JYU DISSERTATIONS 858

Dong Tang

Processing of Emotion-Label Words and Emotion-Laden Words in L1 and L2

Behavioral and Electrophysiological Evidence

UNIVERSITY OF JYVÄSKYLÄ
FACULTY OF INFORMATION TECHNOLOGY

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Esitetään Jyväskylän yliopiston informaatioteknologian tiedekunnan suostumuksella
julkisesti tarkastettavaksi Mattilanniemen auditoriossa MaA103
marraskuun 29. päivänä 2024 kello 12.

Academic dissertation to be publicly discussed, by permission of
the Faculty of Information Technology of the University of Jyväskylä,
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JYVÄSKYLÄN YLIOPISTO
UNIVERSITY OF JYVÄSKYLÄ

JYVÄSKYLÄ 2024

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ISBN 978-952-86-0419-8 (PDF)
URN:ISBN:978-952-86-0419-8
ISSN 2489-9003

Permanent link to this publication: http://urn.fi/URN:ISBN:978-952-86-0419-8

ABSTRACT

Tang, Dong
Processing of emotion-label words and emotion-laden words in L1 and L2: Behavioral and electrophysiological evidence
Jyväskylä: University of Jyväskylä, 2024, 68 p. + original papers
(JYU Dissertations
ISSN 2489-9003; 858)
ISBN 978-952-86-0419-8 (PDF)

The interaction between emotion and language remains an area of inquiry in bilingualism research. Employing behavioral and EEG (electroencephalography) measurements, this thesis explores how late bilinguals process emotion-label words (e.g., happy, angry) and emotion-laden words (e.g., worthy, poor) with positive or negative valence, comparing their processing to neutral words and to each other in both their first (L1) and second language (L2). Article I examined the processing of emotion-label and emotion-laden words in L1 and L2. Results showed that emotion-label words induced faster response times than emotion-laden words in both languages, confirming the emotion word type effect in both L1 and L2. Moreover, L2 negative emotion-laden words were associated with slower and fewer accurate responses relative to neutral words, suggesting an emotional disadvantage. Article II employed the event-related potentials (ERP) to investigate the neural correlates underlying the processing of these two types of emotion words in L1 and L2. Results showed that L1 negative emotion-laden words and L2 negative emotion-label words elicited larger N170 amplitudes than neutral words, suggesting stronger emotion effect. Emotion-label words, particularly those with positive valence, elicited reduced early posterior negativity (EPN) compared to emotion-laden words, indicating fewer attentional resources allocated to these words. Additionally, L1 emotion words elicited larger N400 amplitudes and smaller late posterior complex (LPC) amplitudes than those in L2, suggesting that late bilinguals exhibited less complete access to L2 emotion words compared to L1. Article III explored the different brain activation during the processing of L2 emotion-label and emotion-laden words in explicit and implicit processing tasks. Results showed that in the explicit task, compared to the other three groups of emotion words, L2 negative emotion-laden words induced slower responses, and positive emotion-label words elicited increased LPC amplitudes. No such effects were observed in the implicit task. Overall, this dissertation provides evidence that L1 evokes greater emotional engagement than L2, and that emotion-label and emotion-laden words are processed differently in late bilinguals' L1 and L2 at both behavioral and electrophysiological levels. Nonetheless, the effects of emotion word type and valence appear to be potentially task-dependent, at least in the L2 context.

Keywords: emotion-label words, emotion-laden words, valence, L1, L2, ERP

TIIVISTELMÄ (ABSTRACT IN FINNISH)

Tang, Dong
Tunteita kuvaavien ja tunteita sisältävien sanojen käsittelymekanismit L1- ja L2 kielissä: Käyttäytymis- ja elektrofysiologinen näyttö
Jyväskylä: Jyväskylän yliopisto, 2024, 68 s. + alkuperäiset artikkelit
(JYU Dissertations
ISSN 2489-9003; 858)
ISBN 978-952-86-0419-8 (PDF)

Kaksikielisyyden tutkimuksessa tunteiden ja kielen välinen vuorovaikutus on merkittävä tutkimusalue. Käyttäytymiseen liittyviä ja EEG-mittauksia käyttäen tässä väitöskirjassa tutkittiin, miten myöhäiskaksikieliset käsittelevät "emootiomerkittyjä" sanoja (esim. iloinen, vihainen) ja "emootioladattuja" sanoja (esim. arvokas, huono), joilla on positiivinen tai negatiivinen valenssi. Näiden sanojen käsittelyä verrattiin neutraaleihin sanoihin ja toisiinsa sekä äidinkielessä (L1-kieli) että toisessa kielessä (L2-kieli). Artikkelissa I tutkittiin emootiomerkittyjen ja emootioladattujen sanojen prosessointia L1- ja L2-kielissä. Tulokset osoittivat, että emootiomerkittyihin sanoihin liittyi nopeampia reaktioaikoja kuin emootioladattuihin sanoihin molemmissa kielissä, mikä vahvistaa emootiosanan tyypin vaikuttavan sanan prosessointiin sekä L1- että L2-kielissä. Lisäksi L2-kielen negatiivisiin emootioladattuihin sanoihin liittyi hitaampia ja epätarkempia vastauksia verrattuna neutraaleihin sanoihin, mikä viittasi niiden aiheuttamaan emotionaaliseen haittaan. Artikkelissa II käytettiin tapahtumasidonnaisia herätevasteita selvittämään näiden kahden tunnesanatyypin prosessoinnin taustalla olevia hermostollisia korrelaatteja L1- ja L2-kielissä. Tulokset osoittivat, että L1-kielen negatiivisesti emootioladatut sanat ja L2-kielen negatiiviset emootiomerkityt sanat aiheuttivat voimakkaamman tunnevaikutuksen. Emootiomerkittyihin sanoihin, erityisesti niihin, joilla oli positiivinen valenssi, kohdistui vähemmän tarkkaavaisuusresursseja. Lisäksi näyttää siltä, että myöhäiskaksikielisillä on heikompi pääsy L2-kielen tunnesanoihin verrattuna L1-kieleen. Artikkelissa III tarkasteltiin L2-kielen emootiomerkittyjen ja emootioladattujen sanojen aiheuttamia eroja aivoaktivaatiovasteissa eksplisiittisten ja implisiittisten prosessointitehtävien aikana. Tulokset osoittivat, että eksplisiittisessä tehtävässä L2-kielen negatiiviset emootioladatut sanat aiheuttivat hitaampia vasteita verrattuna muihin kolmeen tunnesanaryhmään, kun taas positiiviset emootiomerkityt sanat vahvistivat LPC-vasteita. Implisiittisessä tehtävässä tällaisia vaikutuksia ei havaittu. Tämä väitöskirja osoittaa, että L1-kielessä tunteiden käsittely on voimakkaampaa kuin L2-kielessä ja että emootiomerkittyjen ja emootioladattujen sanojen prosessointi eroaa myöhäiskaksikielisten L1- ja L2-kielissä sekä käyttäytymisen että aivotoiminnan tasolla. Emootiosanatyypin ja valenssin vaikutukset ovat mahdollisesti tehtävästä riippuvaisia ainakin L2-kielen kontekstissa.

Asiasanat: emootiomerkitty sana, emootioladattu sana, valenssi, L1, L2, ERP

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ACKNOWLEDGEMENTS

My doctoral journey has been a twist of emotions, interwoven with strands of happiness and sadness, much like the positive and negative words that flowed through my research. The support and presence of the following individuals have imbued this twist with strength and resilience, making it a truly unforgettable odyssey.

First and foremost, I would like to extend my heartfelt thanks to my supervisor, Professor Tommi Kärkkäinen, whose support and encouragement have been instrumental throughout this journey. His positive attitude and sense of humor, both in academic pursuits and in life, have had a profound impact on me. Despite any setbacks I encountered during the preparation, presentation and conduct of my research, his consistent affirmation of "Good! Let's do it!" was a constant source of motivation. I vividly recall the moment I submitted my first manuscript, feeling a twinge of nervousness. Tommi's reassuring words, "Keep calm, as it is the reviewer's feedback that matters!" helped ease my anxiety, even though the reviewer's decision was, and still is, significant to me. Anyway, his words gave me a sense of calm amidst uncertainty, nurturing an environment for me to grow in the realm of research. I wish to express my thanks to Professor Tarmo Lipping and Professor Lin Fan for their comments on improving this doctoral thesis.

I would like to convey my gratitude to Professor Huili Wang for her invaluable guidance. Her mentorship, which introduced me to the field of psycholinguistics from English language and literature, has significantly changed my academic trajectory to some extent. Her influence has been crucial in shaping my academic journey. Additionally, I consider myself fortunate enough to have Associate Professor Tiina Parviainen as my second official supervisor. Her professional and insightful feedback has been crucial in improving each of my experiments and manuscripts. Without her guidance, I am certain that the publication process would not have gone so smoothly. Every discussion with Tiina has sparked new ideas, whether in experimental design or future research directions. Her dedication to research has left a lasting impact on me. I am also deeply appreciative of the Language and Cognition research group for their insightful suggestions during our weekly Tuesday night meetings, which have enriched my research endeavors.

I am deeply grateful to all the Chinese participants who took part in my three studies. Their willingness to engage was crucial to the completion of my research endeavors. Furthermore, I would also like to convey my sincere appreciation to my collaborators, Dr. Xueqiao Li, Dr. Yang Fu, Dr. Bo Liu, Dr. Anqi Zang and Dr. Xueyan Li for their contributions to various aspects of my research, including experimental design, data collection, statistical modeling and manuscript revision. Without their help, I would not have managed to finish my doctoral studies. Furthermore, I would like to express special thanks to Chi Jin for his help in coding, and to Viki-Veikko Elomaa, Yalin Sun and Research

Assistant Reetta Joukainen for their assistance in data collection. Their support was indispensable in achieving the goals of my research.

I wish to express my appreciation to all my friends in Finland, including Dr. Huashuai Xu, Dr. Xin Zuo, Dr. Zhonghua Chen, Yuxing Hao, and others from Professor Fengyu Cong's research group; Liting Song, Jiaqi Zheng, Xiangyu Rong, Yuan Qin, Limin Hou, Lina Sun, and others from our LEACS group; Dr. Chaoxiong Ye, Dr. Lili Tian, Xichu Zhu, Wei Qi, Kaijun Jiang, Ziang Chen, Chenxiao Wu, Qin Li, Xinyang Liu, Tongtong Sun, Weiyi Wang, and others from the Department of Psychology; Dr. Fufan Liu, Xinying Chen, Yu Han, and others from the Faculty of Information Technology. I would also like to thank Dr. Weiyong Xu, Veikka Ikäheimonen, Jun Zhou, Zhanjun Tan, John Sayson, Kasperi Kinnunen, Elina Majuri, Tianjun Shen, Biying Wang, Lin Zheng, Alex Liao, and others from our badminton group. Their companionship and support have been invaluable in both my studies and daily life.

Finally, I must convey my deepest thanks to my parents for their unconditional love and support, and strong belief in me, which have served as a source of motivation throughout my journey. I also want to thank my elder sister and my brother-in-law for their devoted care of our parents. Their dedication has granted me the freedom to immerse myself in my studies while abroad over the past four years. Furthermore, my thanks go to my nephew who brings boundless joy to our family and adds a special warmth to this journey.

I would like to extend my thanks to the Chinese Scholarship Council for funding my doctoral studies, as well as to the Faculty of Information Technology and the Department of Psychology for their financial support and provision of experimental facilities. Their support has been indispensable in completing this dissertation.

I extend my appreciation to all those who have, in one way or another, contributed to my doctoral journey.

