and Gyselinck, 2016; Dutriaux et al., 2018; de Vega et al., 2021; Vitale et al., 2021). Since the names are the same in both contexts, this should be explained by some feature of the verbs, such as their differences in concreteness (see Table 1) or the fact that action verbs are multimodal (e.g., visual and motor) recruiting more extensive neural networks than attentional verbs. Another possibility is that the name of manipulable objects is more predictable in the context of action verbs than in the context of attentional verbs, because the associative strength verb-object is larger in the former than the later.

*Cortical inhibition improved performance.* Previous research has shown that 1 Hz-rTMS on M1 inhibits or reduces cortical excitability (Maeda et al., 2000; Houdayer et al., 2008; Hoogendam et al., 2010, see Fitzgerald et al., 2006 for a review). If so, we might expect impaired performance in tasks that depend on M1, such as action related language. However, we found the opposite, that is, an enhanced memory of manipulable object names after receiving inhibitory rTMS. This paradoxical effect is not new in the literature of memory. For instance, 1 Hz rTMS applied over DLPF, although it reduces the activation of this region, improves working memory and episodic memory performance (Turriziani et al., 2012; Patel et al., 2020; van der Plas et al., 2021). There is even a study in which inhibitory theta burst applied on PMC improved performance on a lexical decision task with action verbs (Willems et al., 2011). Thus, we can tentatively state that reducing M1 excitability could induce facilitatory effects on memory for action related language, as has been frequently reported in other studies of memory with verbal and nonverbal materials. However, the specific computational mechanisms at the neuron level and functional connectivity, by which the reduction of cortical excitability can improve memory, have not yet been established in the literature. The development of neurocomputational approaches could provide a better comprehension of some paradoxical effects frequently found in the embodied semantic literature (Pulvermüller, 2013, 2018).

*Neuromodulation improves names recall in action and attentional contexts.* Contrary to our expectations, the rTMS on M1 enhanced recall of manipulable names in both action verb and attentional verb contexts. In previous studies with similar materials and task demands, the hands-back posture at learning (Dutriaux et al., 2018; de Vega et al., 2021) or the offline excitatory tDCS on M1 (Vitale et al., 2021) selectively modulated memory performance for action verb contexts, either impairing or improving retrieval, respectively. So, why did we not replicate the selective effect of the verb? Here, stimulating the motor cortex with high-precision and focal inhibitory rTMS improved retrieval in both verb contexts, and this was a robust pattern shared by most participants (23 out of 30, see Figure 2B), compared to the diffuse effect and high inter-individual variability of tDCS neuromodulation (Evans et al., 2022, see Li et al., 2015; Vergallito et al., 2022 for reviews). As we mentioned earlier, action sentences are systematically better remembered than attentional sentences in all conditions, indicating that some differential property of the verbs induced this result, since the object names associated with the verbs were the same. In turn, the fact that recall improved after rTMS for the two sentence types can only be attributed to features of the of the shared objects. In other words, focal and intensive activation in M1 acts upon the motor representations of object names, which seems to increase their associative strength with contexts, whether they are action verbs or attentional verbs, improving cue-based recall in both cases. The best explanation for this undifferentiated impact of stimulation comes from the features of the target words to be recalled, which unlike in many other studies on embodied language, were manipulable object names, which were shared by both action and attentional contexts. Manipulable object names are action words that may themselves activate motoric brain regions. Thus, manipulable object names exhibit motor compatibility effects in behavioral experiments (Zhang et al., 2016; Buccino et al., 2018), share motor cortex activations with action verbs in neuroimaging studies (Saccuman et al., 2006), induce corticospinal modulations when TMS is applied in M1 (Gough et al., 2012), show similar changes of performance on a semantic task as action verbs after rTMS in M1 (Gerfo et al., 2008), and reduce recall when learning takes place in hand-behind-back posture (Dutriaux and Gyselinck, 2016).

In conclusion, this research supports the functional link between the activity of the motor cortex and the performance in a long-term memory task for action language. Specifically, the offline modification of M1 excitability by means of focal and high-precision rTMS determined an improvement in the memory of manipulable object names learned both in the context of action verbs and attentional verbs. The affordances of the names, presumably associated with the activity of motoric brain networks, could be responsible of this overall improvement in recall after M1 stimulation. The study reinforces the embodiment semantic approach by demonstrating a brain-memory causal link for action language.

*Limitations.* Despite the contribution of this study, it has some limitations. First, here we focus on the impact of low-frequency rTMS exclusively in M1, yet other areas of the motor network, in particular the PMC, contribute significantly to action language comprehension (Hauk and Pulvermüller, 2004; Pulvermüller, 2013, 2018). Indeed, modulation of PMC activity affects performance on some language tasks, specifically those involving verbs and sentences with motor content (Willems et al., 2011; Tremblay et al., 2012; Gijssels et al., 2018). Future complementary studies could assess whether PMC plays also a role in memory for manipulable objects. Second, due to high inter-individual variability in response to rTMS, and because the direction rTMS-induced behavioural effects was unexpected, physiological data, such as cortico-spinal excitability measured by TMS-induced MEP, should be recorded before and after the stimulation. This could allow assessment of whether TMS is actually inhibiting M1 activity in each participant.

## Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

## Ethics statement

The studies involving human participants were reviewed and approved by Comité de Ética de la Investigación y de Bienestar Animal, Universidad de La Laguna. The patients/participants provided their written informed consent to participate in this study.

## Author contributions

FV analyzed and interpreted the data, wrote the original draft, and provided funding. MV conceptualized the study, supervised the research at all stages, and provided funding. All authors contributed to the article and approved the submitted version.

## Funding

This work was supported by grants from the Spanish Ministerio de Ciencia e Innovación and the European Regional Development Funds (grant PID2021-126172NB-I00) awarded to MV and the Research Training Predoctoral grant (BES-2016-078438) to FV.

## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

## Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

## References

Avenanti, A., Annela, L., and Serino, A. (2012). Suppression of premotor cortex disrupts motor coding of peripersonal space. *NeuroImage* 63, 281–288. doi: 10.1016/j.neuroimage.2012.06.063

Bak, T. H., O'Donovan, D. G., Xuereb, J. H., Boniface, S., and Hodges, J. R. (2001). Selective impairment of verb processing associated with pathological changes in Brodmann areas 44 and 45 in the motor neurone disease-dementia-aphasia syndrome. *Brain* 124, 103–120. doi: 10.1093/brain/124.1.103

Barsalou, L. W. (2008). Grounded cognition. *Annu. Rev. Psychol.* 59, 617–645. doi: 10.1146/annurev.psych.59.103006.093639

Bates, D., Mächler, M., Bolker, B., and Walker, S. (2015). Fitting linear mixed-effects models using lme4. *J. Stat. Softw.* 67, 1–48. doi: 10.18637/jss.v067.i01

Benjamini, Y., and Hochberg, Y. (1995). Controlling the false discovery rate: a practical and powerful approach to multiple testing. *J. R. Stat. Soc. Ser. B* 57, 289–300. Available at: http://www.jstor.org/stable/2346101

Birba, A., Fittipaldi, S., Cediel Escobar, J. C., Gonzalez Campo, C., Legaz, A., Galiani, A., et al. (2022). Multimodal neurocognitive markers of naturalistic discourse typify diverse neurodegenerative diseases. *Cereb. Cortex* 32, 3377–3391. doi: 10.1093/cercor/bhab421

Boggio, P. S., Zaghi, S., Lopes, M., and Fregni, F. (2008). Modulatory effects of anodal transcranial direct current stimulation on perception and pain thresholds in healthy volunteers. *Eur. J. Neurol.* 15, 1124–1130. doi: 10.1111/j.1468-1331.2008.02270.x

Bub, D. N., Masson, M. E. J., and Kumar, R. (2018). Time course of motor affordances evoked by pictured objects and words. *J. Exp. Psychol. Hum. Percept. Perform.* 44, 53–68. doi: 10.1037/xhp0000431