Jyväskylä 03.10.2024
Dong Tang

FIGURES

TABLES

ACRONYMS

ACC	Accuracy rate
CRI	Complex Random Intercept
ECT	Emotional Categorization Task
EEG	Electroencephalogram
EMM	Estimated Marginal Mean
EPN	Early Posterior Negativity
ERP	Event-Related Potential
EST	Emotional Stroop Task
HDI	Highest Density Interval
L1	First/native language
L2	Second language
LDT	Lexical Decision Task
LMEM	Linear Mixed Effects Model
LPC	Late Positive Complex
MPE	Maximum Probability of Effect
N170	Negative-going deflection peaking around 170 ms
N400	Negative-going deflection peaking around 400 ms
P200	Component peaking around 200 ms
ROPE	Regions Of Practical Equivalence
RT	Response Time

CONTENTS

LIST OF INCLUDED ARTICLES

I Tang, D., Fu, Y., Wang, H., Liu, B., Zang, A., & Kärkkäinen, T. (2023). The embodiment of emotion-label words and emotion-laden words: Evidence from late Chinese–English bilinguals. *Frontiers in Psychology*, 14. https://doi.org/10.3389/fpsyg.2023.1143064

II Tang, D., Li, X., Fu, Y., Wang, H., Li, X., Parviainen, T., & Kärkkäinen, T. (2024). Neural correlates of emotion-label vs. emotion-laden word processing in late bilinguals: Evidence from an ERP study. *Cognition and Emotion*, 1-18 (published online). https://doi.org/10.1080/02699931.2024.2352584

III Tang, D., Fu, Y., Li, X., Wang, H., Parviainen, T., & Kärkkäinen, T. (2024). Neural correlates of explicit and implicit processing of emotion-label vs. emotion-laden words in L2: Behavioral and electrophysiological evidence. Submitted manuscript.

Considering the instructions and feedback provided by the co-authors, the author of this dissertation designed the experiments, collected the data, conducted the EEG data pre-processing, and wrote the manuscripts for the three articles, while Yang Yu performed the statistical analysis. All authors contributed to the review and improvement of the manuscripts for the three articles.

1 INTRODUCTION

Emotion is an intrinsic element of language that profoundly influences how individuals use and process it (Hinojosa et al., 2023). As the multilingual community rapidly expands, the representation of emotion across languages has been increasingly highlighted. This thesis focuses on written emotion-related words, which serve as a suitable approach for exploring the interface between emotion and language (see Citron, 2012, for an overview). Studies have shown that words with emotional content (e.g., "angry") are represented and processed distinctly compared to both abstract words (e.g., "thought") and concrete words (e.g., "chair") (El-Dakhs & Altarriba, 2019; Pavlenko, 2008). For instance, emotion words received significantly lower ratings on both the concreteness and context availability scales when compared to concrete and abstract words. In addition, they were rated lower than concrete words and higher than abstract words on the imagery scale (E. Altarriba & Benvenuto, 1999). Follow-up research indicated that participants demonstrated superior recall rates for emotion words relative to both concrete and abstract words when recalling words from a list (J. Altarriba & Bauer, 2004).

The above-mentioned studies underscore the uniqueness of emotion words, establishing them as a distinctive category of words in the mental lexicon. So far, various methodological approaches have sought to delineate the affective properties inherent in emotion words, with the two-dimensional model (Russell et al., 1980) emerging as the most influential. This model characterizes emotion words along two main dimensions: valence, which refers to the intrinsic positivity or negativity related to stimuli, and arousal, which denotes the low or high degrees of emotional reactivity evoked by stimuli. Within this framework, emotion words have been typically categorized as either positive or negative, each exhibiting a range of arousal levels. This model offers a universal framework for categorizing emotion words across different languages (see Aguilar et al., 2024, for an overview; Bromberek-Dyzman et al., 2021). Extensive research has built on this foundation, demonstrating the effect of emotion on language processing (Hinojosa et al., 2020a).

Despite this extensive investigation, the emotion word type has often been overlooked in previous research (J. Zhang et al., 2017, 2020). Accordingly, emotion words encompass two subtypes (Pavlenko, 2008):

1. emotion-label words, which directly signify specific feelings or emotional states (e.g., "happy", "angry") and
2. emotion-laden words, which evoke emotions through word connotations (e.g., "wealthy", "poor").

Apparently, the traditional two-dimensional model appears inadequate for distinguishing between these two kinds of emotion words (Betancourt et al., 2024). In addition, the impact of emotion on language processing may be limited to the language acquired during individual development. In the bilingual research realm, although a growing body of studies has endeavored to determine whether the influence of emotion on word processing is comparable across an individual's

- first/native language (L1) and
- second language (L2),

the results have been inconsistent (Aguilar et al., 2024).

This doctoral thesis aims to investigate how late bilinguals process emotion-related words in their L1 and L2, with a focus on the emotion word type. Specifically, it seeks to explore and compare how emotion-label words and emotion-laden words are represented in L1 and L2 at both behavioral and electrophysiological levels. The central question is:

- Does the emotion word processing in L1 share a similar pattern with that in L2?

To address this, the thesis explores the following questions:

1. Is there a distinction in the processing of emotion-label and emotion-laden words in both L1 and L2?
2. What are the temporal dynamics that underlie this distinction?
3. Is this distinction consistent across different decoding tasks?

Three studies have been undertaken to answer these questions. Article I examines the effects of emotion and emotion word type on word processing in both L1 and L2, focusing on behavioral measures like reaction times and accuracy rates. Building on this, Article II employs the event-related potentials (ERP) technique to compare the time course of these effects in both L1 and L2. Article III extends the investigation by examining the effect of emotion word type across both explicit and implicit tasks, also utilizing the ERP technique. Collectively, this thesis aims to enhance our understanding of the mental representations of these two categories of emotion words in the bilingual mind.

1.1 Emotion word research in L1 and L2

Increasing research has evidenced that emotion-related words are represented divergently from non-emotional, neutral words, a phenomenon known as the "emotion effect" (Citron, 2012; F. Knickerbocker et al., 2019). This effect often manifests as quicker and more effective processing for emotion words in some experimental paradigms (Wu et al., 2024). For example, behavioral research in L1 has shown that in a lexical decision task (LDT) where subjects were asked to quickly and accurately judge whether a letter string constitutes a real word, emotion words, irrespective of their polarity, exhibited a processing facilitation relative to neutral words. This facilitation is evidenced by faster processing speeds and fewer response errors (Kousta et al., 2009). Similarly, Ferré et al. (2015) reported that emotion words, regardless of their degree of semantic relatedness, are advantaged in memory over neutral words. However, this advantage can vary based on the specific decoding task used, and the results concerning valence effect on word processing are rather mixed (see Hinojosa et al., 2020a, for a review).

Electrophysiologically, the electroencephalogram (EEG) has been used to monitor brain activation in both medical and research fields (Lipping & Beiramvand, 2024; Teplan, 2002). Among its various applications, the event-related potentials (ERP) technique stands out for its high temporal resolution in capturing cognitive processes and has been employed to investigate the temporal dynamics of emotion word processing. Research has shown the modulation of emotional content on word processing identified at both early and late processing stages (see Citron, 2012; Hinojosa et al., 2020a, 2023, for reviews). This has led to the development of affective neurolinguistics, a framework emphasizing the interaction between emotion and language processing (Hinojosa et al., 2020a). For instance, in the early stage of word processing, the N170, a negative-going deflection peaking around 170 ms, with an occipital-temporal distribution, has been found to differentiate emotional from non-emotional information (e.g., D. Zhang et al., 2014). In addition to this, the early posterior negativity (EPN), a negative deflection occurring 200 to 300 ms post-stimulus onset and distributed over the occipito-temporal regions, has been associated with increased visual attention to words containing affective information compared to neutral words. This enhancement is thought to indicate implicit and automatic attentional capture triggered by emotionally salient words (Citron, 2012; Schacht & Sommer, 2009a).

In the later processing stages, the N400 component, which typically peaks about 400 ms after stimulus onset and exhibits a centro-parietal distribution, has been associated with emotion word processing. Research has demonstrated that emotion words elicit an attenuated N400 response compared to neutral words, suggesting facilitated semantic integration of emotion words (Sass et al., 2010; Wang et al., 2019). Additionally, the late positive complex (LPC) is frequently reported in research on the processing of emotion words. The LPC is a positivegoing ERP component that peaks around 500 ms over centro-parietal sites after stimulus onset, reflecting the in-depth processing of emotionally salient stimuli. Studies have consistently reported that emotion words elicit larger LPC amplitudes relative to neutral words, indicating more elaborate processing of emotional content (see Citron, 2012, for a review). In addition, the LPC amplitudes appear to reflect task demands, with enhanced amplitudes being observed in tasks involving deeper semantic processing (Hinojosa et al., 2014; Schirmer & Adolphs, 2017), compared to tasks requiring more superficial processing (González-Villar et al., 2014; Schacht & Sommer, 2009a).

In terms of bilingualism research, however, the emotional experiences associated with L1 and L2 has been shown to differ significantly. Individuals often report that emotional experiences in their later-acquired language feel less intense or emotionally muted compared to those in their L1. For example, research has shown that L2 speakers demonstrate reduced physiological responses, such as diminished skin conductance, when exposed to emotionally charged stimuli like taboo words and reprimands in their L2 (Harris et al., 2003). Similarly, L2 speakers tend to rate the emotional valence of words—whether positive or negative—with less intensity than native speakers, indicating a reduced emotional resonance in L2 contexts (Ferré et al., 2022). This phenomenon, known as affective distance (Aguilar et al., 2024; Champoux-Larsson & Nook, 2024), suggests that affective content in L1 words elicits stronger affective responses compared to L2 words. This affective distance may also influence decision-making, leading individuals to make more rational and less emotionally biased decisions in L2 settings (e.g., Costa et al., 2014).

It is worth mentioning that only a limited number of investigations have focused on the neural correlates underlying how bilinguals process emotion words differently across languages. To the author's knowledge, one study pointed out that the emotionality of words in an L2 context is a matter of time. Specifically, the processing of emotion words was enhanced, as evidenced by greater EPN responses, in both L1 and L2. However, while there was no significant difference in the magnitude of the EPN effect between L1 and L2, the EPN in L2 was observed to be delayed, suggesting that emotion processing in L2 occurs less immediately (Opitz & Degner, 2012). Another study reported that in L1, emotional words elicited larger EPN amplitudes and smaller LPC amplitudes compared to neutral words. Conversely, in L2, positive emotion words were associated with a reduced N400 relative to neutral words (Chen et al., 2015). These results indicate that the processing facilitation for emotion words in L1 is primarily driven by rapid, automatic attentional capture, whereas emotion words in L2 may benefit from facilitated semantic retrieval during later stages of word processing.

The L1-L2 differences in emotion word processing can be explained within the framework of the emotional contexts of learning theory (Harris et al., 2006). According to this theory, L1 acquisition typically occurs within emotionally rich environments, where strong sensory experiences and affective interactions are integrated with language learning. In contrast, L2 is often learned in more constrained contexts, such as formal classroom settings, where emotional engagement is limited. This can result in weaker connections between L2 lexical meanings and emotionally relevant autobiographical experiences and daily social interactions (Pavlenko, 2012; Tang & Ding, 2023). This disparity contributes to a greater emotional distance in L2, where emotional activations associated with L2 words are often less intense than those triggered by L1 words. This is particularly evident in late bilinguals, who acquire their L2 at a later stage of language development and may not have had early exposure to bilingual environments or diverse social contexts (Toivo & Scheepers, 2019). As a result, L2 processing tends to be less emotionally grounded and more semantically driven, which may explain why emotional experiences in L2 feel less vivid or intense compared to L1.

1.2 Emotion word type research in L1 and L2

What are emotion words? Recent research has highlighted the need to reexamine the nuanced emotional properties that constitute an emotion word. It is proposed that emotion words are not a homogeneous set (Betancourt et al., 2024), but a mixture of two subtypes: emotion-label words and emotion-laden words (Pavlenko, 2008; Wu & Zhang, 2020; J. Zhang et al., 2017). Specifically, emotion-label words explicitly describe emotions like happiness or anger, whereas emotion-laden words evoke emotions through their emotional content. Over the past decade, researchers have provided evidence, across a variety of cognitive tasks, supporting the division between these two kinds of emotion words, which is referred to as the emotion word type effect (Wu et al., 2021b; J. Zhang et al., 2024).

The emotion word type effect has been identified across a number of behavioral studies within L1 research (Kazanas & Altarriba, 2015, 2016b, 2016a; H. Knickerbocker & Altarriba, 2013). For example, using a rapid serial visual presentation paradigm, where participants recalled repeated stimuli from sequentially presented trials, it was found that words that label emotions produced a stronger repetition blindness effect relative to words that evoke emotions through connotations and neutral words (H. Knickerbocker & Altarriba, 2013). Additionally, both explicit and implicit LDTs showed that emotion-label words were associated with faster reaction times and stronger priming effects compared to emotion-laden words (Kazanas & Altarriba, 2015). Follow-up studies (Kazanas & Altarriba, 2016b) replicated these findings even when using a longer stimulus onset asynchrony (1,000 ms). This further supports the conclusion that words directly naming emotional states induce increased emotion evocation and recruit more attentional resources, leading to processing facilitation.

Recent ERP research in L1 has explored the brain activation associated with the processing of emotion-label and emotion-laden words (Jia et al., 2022; W. Li et al., 2022; Liu, Fan, Jiang, et al., 2022; Liu, Fan, Tian, et al., 2022; Wang et al., 2019; Yeh et al., 2022; J. Zhang et al., 2017). For instance, J. Zhang et al. (2017) employed an LDT and found that emotion-label words elicited an enhanced N170 response relative to emotion-laden words. This suggests that words directly labeling emotions capture attention more effectively. Furthermore, a right hemisphere advantage was observed for negative emotion-label words, as indicated by larger LPC amplitudes. This article is among the first to demonstrate distinct neural correlates in the processing of these two types of emotion words across both early and late processing stages. Additionally, ERP research has investigated how the emotion word type influences priming effects. For example, using a masked priming paradigm, Wu et al. (2020) found that emotion-label words used as primes facilitated the processing of target affective pictures more effectively than emotion-laden words, as evidenced by a reduced EPN. This research underscores the impact of emotion word type on both attentional capture and semantic processing.

Research examining the effect of emotion word type in L2 contexts, or in L1-L2 comparisons, consistently demonstrates that these two kinds of emotion words elicit different responses across various tasks. This effect has been observed in a range of paradigms, including the affective Simon task (J. Altarriba & Basnight-Brown, 2011), LDT (Kazanas & Altarriba, 2016a), free recall and rating tasks (El-Dakhs & Altarriba, 2019; Ferré et al., 2022), and emotional categorization tasks (ECT) (Gu & Chen, 2024). For example, Kazanas and Altarriba (2016a) conducted a masked LDT and found that L2 emotion-label words elicited faster responses compared to emotion-laden words, even though this observed effect was restricted to individuals' dominant language.

ERP research has demonstrated that the emotion word type significantly influences brain activation at both early and late processing stages during L2 word reading (e.g., J. Zhang et al., 2020, 2024). For instance, J. Zhang et al. (2020) found that negative emotion-label words elicited larger N170 amplitudes compared to negative emotion-laden words in L2, suggesting that emotion-label words evoke enhanced emotional activation. Additionally, emotion-laden words were associated with increased LPC amplitudes relative to emotion-label words, suggesting that emotion-laden words require more extensive cognitive processing. Further studies have indicated that the type of emotion word also affects conflict processing in L2 contexts (e.g., Wu & Zhang, 2019; J. Zhang et al., 2019). For example, Wu and Zhang (2019) employed a flanker task, where participants were required to identify the color of a central word flanked by either matching or differing colors. This research revealed that positive emotion-laden words influenced conflict processing at both early and late stages, as reflected by differential cortical responses in the N100, N200, and N400 components.

Building on these findings, Wu and Zhang (2020) proposed integrating the concept of the emotion word type into the framework of affective neurolinguistics. According to the mediated account (J. Altarriba & Basnight-Brown, 2011; Wu et al., 2021a), emotion-laden words can be understood as mediated affective concepts. Specifically, emotion-label words explicitly name emotional states of mind, thereby establishing a straightforward connection to their affective meanings, which enhances emotional activation. In contrast, the emotional content of emotion-laden words is accessed indirectly, relying on mediated emotion-label words to link their lexical representations with relevant affective experiences. This mediated process requires more cognitive resources (Liu, Fan, Jiang, et al., 2022; Wu et al., 2021a). Consequently, emotion words that directly label emotions often exhibit a processing advantage over emotion-laden words due to their more direct emotional connection. Notably, while emotion-label and emotion-laden words are highly relevant, their mapping is rather contextualized, as a single emotion-laden word may correspond to multiple emotion-label words.

1.3 Evaluation of the previous research

Despite the extensive behavioral and ERP research on emotion word processing in bilingualism, several critical issues remain to be addressed. To begin with, although many studies suggest that emotional reactivity to words in L2 is reduced compared to that in L1, supporting the context-of-learning theory, there are notable discrepancies. For instance, some research has indicated that the emotional connotations of L2 words are activated during L2 word reading, comparable to those in L1 (J. Altarriba & Basnight-Brown, 2011; Ayçiçeği & Harris, 2004; Dudschig et al., 2014). Furthermore, Caldwell-Harris (2014) found that the emotional activation in L2 might be stronger than that in L1, as evidenced by larger skin conductance responses, thus challenging the prevailing notion of affective disengagement in L2.

Electrophysiologically, while previous ERP research has provided evidence of the emotion effect on word processing, a consistent pattern, particularly regarding the early stage of word processing, has yet to emerge (Wang et al., 2019). For example, some studies have suggested that early ERP components, such as N170 and EPN, appear to be unaffected by the emotion effect (e.g., Schacht & Sommer, 2009b; Wang et al., 2019), indicating that the affective connotations inherent in written words may not be activated during the early word processing stage. In the later processing stages, the results regarding the valence effects on the LPC are mixed (Chen et al., 2015; Citron, 2012). Some research has revealed a processing superiority for emotion words with positive content (e.g., Herbert et al., 2008; Kissler et al., 2009), while other studies have observed the reverse pattern of findings (Hofmann et al., 2009; Schacht & Sommer, 2009a). Given these inconsistencies, it is necessary to explore whether the emotion word type might contribute to these conflicting results in emotion word processing.

The second concern addresses the distinction between emotion-label words and emotion-laden words, which serves as the primary focus of this dissertation. Regarding the emotion word type effect, conclusive evidence remains elusive (Hinojosa et al., 2020b; J. Zhang et al., 2024), as some studies reported no significant difference between these two sorts of emotion words. For instance, in an LDT using hemifield presentation, no discernible difference was observed between emotion-label words and emotion-laden words, with both types eliciting comparable reaction times (Martin & Altarriba, 2017). Similarly, Vinson et al. (2014) found that the emotion effect was not limited solely to emotion words that straightforwardly label affective states (emotion-label words) but also to emotion words that evoke emotions through their connotations in a more general way. This view is supported by similar findings from Kousta et al. (2009, 2011).

In addition to that, there are several methodological concerns associated with prior research on the emotion word type. Firstly, although J. Zhang et al. (2020) identified ERP differences at both early and later stages when processing emotion-label and emotion-laden words in L2, their study excluded neutral words. This precluded the investigation of the temporal dynamics of the emotion effect on L2 word processing. Secondly, in selecting experimental stimuli, some researchers relied on their subjective intuition to classify emotion-label words and emotion-laden words, which lacks objectivity (e.g., Kazanas & Altarriba, 2015; J. Zhang et al., 2017, 2020). Thirdly, the lexical categories were intermixed in much of the prior research (e.g., Kazanas & Altarriba, 2016a; J. Zhang et al., 2017). For example, there were both nouns (e.g., "birthday" and "injury") and adjectives (e.g., "happy" and "loyal") in the study of Kazanas and Altarriba (2016a). It has been reported that different word classes can influence emotion word processing due to variations in concreteness, imageability, and semantic references associated with nouns, verbs, and adjectives (Citron, 2012; Liao & Ni, 2021). Therefore, the inclusion of various word classes may introduce variability in the complexity of recognizing and processing emotion-label and emotion-laden words.

The fourth methodological concern is the variable of concreteness, which refers to the degree to which a concept has a clear and tangible referent that can be sensed physically (Borghi et al., 2017). In many previous studies on the emotion word type, the degree of concreteness has not been well-controlled (e.g., Kazanas & Altarriba, 2015, 2016b, 2016a; J. Zhang et al., 2017, 2020). For instance, Kazanas and Altarriba (2016a) included both abstract words (e.g., "cheer" and "pride") and concrete words (e.g., "coffin" and "knife") in their experimental stimuli. It should be highlighted that concrete and abstract words differ significantly in sensory grounding, with concrete words often being associated with more distinct mental representations and tangible sensory experiences (Yao et al., 2023). Thus, the degree of concreteness may contribute to the observed differences between emotion-label and emotion-laden words, as emotion-label words may be perceived as more abstract (Hinojosa et al., 2020b; Kissler, 2020). Supporting this notion, one extended investigation utilized the same LDT paradigm in the study of J. Zhang et al. (2017) and found that in L1, the emotion word type only influenced early word processing when stimuli were controlled for the concreteness variable (Wang et al., 2019). Specifically, positive emotion-label words elicited a P200 response similar to that of neutral words. The P200 component, peaking around 200 ms, is associated with the allocation of attentional resources. Unfortunately, the extent to which concreteness affects the emotion word type effect in L2 processing remains unexplored.

Lastly, it should be noted that the differentiation between emotion-label and emotion-laden words may not be as consistent as previously assumed, but rather is task-dependent. For example, in the study of El-Dakhs and Altarriba (2019), late bilinguals were instructed to complete a free recall task, a rating task on the concreteness, imageability and context availability of stimuli, and a discrete association task. The results showed a robust distinction between the two types of emotion words in the first two tasks, but not in the word association task. This suggests that the processing of these two types of emotion words may vary depending on the task. More recently, Liu, Fan, Tian, et al. (2022) examined how emotion-label words and emotion-laden words in L1 are processed in the explicit ECT and the implicit emotional Stroop task (EST). Their behavioral results showed that the emotion word type effect was significant only in the explicit ECT and was influenced by valence. ERP findings suggested different processing patterns for the two types of emotion words in both EST and ECT, as evidenced by differences in the N400 and LPC components. These findings suggest that the effect of emotion word type may be sensitive to decoding tasks. Nevertheless, it remains uncertain whether task type similarly affects the processing of emotion-label versus emotion-laden words in the L2 context.

1.4 Present research

The direct comparison of emotion-label and emotion-laden word processing in both native and nonnative languages is of great interest in the present research. Existing studies, particularly in the realm of behavioral research, have predominantly involved Spanish-English bilinguals (e.g., the research series by Kazanas and Altarriba; Bromberek-Dyzman et al., 2021). Given that emotional conceptualization may vary across languages (Kissler & Bromberek-Dyzman, 2021; Zhou et al., 2022), this research aims to extend these investigations to include logographic Chinese (L1) and alphabetic English (L2). This allows for an examination of whether and how emotion-label and emotion-laden words are processed differently among late Chinese-English bilinguals. The specific aims for each study are outlined below:

Article I employs an ECT to investigate and compare differences in processing emotion words (both emotion-label and emotion-laden) and neutral words (the emotion effect) in both L1 and L2. It also examines the differences between processing emotion-label and emotion-laden words (the emotion word type effect) across both L1 and L2. We hypothesized that the facilitation effects of words' emotional content would be observed in both L1 and L2, except for L2 negative words. In addition, we expect a processing advantage with faster response times and higher accuracy rates for words in L1 relative to L2, for positive words relative to negative words, and for emotion-label words relative to emotion-laden words.