Buccino, G., Dalla Volta, R., Arabia, G., Morelli, M., Chiriaco, C., Lupo, A., et al. (2018). Processing graspable object images and their nouns is impaired in Parkinson's disease patients. *Cortex* 100, 32–39. doi: 10.1016/j.cortex.2017.03.009

Candidi, M., Leone-Fernandez, B., Barber, H. A., Carreiras, M., and Aglioti, S. M. (2010). Hands on the future: facilitation of cortico-spinal hand-representation when reading the future tense of hand-related action verbs. *Eur. J. Neurosci.* 32, 677–683. doi: 10.1111/j.1460-9568.2010.07305.x

Casula, E. P., Tarantino, V., Basso, D., Arcara, G., Marino, G., Toffolo, G. M., et al. (2014). Low-frequency rTMS inhibitory effects in the primary motor cortex: insights from TMS-evoked potentials. *NeuroImage* 98, 225–232. doi: 10.1016/j.neuroimage.2014.04.065

de Vega, M., Dutriaux, L., Moreno, I. Z., García-Marco, E., Seigneuric, A., and Gyselinck, V. (2021). Crossing hands behind your back reduces recall of manual action sentences and alters brain dynamics. *Cortex* 140, 51–65. doi: 10.1016/j.cortex.2021.03.016

de Vega, M., León, I., Hernández, J. A., Valdés, M., Padrón, I., and Ferstl, E. C. (2014). Action sentences activate sensory motor regions in the brain independently of their status of reality. *J. Cogn. Neurosci.* 26, 1363–1376. doi: 10.1162/jocn_a_00559

Desai, R. H., Herter, T., Riccardi, N., Rorden, C., and Fridriksson, J. (2015). Concepts within reach: action performance predicts action language processing in stroke. *Neuropsychologia* 71, 217–224. doi: 10.1016/j.neuropsychologia.2015.04.006

Dutriaux, L., Dahiez, X., and Gyselinck, V. (2018). How to change your memory of an object with a posture and a verb. *Q. J. Exp. Psychol.* 72, 1112–1118. doi: 10.1177/1747021818785096

Dutriaux, L., and Gyselinck, V. (2016). Learning is better with the hands free: the role of posture in the memory of manipulable objects. *PLoS One* 11:e0159108. doi: 10.1371/journal.pone.0159108

Evans, C., Zich, C., Lee, J. S. A., Ward, N., and Bestmann, S. (2022). Inter-individual variability in current direction for common tDCS montages. *NeuroImage* 260:119501. doi: 10.1016/j.neuroimage.2022.119501

Fischer, M. H., and Zwaan, R. A. (2008). Embodied language: a review of the role of the motor system in language comprehension. *Q. J. Exp. Psychol.* 61, 825–850. doi: 10.1080/17470210701623605

Fitzgerald, P. B., Fountain, S., and Daskalakis, Z. J. (2006). A comprehensive review of the effects of rTMS on motor cortical excitability and inhibition. *Clin. Neurophysiol. Off. J. Int. Fed. Clin. Neurophysiol.* 117, 2584–2596. doi: 10.1016/j.clinph.2006.06.712

Gallese, V., and Lakoff, G. (2005). The Brain's concepts: the role of the sensory-motor system in conceptual knowledge. *Cogn. Neuropsychol.* 22, 455–479. doi: 10.1080/02643290442000310

García, A. M., and Ibáñez, A. (2016). A touch with words: dynamic synergies between manual actions and language. *Neurosci. Biobehav. Rev.* 68, 59–95. doi: 10.1016/j.neubiorev.2016.04.022

Gerfo, E. L., Oliveri, M., Torriero, S., Salerno, S., Koch, G., and Caltagirone, C. (2008). The influence of rTMS over prefrontal and motor areas in a morphological task: grammatical vs. semantic effects. *Neuropsychologia* 46, 764–770. doi: 10.1016/j.neuropsychologia.2007.10.012