Article II employs the ERP technique to further investigate the temporal dynamics associated with the emotion effect and the emotion word type effect in an LDT. As a result, both emotion words and neutral words were included. We hypothesized that the emotion word type effect would be present in both L1 and L2. Specifically, we expect that emotion-label words, especially those with negative valence, would elicit stronger emotional activation, as indicated by augmented N170 and/or EPN during the early word processing stage in both L1 and L2. Additionally, we expect that emotion words, irrespective of the emotion word type, valence or language, would elicit decreased N400 compared to neutral words due to semantic facilitation in both L1 and L2. L2 emotion words would elicit larger N400 amplitudes compared to those in L1 due to greater difficulty in semantic integration. Emotion-laden words would elicit larger LPC across both languages due to higher demand for elaborate processing.

Article III employs the ERP technique to further investigate whether the effect of emotion word type is consistent across explicit and implicit tasks in an L2 context. This study focuses exclusively on emotion-label and emotion-laden words. The ECT and the EST were employed to examine potential differences in cortical responses when processing these two types of emotion words in a controlled versus an unintentional manner in the L2 context. We hypothesized that the emotion word type effect would be observed in L2 but may be more pronounced in the ECT, where the affective content of stimuli is directly relevant to the task, necessitating deep processing. Behaviorally, we expect that emotion words would be processed more efficiently in the EST compared to the ECT, with a particular advantage for emotion-label words over emotion-laden words. For ERP results, we expect that emotion-label words, especially those with positive valence, would elicit an LPC effect in the ECT.

2 METHODS

To examine how emotion-label words and emotion-laden words with different valence are processed by bilinguals, we recruited late Chinese-English bilinguals as participants and employed a more objective approach to construct the experimental stimuli. Across three studies, participants' behavioral and/or ERP responses were recorded and included in the statistical analysis.

2.1 Participants

In all these studies, late Chinese-English bilinguals, with Chinese as their L1 and English as their L2, were enlisted as participants. All participants were right-handed individuals, with either normal or corrected-to-normal vision and normal color perception. In addition, they had no recorded history of brain damage, neuropsychological disorders, or drug or alcohol abuse.

In terms of the assessment of their L2 competence, participants were required to complete three questions derived from the Language History Questionnaire (P. Li et al., 2020), which inquired about their age of L2 acquisition, the duration of L2 learning, and the learning environment for their L2. Results indicated that all participants started learning English as their L2 primarily through instructional settings, such as classrooms, at around the age of 9, which indicates that they were late learners of L2. In addition, they were required to complete the LexTALE (Lemhöfer & Broersma, 2012), a test designed to objectively measure the L2 learner’s proficiency, particularly in vocabulary knowledge. Findings revealed that participants across the three articles exhibited an upper-intermediate level of L2 proficiency (60% - 80%). Furthermore, in Articles II and III, they were required to provide a subjective rating of their L2 knowledge in listening, speaking, reading, and writing on a 7-point Likert scale (1 = very poor, 7 = very excellent).

Notably, eight out of fifty-two participants were excluded from Article I because of data collection errors (one participant) and poor response accuracy (seven participants). Four out of thirty-two participants in Article II and one out of thirty participants in Article III were excluded due to excessive EEG noise. Consequently, the final samples consisted of 44 participants in Article I, 28 participants in Article II, and 29 participants in Article III. A detailed description of the final participant samples for the three articles is presented in TABLE 1.

TABLE 1 Summary of the description for participants in the three articles.

Article	Participants	L2 learning
Article I	N = 44 (14 males, 30 females) Mean age: 27. 69 (SD = 3.78)	Age of acquisition: 9.8 Length of acquisition: 17.89 LexTALE: 68.28% (SD = 11.5%)
Article II	N = 28 (10 males, 18 females) Mean age: 28.25 (SD = 3.03)	Age of acquisition: 8.61 (SD = 1.75) Length of acquisition: 19.61 (SD = 2.63) LexTALE: 68.61% (SD = 9.81%) Subjective rating: 66.58% (SD = 7.91%)
Article III	N = 29 (9 males, 20 females) Mean age: 29.45 (SD = 2.61)	Age of acquisition: 9.07 (SD = 1.85) Length of acquisition: 20.38 (SD = 2.44) LexTALE: 66.94% (SD = 10.27%) Subjective rating: 66.87% (SD = 7.33%)

2.2 Research ethics

The research protocols for these three articles adhered to the ethical guidelines set forth by the “World Medical Association Declaration of Helsinki: Ethical Principles for Medical Research Involving Human Subjects” (2013). Concretely, Article I was approved by the ethics committee of the Dalian University of Technology, while Articles II and III were approved by the ethics committee of the University of Jyväskylä. Participation in the three articles was voluntary. Prior to participating, all participants provided informed consent, and they received compensation upon the completion of the experiments.

The data from Article I were stored on the server of the Dalian University of Technology, and the data from Articles II and III were stored on the server of the University of Jyväskylä. These data were secured with institutional backup and protection measures. For analysis, the data were pseudonymized and aggregated to make them unrecognizable. The data were used exclusively for research purposes, with access restricted to project members only. Experimental stimuli and analysis codes from all three articles are available to the research community upon reasonable request.

2.3 Stimuli

Articles I and II consisted of experiments in both L1 and L2. Article III included L2 experiments only. Since no available databases focused on emotion word type in either Chinese (L1) (prior to 2023) or English (L2), we prepared two distinct sets of stimuli for each language. This approach was employed to mitigate the risk of unconscious and indiscriminate lexico-semantic access to L1 words when participants were engaged in tasks within an L2 context (Y. J. Wu & Thierry, 2012). In addition, only adjectives were included, as they constitute a predominant portion of emotion-label and emotion-laden words in these categories (Bromberek-Dyzman et al., 2021).

In Article I, to obtain an adequate number of L1 stimuli, initially, a pool of 408 Chinese two-character adjectives sourced from a Chinese database (Cai & Brysbaert, 2010) and prior research (Wang et al., 2019; J. Zhang et al., 2017) was established. Similarly, 296 English adjectives from a normative database (Warriner et al., 2013) were included to create a corresponding pool for L2 stimuli. Employing a voting method utilized in previous research on emotion word type (Liu, Fan, Jiang, et al., 2022; Liu, Fan, Tian, et al., 2022; Wang et al., 2019), for each language, we invited 20 participants, who were not involved in the behavioral experiments, to classify the selected words into categories of emotion-label words, emotion-laden words and neutral words based on their definitions. By applying a criterion requiring at least around 80% consensus among participants for inclusion within each category, we finalized 276 L1 words (emotion-label words: 101; emotion-laden words: 94; neutral words: 81) and 240 L2 words (emotion-label words: 83; emotion-laden words: 82; neutral words: 75).

Afterwards, for each language, four groups of raters (each group comprising at least 20 participants) who were not involved in the behavioral measurements were enlisted to assess the valence, arousal, concreteness, and familiarity of the selected words on a 7-point scale (7 = very pleasant, very excited, very abstract, and very familiar, respectively). Ultimately, each language experiment comprised 180 adjectives, evenly distributed across three types: 60 emotion-label words (30 positive and 30 negative), 60 emotion-laden words (30 positive and 30 negative), and 60 neutral words. These words were matched in terms of concreteness, familiarity and strokes/length ($ps > 0.1$) within each language. Regarding valence ratings, positive words received significantly higher ratings than neutral words in both L1 and L2 ($ps < 0.001$), and neutral words were rated much higher than negative ones ($ps < 0.001$). However, there was no significant difference between emotion-label and emotion-laden words within the positive and negative valence categories. Concerning arousal ratings, a significant difference was observed among the five groups of words [$F (1, 34) = 52.525$, $p < 0.001$]. Nevertheless, the paired t-test revealed no significant differences in arousal among the four groups of emotion words.

The experimental stimuli for Article II were derived from the initial pool established in Article I. The variables of valence, arousal, concreteness, familiarity, frequency (for English stimuli, see Brysbaert & New, 2009; for Chinese stimuli, see Cai & Brysbaert, 2010) and strokes/length were well controlled. Additionally, since Article II employed a lexical decision task, nonwords (N = 180) in each language were selected from a Chinese Lexicon Project (Tse et al., 2017) and an English Lexicon Project (Balota et al., 2007), respectively. These nonwords were comparable to real words in terms of strokes/length (*ps* > 0.44).

In Article III, the experimental stimuli were drawn from Article II. Since Article III intended to investigate the potential differences in explicit and implicit processing of emotion-label words and emotion-laden words, neutral words were not included. The stimuli were matched for length ($p > 0.98$), familiarity ($p > 0.08$), frequency ($p > 0.72$) (Brysbaert & New, 2009), concreteness ($p > 0.74$), and arousal ($p > 0.42$). Regarding the valence ratings, positive words were rated with significantly higher scores than negative words ($p < 0.001$). The paired *t*-tests revealed no differences either between positive emotion-label and positive emotion-laden words ($t = -1.67$, $p = 0.11$), or between negative emotion-label and negative emotion-laden words ($t = 0.75$, $p = 0.46$).

2.4 Procedure

In these three articles, all participants were asked to sit in a quiet room, and all stimuli were presented in random order. Article I utilized the psychological software PsychoPy 2 (Peirce et al., 2019), while Articles II and III employed the E-prime 2.0 software (Psychology Software Tools, Pittsburgh, PA).

In Article I, the L1 and L2 blocks followed the same procedure. Each language block consisted of 180 trials, evenly distributed into three non-repeated blocks, each containing 20 neutral words, and 10 words from each of the four emotion word groups: positive emotion-label words, negative emotion-label words, positive emotion-laden words, and negative emotion-laden words. A practice session of 24 words (12 in L1 and 12 in L2) was included prior to the formal experiment. Each trial started with a fixation cross "+" displayed at the center of the screen for 250 ms, followed by a blank interval lasting between 300 and 500 ms. Subsequently, a stimulus was displayed for a duration of up to 3,000 ms, during which subjects were instructed to rapidly and accurately classify each given word as negative, neutral or positive by pressing the appropriate keys. The stimulus disappeared immediately after a response. After the behavioral measurement, participants were asked to evaluate the valence of each experimental stimulus on a 7-point scale (7 = very pleasant). The language blocks and response keys were counterbalanced across all participants.

In Article II, the L2 experiment was carried out prior to the L1 experiment to prevent any priming effects from L1 on L2. Both L1 and L2 experiments followed the same procedure. Each language experiment comprised three non-repeated blocks with 120 stimuli (10 words for each group of emotion words, 20 neutral words, and 60 nonwords). These three blocks were then presented again.

Each trial started with a fixation cross "+" displayed at the center of the screen for 500 ms. This was followed by a blank screen that lasted between 200 and 400 ms. Subsequently, a stimulus was presented on the screen for 1,000 ms, after which it was replaced by a question mark "?" prompting participants to determine whether the presented letter string was a real word or not. Finally, a blank screen was displayed for 200 to 400 ms. Notably, the assignment of response keys for "Yes" and "No" was counterbalanced among participants in the two language blocks.

Article III consisted of two tasks, the ECT and the EST, both following the same procedure. Each task included two non-repeated blocks, presented in random order, with each block consisting of 60 trials (15 words for each emotion word group) randomly presented in either blue or green color. These two blocks were then presented again. As shown in FIGURE 1, each trial started with a fixation cross "+" displayed at the center of the screen for 500 ms, which was then followed by a blank screen that lasted between 200 and 400 ms. An L2 word then appeared, and participants were tasked with determining the color (blue or green) of the stimulus in the implicit EST and deciding the valence (pleasant or unpleasant) of the given word in the explicit ECT as quickly and accurately as possible. Notably, the presentation order, stimuli color, task order, and response keys were counterbalanced across all participants.

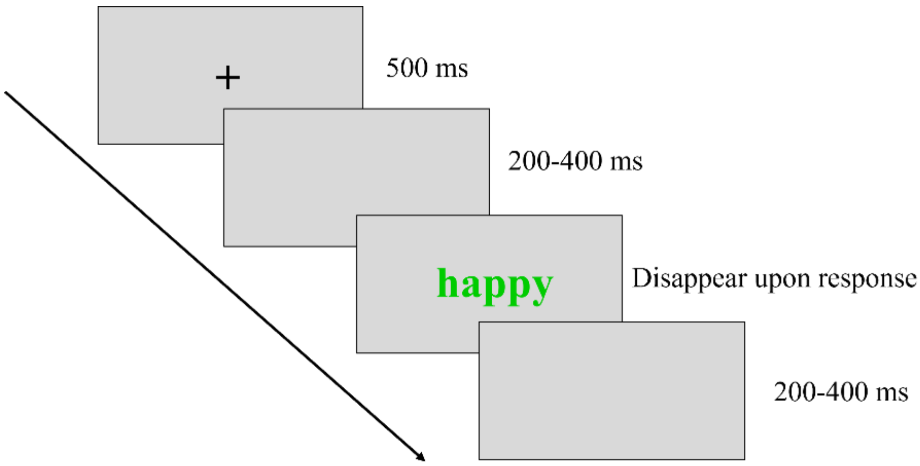

FIGURE 1 Schematic view of the experimental procedure for one trial in Article III.

2.5 Data recording and processing

For behavioral measures, in Article I, response times (RTs) and accuracy rates (ACCs) for the emotion categorization of the given word in L1 and L2 were collected when participants pressed buttons on a keyboard. In Article III, reaction times and accuracy rates for both color judgments and emotion categorization of the given stimuli were also collected. In Articles II and III, EEG data were recorded using a 128-channel HydroCel Geodesic Sensor Net, a Net Amps 400 amplifier featuring high impedance, and Net Station 4.5.7 software[1], at a sampling rate of 1,000 Hz. During the measurement, the impedances of all electrodes were maintained below 50 kΩ, and the online filter ranged from 0.1 to 250 Hz. A reference electrode was placed at the vertex electrode (Cz) during recording.

In Article I, due to data recording errors, data from one subject were discarded from the initial 18,720 data points. In addition, the threshold of fewer than 70% correct responses as a criterion for exclusion led to the removal of data from seven subjects and nine stimuli presented in both L1 ("准时" means "punctual", "明确" means "clear", "冷静" means "calm", and "紧急" means "urgent") and L2 ("moved", "concerned", "sympathetic", "contented", and "thrilled") blocks. Consequently, the final dataset comprised 44 participants and 351 stimuli, resulting in a total of 15,307 trials for further ACCs analysis. For RTs analysis, incorrect responses (n = 952, 6% of overall trials) and omissions (n = 181, 1% of overall trials) were considered response errors and thus excluded from the analysis. Data points (n = 477, 3% of overall trials) falling outside the range of -2.5 to 2.5 standardized residual errors were excluded by applying model criticism (Baayen et al., 2008; Baayen and Milin, 2010). Subsequently, the models were re-fitted using the refined dataset, which included 13,878 trials.

In Article II, EEG data were processed by the BrainVision Analyzer 2.2 (Brain Products GmbH, Munich, Germany). First, the EEG data were re-referenced offline to an average of all the channels and band-pass filtered to a range of 0.1 to 30 Hz, with a 50 Hz notch filter applied to eliminate power line noise. Then, bad channels were detected and interpolated using the spherical spline method implemented in the BrainVision Analyzer. Epochs ranging from 200 ms before to 800 ms after the onset of stimuli were extracted. The 200 ms period preceding the stimulus served as the baseline and was corrected by calculating the mean value from -200 to 0 ms for each time point. Subsequently, epochs with artifacts from eye movements and blinks were excluded from the analysis. The automatic segment selection integrated within BrainVision facilitated the identification of bad epochs. Specifically, within each epoch, the absolute difference between two consecutive time points should not exceed 50 μV/ms. The maximum allowable voltage difference was set at 150 μV within a 200 ms interval, and the amplitude value had to be between - 150 and 150 μV. In addition, the minimum activity threshold within a 100 ms interval was set at 0.5 μV. If any of those criteria were violated within a 200 ms time frame before or after an event, the corresponding epoch was marked as bad. Finally, for each participant, EEG segments were averaged individually for each type of stimulus.

Only epochs associated with correct responses, and data from participants who had at least two-thirds of accepted trials for each stimulus type (a minimum of 40 out of 60 for the four groups of emotion words, and 80 out of 120 for neutral words) were considered for the subsequent analysis. In Article II, the primary ERP components examined were N170, EPN, N400 and LPC. In prior research, a left-lateralized pattern for N170 (see Nan et al., 2022, for a review), where the

[1] The equipment was supplied by Electrical Geodesics Inc., USA.

processing difference between neutral and emotion words has been observed within the left hemisphere only (D. Zhang et al., 2014). As a result, we investigated the mean amplitudes of N170 within the time window of 120-170 ms over the left parieto-occipital sites (electrodes: 58, 64, 65, and 70) based on prior research (J. Zhang et al., 2017, 2020). We investigated the mean amplitudes of EPN within the time window of 180-290 ms over the parieto-occipital sites (electrodes: 58, 64, 65, 70, 75, 83, 90, 95, and 96) based on one study (Liu, Fan, Tian, et al., 2022). We investigated the mean amplitudes of N400 within the time window of 320-440 ms over the centro-frontal sites (electrodes: 6, 7, 13, 29, 30, 36, 104, 105, 106, 111, 112 and 129) based on one previous study (Wang et al., 2019). We investigated the mean amplitudes of LPC within the window of 440-680 ms over the centro-parietal sites (electrodes: 37, 54, 55, 61, 62, 78, 79, and 87) based on previous research (Liu, Fan, Jiang, et al., 2022; Liu, Fan, Tian, et al., 2022; Wang et al., 2019; J. Zhang et al., 2017, 2020).

In Article III, EEG data were processed using MNE-Python (Gramfort et al., 2013; MNE version: 1.4.0; Python: 3.10.9). First, channels with excessive noise were identified and interpolated using the spherical spline method. The EEG data were then re-referenced offline to the average across all channels, and the signals were filtered with a bandpass filter between 0.1 and 30 Hz. The lower transition bandwidth was set at 0.10 Hz (with a -6 dB cutoff frequency at 0.05 Hz), while the upper transition bandwidth was 7.50 Hz (with a -6 dB cutoff frequency at 33.75 Hz). The filter had a length of 33,001 samples, corresponding to 33.001 s. In addition, a 50 Hz notch filter was applied to minimize power line interference. Epochs were extracted from the EEG data, covering 100 ms before and 800 ms after the onset of the stimuli, with the pre-stimulus 100 ms used as the baseline. MNE functions were employed to identify and correct for any blinks using independent component analysis. Baseline correction was applied to the pre-stimulus points of each epoch, and then epochs across conditions were grand averaged. Notably, only data corresponding to correct responses were included in the preprocessing. For the final statistical analysis, the average number of valid trials per condition for each participant in both the ECT and EST was 52 out of 60 trials (SD = 2.88, range 44-59).

2.6 Statistical analysis

RTs and ACCs in Articles I and II were analyzed using linear mixed effects models (LMEMs) and Generalized LMEMs respectively, as implemented in the lme4 package in R (Version 4.2.1; Baayen et al., 2008; Bates et al., 2015; Lo & Andrews, 2015; R Core Team, 2022). A Box-Cox power transformation of response latency was performed following Osborne (2010) to promote the normality of the error distribution, with the choice of transformation depending on the residual sum of squares of our basic model. Random intercepts for participants and items were included to estimate variability in these random factors. The fixed effects included five groups of words: positive emotion-laden words, negative emotion-laden words, positive emotion-label words, negative emotion-label words and neutral words. Repeated contrast coding was applied using the *hypr* package (Rabe et al., 2020) to compare each type of emotion stimulus against neutral words. The same model structure was used for both L1 (Chinese) and L2 (English) datasets.

To ensure that the final models converged appropriately, we followed the recommendations of Barr et al. (2013), initially fitting a maximal model and then simplifying it by removing correlations among random factors and interactions as necessary. All final models were restarted with appropriate optimizers to guarantee convergence, and they were compared to the maximal model using chi-square difference tests and Akaike's Information Criterion (Kline, 2011). Notably, the results from the final simplified models were consistent with those from the maximal models, indicating that a parsimonious and interpretable model was suitable.

Regarding EEG data analysis in Article II, the epoched EEG data were also analyzed using LMEMs (Baayen et al., 2008) with the lme4 package in R. The model included fixed effects for the five groups of words and random intercepts for participants and items. Repeated contrast coding was used to compare each emotion stimulus to neutral ones, and sequential contrast coding was applied after excluding the neutral condition to investigate the main effects and interactions among emotion word type, valence, and language. Proficiency, centered around its mean value, was included as a covariate.

Following Scandola and Tidoni (2024), we employed complex random intercepts (CRI) to balance model complexity and convergence. The iterative model fitting process involved removing the least significant CRI components until convergence was achieved. Consistent results between final and maximal models suggested that a simpler model was adequate. T-values above 1.96 were considered significant, and models were fitted using Kenward-Roger estimation (McNeish, 2017).

In Article III, for the analysis of RTs and EEG data, Bayesian multilevel regression models were fitted using the brms package in R (Bürkner, 2017; Stan Development Team, 2018). Bayesian methods were chosen for this research due to their advantages in handling complex hierarchical models and providing a more comprehensive assessment of parameter uncertainty compared to frequentist LMEMs. The models predicted outcomes based on emotion word type, valence, task type, and their interactions. Sequential difference contrasts were specified using the *hypr* package to allow the intercept to represent the grand average of fixed terms. Log-normal and Bernoulli likelihoods were assumed for response latency and accuracy data, respectively, while EEG data were modeled using a normal distribution.

To regularize, weakly informative priors were used to estimate posterior values, with specific priors set for EEG models based on prior domain knowledge (Gelman et al., 2017). Markov Chain Monte Carlo sampling with four chains was applied to extract samples from the posterior distribution. In an attempt to test the hypotheses, regions of practical equivalence (ROPE) around a point null value of 0 were established (Kruschke, 2018), and we reported median posterior point estimates, 95% highest density intervals (HDI), the percentage of the HDI that lies within the ROPE, and the maximum probability of effect (MPE). Parameters with 95% of the HDI outside the ROPE and high MPE values were considered significant.

For the model specification and evaluation, in the first model (Emotion vs. Neutral Words), repeated contrasts compared and collapsed the four emotion word groups to the neutral words in L1 and L2, allowing for investigation of the effects of emotion-label and emotion-laden words with positive or negative valence. This model examined the facilitation or interference elicited by emotion word type or valence. The second model (Main Effects and Interactions) excluded the neutral condition and applied sum-contrast coding to represent the grand mean of fixed factors (Schad et al., 2020). This allowed direct examination of the main effects and interactions among emotion word type, valence, and language. Post-hoc analysis with the emmeans package (Lenth, 2017) provided estimated marginal means and pairwise comparisons, with asymptotic degree of freedoms applied for EMMs. The third model (L2 Proficiency Effects) focused on English words only, including L2 proficiency as a fixed factor. This model assessed the modulation effect of L2 proficiency on emotion word processing by recomputing the statistical models for valence, emotion word type, and proficiency.

In summary, this comprehensive approach combined LMEMs, Bayesian multilevel regression, and rigorous model fitting procedures to analyze RTs, ACCs, and EEG data, ensuring robust and interpretable results across different linguistic and emotional conditions. The use of Bayesian methods in Article III provided a more nuanced understanding of parameter uncertainty and better handled the complexities inherent in the hierarchical data structure.