Gianelli, C., and Volta, R. D. (2014). Does listening to action-related sentences modulate the activity of the motor system? Replication of a combined TMS and behavioral study. *Front. Psychol* 5:1511. doi: 10.3389/fpsyg.2014.01511

Gijssels, T., Ivry, R. B., and Casasanto, D. (2018). tDCS to premotor cortex changes action verb understanding: complementary effects of inhibitory and excitatory stimulation. *Sci. Rep.* 8:11452. doi: 10.1038/s41598-018-29600-6

Glenberg, A. M., and Kaschak, M. P. (2002). Grounding language in action. *Psychon. Bull. Rev.* 9, 558–565. doi: 10.3758/BF03196313

Gough, P. M., Riggio, L., Chersi, F., Sato, M., Fogassi, L., and Buccino, G. (2012). Nouns referring to tools and natural objects differentially modulate the motor system. *Neuropsychologia* 50, 19–25. doi: 10.1016/j.neuropsychologia.2011.10.017

Hauk, O., and Pulvermüller, F. (2004). Neurophysiological distinction of action words in the Fronto-central cortex. *Hum. Brain Mapp.* 21, 191–201. doi: 10.1002/hbm.10157

Hoogendam, J. M., Ramakers, G. M. J., and Di Lazzaro, V. (2010). Physiology of repetitive transcranial magnetic stimulation of the human brain. *Brain Stimul.* 3, 95–118. doi: 10.1016/j.brs.2009.10.005

Houdayer, E., Degardin, A., Cassim, F., Bocquillon, P., Derambure, P., and Devanne, H. (2008). The effects of low- and high-frequency repetitive TMS on the input/output properties of the human corticospinal pathway. *Exp. Brain Res.* 187, 207–217. doi: 10.1007/s00221-008-1294-z

Kuipers, J. R., Van Koningsbruggen, M., and Thierry, G. (2013). Semantic priming in the motor cortex: evidence from combined repetitive transcranial magnetic stimulation and event-related potential. *Neuroreport* 24, 646–651. doi: 10.1097/WNR.0b013e3283631467

Laakso, I., Mikkonen, M., Koyama, S., Hirata, A., and Tanaka, S. (2019). Can electric fields explain inter-individual variability in transcranial direct current stimulation of the motor cortex? *Sci. Rep.* 9:626. doi: 10.1038/s41598-018-37226-x

Li, L. M., Uehara, K., and Hanakawa, T. (2015). The contribution of interindividual factors to variability of response in transcranial direct current stimulation studies. *Front. Cell. Neurosci.* 9:181. doi: 10.3389/fncel.2015.00181

Maeda, F., Keenan, J. P., Tormos, J. M., Topka, H., and Pascual-Leone, A. (2000). Modulation of corticospinal excitability by repetitive transcranial magnetic stimulation. *Clin. Neurophysiol.* 111, 800–805. doi: 10.1016/S1388-2457(99)00323-5

Makoshi, Z., Kroliczak, G., and Van Donkelaar, P. (2011). Human supplementary motor area contribution to predictive motor planning. *J. Mot. Behav.* 43, 303–309. doi: 10.1080/00222895.2011.584085

Mikkonen, M., Laakso, I., Sumiya, M., Koyama, S., Hirata, A., and Tanaka, S. (2018). TMS motor thresholds correlate with TDCS electric field strengths in hand motor area. *Front. Neurosci.* 12:426. doi: 10.3389/fnins.2018.00426

Mikkonen, M., Laakso, I., Tanaka, S., and Hirata, A. (2020). Cost of focality in TDCS: interindividual variability in electric fields. *Brain Stimul.* 13, 117–124. doi: 10.1016/j.brs.2019.09.017

Moreno, I., De Vega, M., and León, I. (2013). Understanding action language modulates oscillatory mu and beta rhythms in the same way as observing actions. *Brain Cogn.* 82, 236–242. doi: 10.1016/j.bandc.2013.04.010

Moreno, I., de Vega, M., León, I., Bastiaansen, M., Glen Lewis, A., and Magyari, L. (2015). Brain dynamics in the comprehension of action-related language. A time-frequency analysis of mu rhythms. *NeuroImage* 109, 50–62. doi: 10.1016/j.neuroimage.2015.01.018