3 RESULTS

Considering both the behavioral and ERP results, the three studies revealed significant effects of emotion word type and valence on word processing in late bilinguals' L1 and L2 at both behavioral and electrophysiological levels. However, it is important to note that these effects were not observed in the implicit task presented in Article III. A more detailed presentation of the results is provided in the following sections.

3.1 Article I: The embodiment of emotion-label words and emotion-laden words

Tang, D., Fu, Y., Wang, H., Liu, B., Zang, A., & Kärkkäinen, T. (2023). The embodiment of emotion-label words and emotion-laden words: Evidence from late Chinese–English bilinguals. Frontiers in Psychology, 14. https://doi.org/10.3389/fpsyg.2023.1143064

Mean RTs and ACCs for neutral words and four groups of emotion words in L1 and L2 are illustrated in TABLE 2. The analysis of RTs showed that participants took less time to classify emotion words relative to neutral ones in their L1 (*ts* < -4.5, *ps* < 0.0001). In L2, while participants responded similarly to negative emotion-laden words and neutral words (β = -0.00053, SE = 0.00077, *t* = -0.69, *p* = 0.49), the other three groups of emotion words induced quicker responses compared to neutral words (*ts* < -2.3, *ps* < 0.024). After the exclusion of neutral words, main effects emerged for valence (β = 0.001, SE = 0.00021, *t* = 4.9, *p* < 0.0001), emotion word type (β = -0.00048, SE = 0.0002, *t* = -2.3, *p* = 0.02), and language (β = -0.0033, SE = 0.00028, *t* = -12, *p* < 0.0001). Concretely, participants were faster when responding to positive words compared to negative words, to emotion-label words relative to emotion-laden words, and to L1 emotion words relative to those in L2.

TABLE 2 Mean RTs (ms) and ACCs (%) and standard deviations (SDs) for the five groups of words in L1 and L2 in Article I.

	RTs		ACCs	
Word type	Chinese	English	Chinese	English
Positive emotion-label	815 (264)	1029 (346)	97.3 (16.4)	92.5 (26.4)
Positive emotion-laden	849 (269)	1053 (316)	94.7 (22.3)	93.5 (24.7)
Negative emotion-label	886 (286)	1098 (333)	96.6 (18.2)	92.6 (26.1)
Negative emotion-laden	895 (290)	1158 (353)	96.4 (18.7)	88.5 (31.9)
Neutral	971 (309)	1187 (370)	92.4 (26.6)	94.2 (23.3)

Regarding ACCs in L1, participants showed comparable categorization ACCs for positive emotion-laden words and neutral words (β = 0.49, SE = 0.28, z = 1.8, p = 0.08), whereas the other three groups of emotion words were associated with higher ACCs compared to neutral words (zs > 2.7, ps < 0.0064). In L2, participants made more categorization errors with negative emotion-laden words compared to neutral words (β = -0.86, SE = 0.25, z = -3.4, p = 0.00074). The ACCs for the other three groups of emotion words and neutral words did not exhibit a significant difference (zs < 0.91, ps > 0.36). When comparing the four groups of emotion words in both L1 and L2, a main effect of language (β = -0.92, SE = 0.22, z = -4.1 p < 0.0001) emerged, indicating that responses to L1 emotion words were more accurate than those to L2 emotion words. In addition, a three-way interaction among valence, emotion word type and language (β = -1.5, SE = 0.68, z = -2.2, p = 0.03) was noted (as shown in FIGURE 2). Specifically, in L2, negative emotion-laden words were associated with lower ACCs compared to positive emotion-laden words (β = 0.7415, SE = 0.320, z = 2.316, p = 0.0206) and negative emotion-label words (β = 0.594, SE = 0.312, z = 2.316, p = 0.0570). While no difference was noted in response to positive emotion-laden words between L1 and L2 (β = 0.340, SE = 0.363, z = 0.936, p = 0.3492), the other three groups of emotion words in L1 elicited higher ACCs relative to those in L2 (ps < 0.0331).

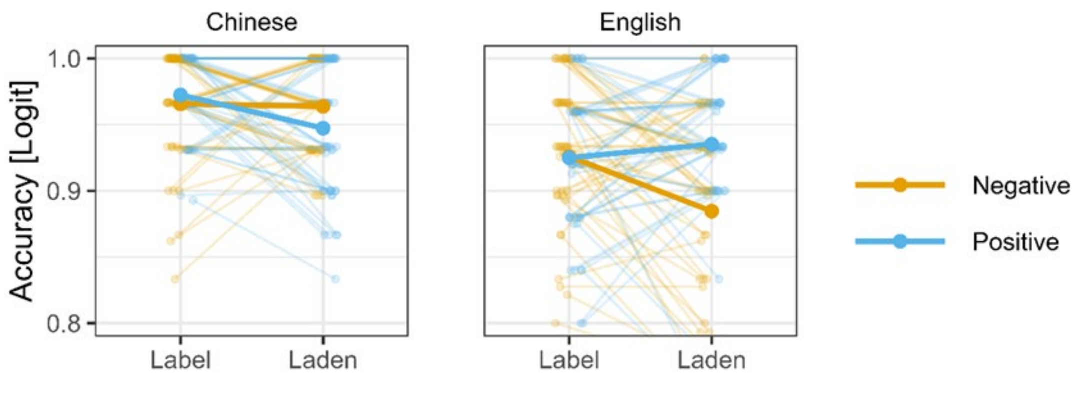

FIGURE 2 The triple interaction between emotion word type (label vs. laden on the x axis), valence (positive vs. negative in color), and language (L1 on the left, L2 on the right) reflected in ACCs (on the y axis) in Article I. Single-subject indices (thin lines) are overlayed by group averages (thick lines).

Regarding the L2 proficiency modulation, our findings suggest that L2 proficiency only modulated the RTs in L2 word processing (β = -0.0012, SE = 0.00039, t = -3, p = 0.046), showing that higher proficiency levels are linked to faster emotion categorization.

3.2 Article II: Neural correlates of emotion-label vs. emotion-laden word processing in late bilinguals

Tang, D., Li, X., Fu, Y., Wang, H., Li, X., Parviainen, T., & Kärkkäinen, T. (2024). Neural correlates of emotion-label vs. emotion-laden word processing in late bilinguals: Evidence from an ERP study. Cognition and Emotion, 1-18 (published online). https://doi.org/10.1080/02699931.2024.2352584

For behavioral results, RTs were not taken into consideration due to the fixed presentation duration of stimuli (1,000 ms). Regarding ACCs, participants demonstrated highly accurate decisions (> 90%) for stimuli in both L1 and L2. For ERP results, significant differences in amplitudes of N170, EPN, N400 and LPC were observed across all conditions of stimuli in both L1 and L2.

Further specific ERP results are the following:

N170

In L1, significantly larger N170 amplitudes were elicited by negative emotion-laden words (average amplitudes: -3.69 μV) compared to neutral words (average amplitudes: -3.25 μV) (β = -0.44, t = -2.6, p = 0.011). The other three groups of emotion words and neutral words elicited similar N170 amplitudes (ts < 1.3, ps > 0.2). In L2, larger N170 amplitudes were elicited by negative emotion-label words (average amplitudes: -3.61 μV) relative to neutral words (average amplitudes: -3.31 μV) (β = −0.3, t = -2.1, p = 0.032). There were no differences between the other three groups of emotion words and neutral words (ts < 1.4, ps > 0.17). When neutral words were removed, no significant differences were observed among the four emotion word groups (ts < 1.7, ps > 0.092).

EPN

The grand average of the waveforms, topographic maps, and raincloud plots of EPN amplitudes for all conditions of words are depicted in FIGURE 3 (Note: hereafter in the figures, “P-label” represents “Positive emotion-label words”, “P-laden” represents “Positive emotion-laden words”, “N-label” represents “Negative emotion-label words”, “N-laden” represents “Negative emotion-laden words”). Neutral words elicited similar EPN amplitudes to positive emotion-label words in both L1 and L2 (ts < 1.8, ps > 0.077), and smaller EPN amplitudes than the other three groups of emotion words (all average amplitudes ≤ -0.37 μV in L1, and -1.30 μV in L2) were elicited in both L1 and L2 (ts > 2.3, ps < 0.02). After removing neutral words, main effects of emotion word type and valence were noted, indicating that negative words elicited larger EPN than positive words (β = 0.23, t = 3.9, p = 0.00011), and emotion-laden words elicited larger EPN than emotion-label words (β = 0.3, t = 4.5, p < 0.0001).

N400

The grand average of the waveforms, topographic maps, and raincloud plots of N400 amplitudes for all conditions of words are depicted in FIGURE 4. In L1, neutral words elicited similar N400 amplitudes to positive emotion-laden words (β = -0.17, t = 1.5, p = 0.16), and larger N400 amplitudes than the other three groups of emotion words (*ts* > 2.5, *ps* < 0.019). In L2, no difference between neutral words and emotion words was detected (*ts* < 1.3, *ps* > 0.21). After the removal of neutral words, a two-way interaction between valence and language was noted (β = -0.16, t = -2.1, p = 0.036), suggesting that positive words elicited larger N400 than negative words in both L1 and L2 (*ps* < 0.0404). Emotion words in L1 induced larger N400 amplitudes than those in L2, with positive words and negative words in L1 eliciting larger N400 amplitudes than their counterparts in L2 (*ps* < 0.0001). The grand average of the waveforms, topographic maps, and raincloud plots of N400 amplitudes to negative and positive words are shown in FIGURE 5.

LPC

In L1, neutral words (average amplitudes: 1.66 μV) elicited attenuated LPC amplitudes relative to negative emotion-laden words (average amplitudes: 2.09 μV) (β = 0.43, t = 4.1, p = 0.00037), and elicited similar LPC amplitudes to positive emotion-label words (average amplitudes: 1.47 μV), positive emotion-laden words (average amplitudes: 1.61 μV) and negative emotion-label words (average amplitudes: 1.86 μV) (*ts* < 1.7, *ps* > 0.096). In L2, neutral words (average amplitudes: 2.42 μV) elicited similar LPC amplitudes to positive emotion-label words (average amplitudes: 2.44 μV) (β = 0.019, t = 0.2, p = 0.84), but larger LPC amplitudes than positive emotion-laden words (average amplitudes: 2.01 μV), negative emotion-label words (average amplitudes: 2.00 μV), negative emotion-laden words (average amplitudes: 2.23 μV) (*ts* > 2.1, *ps* < 0.04).

After the removal of neutral words, a main effect of language suggested that L1 emotion words elicited smaller LPC amplitudes than L2 (β = -0.41, t = -8.1, p < 0.0001), and this main effect was modulated by a three-way interaction between valence, emotion word type and language (β = -0.57, t = -2.8). Specifically, in L1, emotion-label and emotion-laden words with negative valence elicited larger LPC than their counterparts with positive valence (*ps* < 0.0014). In L2, positive emotion-label words were associated with larger LPC amplitudes compared to emotion-label and emotion-laden words with negative valence (*ps* < 0.0007). L1 emotion-label and emotion-laden words with positive valence produced decreased LPC compared to their counterparts in L2 (*ps* ≤ 0.0001).

Finally, regarding the modulation of L2 proficiency, no significant effects were observed on the N170 (β = 0.38, t = -1.5), EPN (β = 0.44, t = 0.11), N400 (β = 0.24, t = -0.24), or LPC (β = 0.21, t = -0.32).

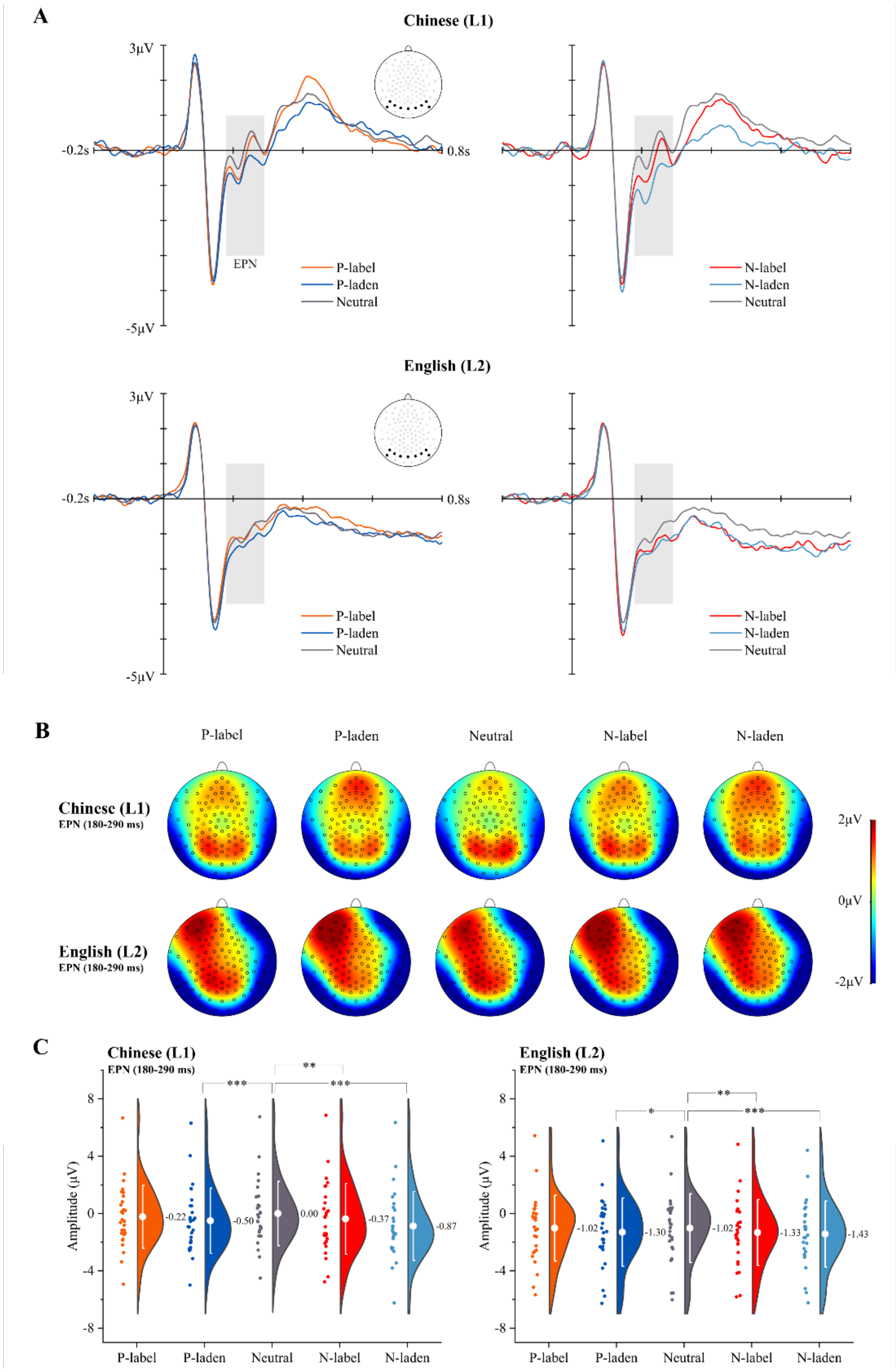

FIGURE 3 EPN responses to all conditions of words in Article II. Panel A represents the grand average waveforms of EPN over parieto-occipital sites, in which the gray rectangle shadows indicate the time window (180-290 ms after stimulus onset) for the analysis of EPN, and the black dots represent the cluster for the region of interest (hereafter referred to as ROI). Panel B represents topographic maps of EPN. Panel C represents raincloud plots of EPN, in which the colored dots and the area with the mean value indicate the distribution of electrophysiological data from a participant-based level.

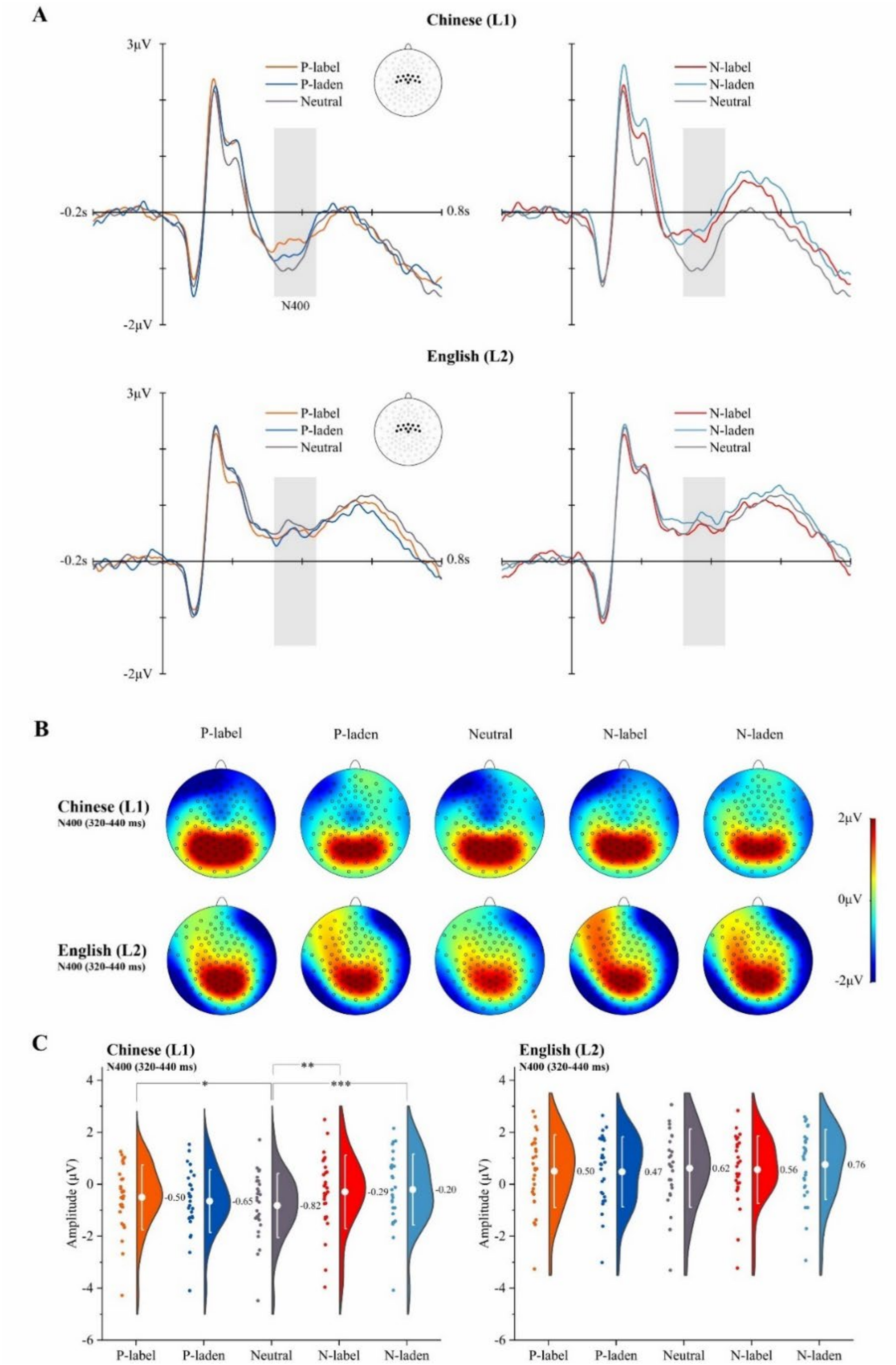

FIGURE 4 N400 responses to all conditions of words in Article II. Panel A represents the grand average waveforms of N400 over centro-frontal sites, in which the gray rectangle shadows indicate the time window (320-440 ms after stimulus onset) for the analysis of N400, and the black dots represent the cluster for the ROI. Panel B represents topographic maps of N400. Panel C represents raincloud plots of N400, in which the colored dots and the area with the mean value indicate the distribution of electrophysiological data from a participant-based level.

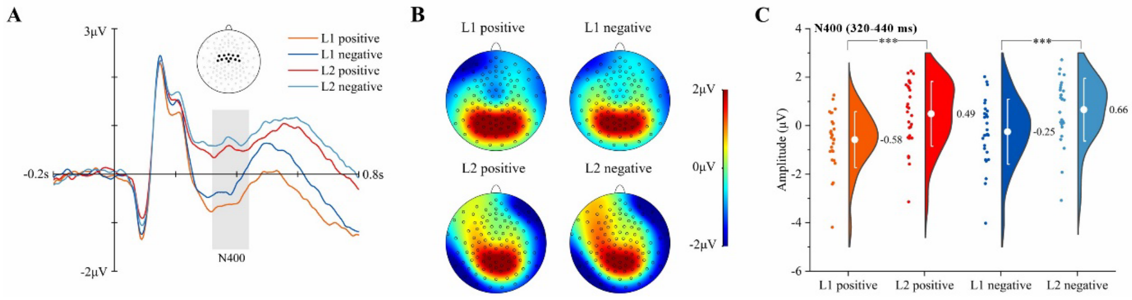

FIGURE 5 N400 responses to positive and negative words in Article II. Panel A represents the grand average waveforms for all emotion word conditions, with black dots indicating the ROI. Panels B and C display the topographic maps, and raincloud plots of N400 responses to positive and negative words in L1 and L2, respectively.

3.3 Article III: Neural correlates of explicit and implicit processing of emotion-label vs. emotion-laden words in L2

Tang, D., Fu, Y., Li, X., Wang, H., Parviainen, T., & Kärkkäinen, T. (2024). Neural correlates of explicit and implicit processing of emotion-label vs. emotion-laden words in L2: Behavioral and electrophysiological evidence. Submitted manuscript.

Participants demonstrated high accuracy in both the explicit ECT and the implicit EST, with accuracy rates exceeding 90%. The RTs, as presented in TABLE 3, revealed a significant two-way interaction between emotional valence and task type. (Median = -0.06, 95% HDI [-0.08, -0.04], ROPE = 0, MPE = 1). Specifically, positive words were associated with faster responses compared to negative words only in the ECT. In addition, a three-way interaction emerged between valence, emotion word type, and task type (Median = -0.03, 95% HDI [-0.06, -0.01], ROPE = 0.26, MPE = 0.99), indicating that while bilingual participants made valence categorization for negative emotion-label words with a faster processing speed relative to negative emotion-laden words in the ECT, no marked difference in RTs was observed for positive emotion words. Notably, no effects of valence, emotion word type, or task type, nor their interactions, were observed in the implicit EST.

TABLE 3 Mean RTs (ms) with standard deviations (SDs) in parenthesis for the four groups of emotion words in the ECT and EST in Article III.

Word type	ECT	EST
Positive emotion-label words	739 (204)	444 (132)
Positive emotion-laden words	742 (195)	448 (132)
Negative emotion-label words	798 (199)	455 (135)
Negative emotion-laden words	811 (217)	446 (134)

The segmented EEG data were analyzed by a cluster-based permutation test to preliminarily identify potential time windows and regions of interest. The spatiotemporal data points for this test included 129 channels × 900 samples, derived from the average ERP of participants. In this study, the within-subject factors were emotion word type (emotion-label vs. emotion-laden), and valence (positive vs. negative) in both the explicit ECT and implicit EST. The F-threshold, corresponding to a p-value of 0.05, was automatically determined for the given number of observations using 10,000 permutations (Bricker, 2020). A non-parametric cluster-level paired t-test for spatiotemporal data was then employed, with thresholds on both sides of the distribution to investigate any significant interactions related to the effects of emotion word type and valence in ANOVAs. This test provided an objective measure to determine whether there were differences in ERP components reflecting neural modulations of emotion word type and/or valence on L2 emotion word processing within each task. The test revealed modulations of valence, emotion word type and their interaction on word processing in the explicit ECT, as shown in FIGURE 6. Specifically, the valence effect was observed at 372 -600 ms over the centro-parietal sites ($p = 0.0009$); the effect of emotion word type was evident at 396-600 ms over the centro-parietal sites ($p = 0.0009$); and the interaction between valence and emotion word type was detected at 350-595 ms over the centro-parietal sites ($p = 0.007$). In the implicit EST, no such effects were found ($ps > 0.3619$). The average EEG data across pre-selected channels and time windows were further analyzed using Bayesian multilevel regression with a comprehensive structure of population terms to explore interactive effects.