Oliveri, M., Finocchiaro, C., Shapiro, K., Gangitano, M., Caramazza, A., and Pascual-Leone, A. (2004). All talk and no action: a transcranial magnetic stimulation study of motor cortex activation during action word production. *J. Cogn. Neurosci.* 16, 374–381. doi: 10.1162/089892904322926719

Papeo, L., Vallesi, A., Isaja, A., and Rumiati, R. I. (2009). Effects of TMS on different stages of motor and non-motor verb processing in the primary motor cortex. *PLoS One* 4:e4508. doi: 10.1371/journal.pone.0004508

Patel, R., Silla, F., Pierce, S., Theule, J., and Girard, T. A. (2020). Cognitive functioning before and after repetitive transcranial magnetic stimulation (rTMS): a quantitative meta-analysis in healthy adults. *Neuropsychologia* 141:107395. doi: 10.1016/j.neuropsychologia.2020.107395

Pulvermüller, F. (2013). How neurons make meaning: brain mechanisms for embodied and abstract-symbolic semantics. *Trends Cogn. Sci.* 17, 458–470. doi: 10.1016/j.tics.2013.06.004

Pulvermüller, F. (2018). Neural reuse of action perception circuits for language, concepts and communication. *Prog. Neurobiol.* 160, 1–44. doi: 10.1016/j.pneurobio.2017.07.001

Raposo, A., Moss, H. E., Stamatakis, E. A., and Tyler, L. K. (2009). Modulation of motor and premotor cortices by actions, action words and action sentences. *Neuropsychologia* 47, 388–396. doi: 10.1016/j.neuropsychologia.2008.09.017

Repetto, C., Colombo, B., Cipresso, P., and Riva, G. (2013). The effects of rTMS over the primary motor cortex: the link between action and language. *Neuropsychologia* 51, 8–13. doi: 10.1016/j.neuropsychologia.2012.11.001

Rose, N. S., Buchsbaum, B. R., and Craik, F. I. M. (2014). Short-term retention of a single word relies on retrieval from long-term memory when both rehearsal and refreshing are disrupted. *Mem. Cogn.* 42, 689–700. doi: 10.3758/s13421-014-0398-x

Rossi, S., Hallett, M., Rossini, P. M., and Pascual-Leone, A. (2011). Screening questionnaire before TMS: an update. *Clin. Neurophysiol.* 122:1686. doi: 10.1016/j.clinph.2010.12.037

Rossi, S., Hallett, M., Rossini, P. M., Pascual-Leone, A., Nasreldin, M., Nakatsuka, M., et al. (2009). Safety, ethical considerations, and application guidelines for the use of transcranial magnetic stimulation in clinical practice and research. *Clin. Neurophysiol.* 120, 2008–2039. doi: 10.1016/j.clinph.2009.08.016

Rossini, P. M., Burke, D., Chen, R., Cohen, L. G., Daskalakis, Z., Di Iorio, R., et al. (2015). Non-invasive electrical and magnetic stimulation of the brain, spinal cord, roots and peripheral nerves: basic principles and procedures for routine clinical and research application: an updated report from an I.F.C.N committee. *Clin. Neurophysiol.* 126, 1071–1107. doi: 10.1016/j.clinph.2015.02.001

Saccuman, M. C., Cappa, S. F., Bates, E. A., Arevalo, A., Della Rosa, P., Danna, M., et al. (2006). The impact of semantic reference on word class: an fMRI study of action and object naming. *NeuroImage* 32, 1865–1878. doi: 10.1016/j.neuroimage.2006.04.179

Shebani, Z., and Pulvermüller, F. (2013). Moving the hands and feet specifically impairs working memory for arm- and leg-related action words. *Cortex* 49, 222–231. doi: 10.1016/j.cortex.2011.10.005

Shebani, Z., and Pulvermüller, F. (2018). Flexibility in language action interaction: the influence of movement type. *Front. Hum. Neurosci.* 12:252. doi: 10.3389/fnhum.2018.00252

Silvanto, J., Lavie, N., and Walsh, V. (2005). Double dissociation of V1 and V5/MT activity in visual awareness. *Cereb. Cortex* 15, 1736–1741. doi: 10.1093/cercor/bhi050

Silvanto, J., Muggleton, N. G., Cowey, A., and Walsh, V. (2007). Neural activation state determines behavioral susceptibility to modified theta burst transcranial magnetic stimulation. *Eur. J. Neurosci.* 26, 523–528. doi: 10.1111/j.1460-9568.2007.05682.x

Stanfield, R. A., and Zwaan, R. A. (2001). The effect of implied orientation derived from verbal context on picture recognition. *Psychol. Sci.* 12, 153–156. doi: 10.1111/1467-9280.00326

Tettamanti, M., Buccino, G., Saccuman, M. C., Gallese, V., Danna, M., Scifo, P., et al. (2005). Listening to action-related sentences activates fronto-parietal motor circuits. *J. Cogn. Neurosci.* 17, 273–281. doi: 10.1162/0898929053124965

Tremblay, P., Sato, M., and Small, S. L. (2012). TMS-induced modulation of action sentence priming in the ventral premotor cortex. *Neuropsychologia* 50, 319–326. doi: 10.1016/j.neuropsychologia.2011.12.002

Turriziani, P., Smirni, D., Zappalà, G., Mangano, G. R., Oliveri, M., and Cipolotti, L. (2012). Enhancing memory performance with rTMS in healthy subjects and individuals with mild cognitive impairment: the role of the right dorsolateral prefrontal cortex. *Front. Hum. Neurosci.* 6:62. doi: 10.3389/fnhum.2012.00062

van der Plas, M., Braun, V., Stauch, B. J., and Hanslmayr, S. (2021). Stimulation of the left dorsolateral prefrontal cortex with slow rTMS enhances verbal memory formation. *PLoS Biol.* 19:e3001363. Available at:. doi: 10.1371/journal.pbio.3001363

van Elk, M., van Schie, H. T., Zwaan, R. A., and Bekkering, H. (2010). The functional role of motor activation in language processing: motor cortical oscillations support lexical-semantic retrieval. *NeuroImage* 50, 665–677. doi: 10.1016/j.neuroimage.2009.12.123

Vergallito, A., Feroldi, S., Pisoni, A., and Romero Lauro, L. J. (2022). Inter-individual variability in tDCS effects: a narrative review on the contribution of stable, variable, and contextual factors. *Brain Sci.* 12:522. doi: 10.3390/brainsci12050522

Vitale, F., Padrón, I., Avenanti, A., and de Vega, M. (2021). Enhancing motor brain activity improves memory for action language: a tDCS study. *Cereb. Cortex* 31, 1569–1581. doi: 10.1093/cercor/bhaa309

Vukovic, N., Feurra, M., Shpektor, A., Myachykov, A., and Shtyrov, Y. (2017). Primary motor cortex functionally contributes to language comprehension: an online rTMS study. *Neuropsychologia* 96, 222–229. doi: 10.1016/j.neuropsychologia.2017.01.025

Willems, R. M., Labruna, L., D'Esposito, M., Ivry, R., and Casasanto, D. (2011). A functional role for the motor system in language understanding: evidence from theta-burst transcranial magnetic stimulation. *Psychol. Sci.* 22, 849–854. doi: 10.1177/0956797611412387

Ye, L., and Xiaolan, F. (2007). How does distraction task influence the interaction of working memory and long-term memory? *Lect. Notes Comput. Sci. (including Subser. Lect. Notes Artif. Intell. Lect. Notes Bioinformatics)* 4562 LNAI, 366–374. doi: 10.1007/978-3-540-73331-7_40

Zhang, Z., Sun, Y., and Humphreys, G. W. (2016). Perceiving object affordances through visual and linguistic pathways: a comparative study. *Sci. Rep.* 6:26806. doi: 10.1038/srep26806