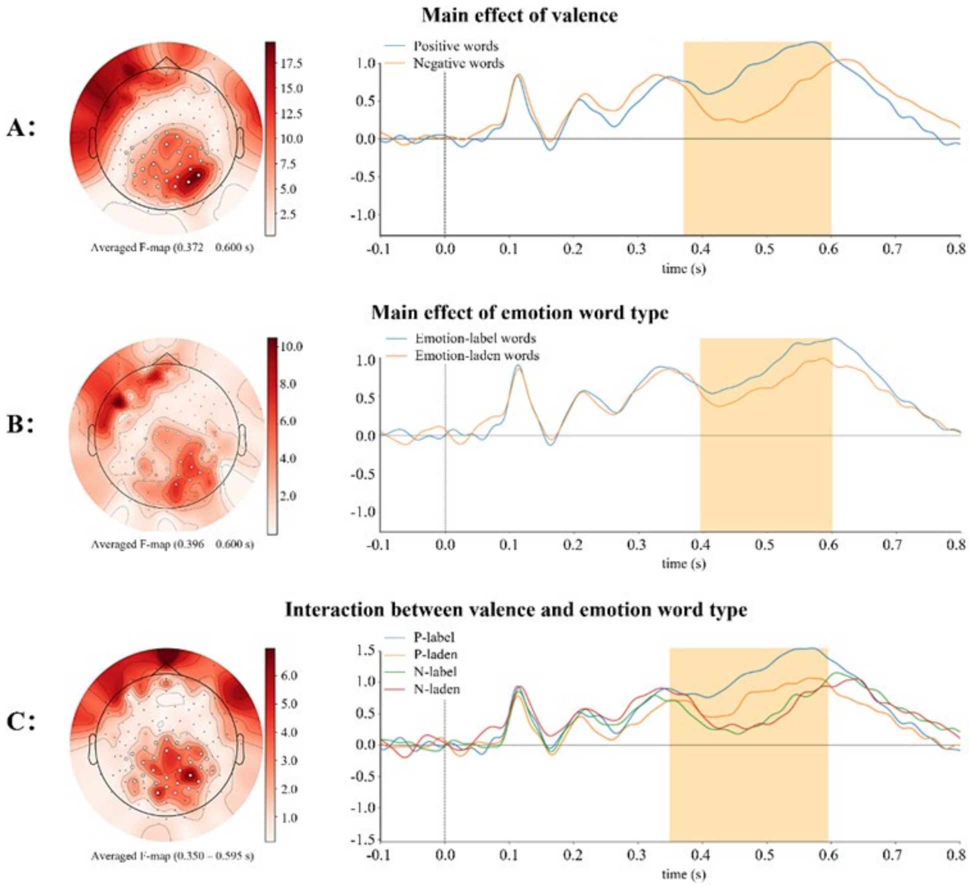

FIGURE 6 The F-maps (left panel) and grand average ERP waveforms (right panel) in Article III. Panels A, B and C represent the main effects of valence, emotion word type, and their interactions over centro-parietal sites in the ECT. The F-maps illustrate the F-values with significance and the white dots represent the channels of the interest cluster. The grand average ERP waveforms represent the four conditions of words, and the shaded areas represent the time windows with significance.

For ERP results, the results showed distinct neural correlates across word conditions over central-parietal sites within the time window of 350-595 ms in the explicit ECT. The grand average ERP waveforms for each word condition, and topographic maps of the difference effects in the explicit ECT and implicit EST are illustrated in FIGURE 7. Specifically, main effects of valence (Median = 0.22, 95% HDI [0.07, 0.36], ROPE = 0.03, MPE = 1), and emotion word type (Median = 0.09, 95% HDI [0.04, 0.13], ROPE = 0.70, MPE = 1) were observed, with larger amplitudes elicited by positive words than by negative words, by emotion-label words relative to emotion-laden words, and by ECT than by EST. In addition, the two-way interaction between valence and task type (Median = 0.43, 95% HDI [0.18, 0.67], ROPE = 0, MPE = 1), and between emotion word type and task type (Median = 0.15, 95% HDI [0.06, 0.24], ROPE = 0.10, MPE = 1) were observed. In detail, in the ECT, positive words elicited greater amplitudes compared to negative words, and emotion-label words elicited greater amplitudes than emotion-laden words. Furthermore, a triple interaction among valence, emotion word type and task type (Median = 0.32, 95% HDI [0.13, 0.50], ROPE = 0, MPE = 1) was observed, which shows that larger amplitudes were elicited by positive emotion-label words than the other three groups of emotion words, and by positive emotion-laden words than negative emotion words. Negative emotion-label words and negative emotion-laden words elicited similar amplitudes. Notably, no such effects were observed in the implicit EST.

Concerning the effect of L2 proficiency, our observation indicates that L2 proficiency only impacted the RTs to emotion words (Median = -0.06, 95% HDI [-0.11, -0.01], ROPE = 0.07, MPE = 0.99), with higher L2 proficiency correlating with slower RTs. L2 proficiency had a null effect on the grand average ERP waveforms over the 350-595 ms window across conditions of emotion words (Median = 0.14, 95% HDI [-0.22, 0.50], ROPE = 0.35, MPE = 0.78).

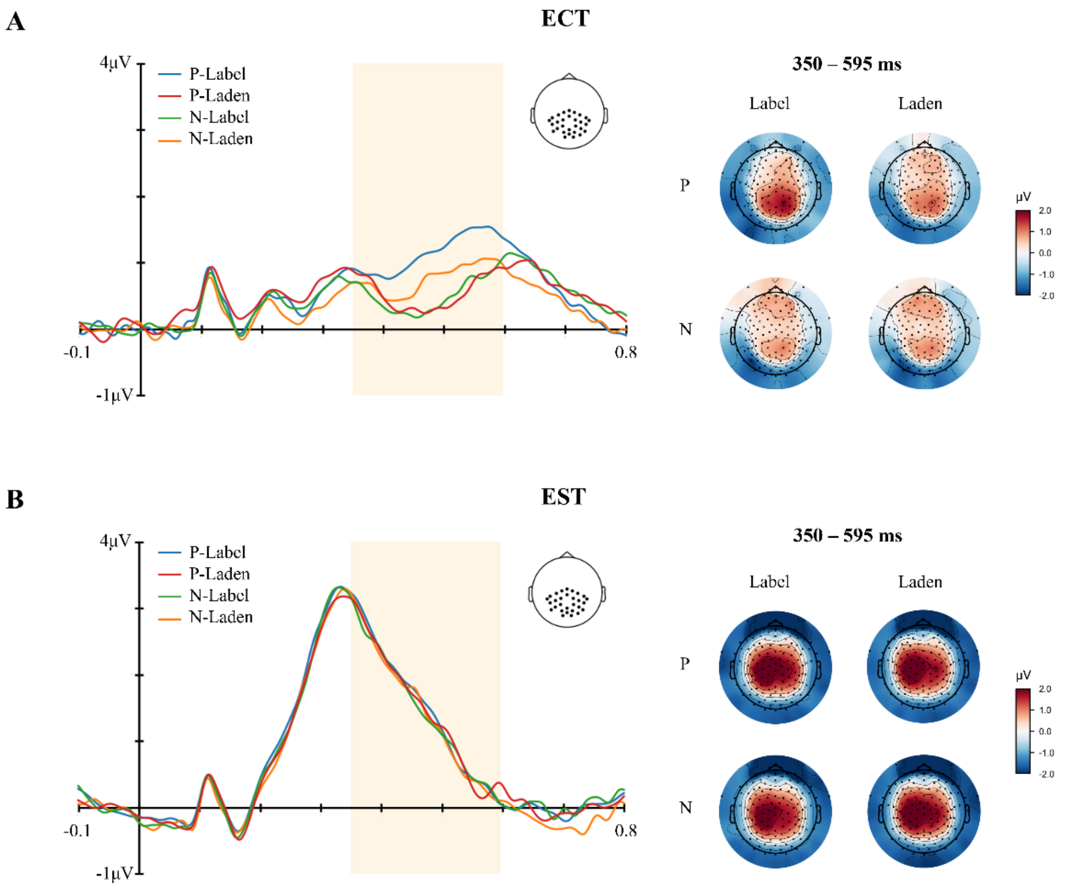

FIGURE 7 Brain responses to four groups of emotion words in the ECT and EST in Article III. The grand average ERP waveforms (left panel) and topographic maps (right panel) of ERP responses to all conditions of words in the explicit ECT (A) and implicit EST (B) over centro-parietal sites. The shadows in the two waveforms indicate the time window (350-595 ms) applied in the analysis. The black dots represent the cluster for the ROI.

4 DISCUSSION

This thesis focused on examining and comparing the responses of late bilinguals to emotion-label and emotion-laden words with either positive or negative valence in both their L1 (Chinese) and L2 (English) at the behavioral and electrophysiological levels. Specifically, Article I employed an emotional categorization task (ECT) to explore whether there is a distinction between emotion-label and emotion-laden words presented in both L1 and L2 at the behavioral level. Article II adopted a lexical decision task (LDT) to further explore the neural correlates underlying the distinction between these two types of emotion word processing in both L1 and L2. Article III used explicit (ECT) and implicit (EST) tasks to examine the consistency of this distinction in an L2 context. Our results confirmed that the emotion word type, along with valence, modulates word processing in both L1 and L2. Nevertheless, these effects may be task-dependent, at least in the non-native context. In the following sections, we discuss how emotion-label and emotion-laden words are processed divergently from neutral words (emotion effect), and how they are processed in comparison to each other (emotion word type effect) in both L1 and L2.

4.1 Emotion effect on word processing in L1 and L2

The emotion effect describes how words with emotional content are processed differently from neutral words (Citron, 2012). In Articles I and II, this emotion effect was explored by including both emotion words, regardless of emotion word type or valence, and neutral words in the experimental design.

In Article I, the emotion effect, manifested as a processing superiority compared to neutral words, was evident across all conditions for L1 emotion words. Specifically, in L1, participants exhibited faster emotion categorization for emotion words relative to neutral words, which aligns with our hypothesis. This finding is in line with the facilitated processing of emotion words observed in previous research (e.g., Goh et al., 2016; Vigliocco et al., 2009). It indicates that in

L1, the emotional content of words, whether they directly label emotional states or evoke emotions through their connotations, facilitates word processing (F. Knickerbocker et al., 2019), leading to faster categorization of the valence of stimuli relative to neutral words. In addition, the ACCs results replicated those observed in RTs, with the exception of positive emotion-laden words. Concretely, while the difference in ACCs between the categorization of neutral words and positive emotion-laden words was non-significant, the other three groups of emotion words were categorized more accurately than neutral words. A possible explanation for this observation might be due to dissimilar representations of emotion-label and emotion-laden words in individuals' mental lexicon. In contrast to emotion-label words, which have a direct and distinct semantic association with emotions, emotion-laden words usually have multiple associations with the general lexicon (Bromberek-Dyzman et al., 2021; J. Altarriba & Basnight-Brown, 2011). For instance, the emotion-laden word "successful" might be associated with words such as "happy", "famous" or even "challenge". This ambiguous and unpredictable association with emotion-laden words makes it more challenging to categorize the stimuli's valence as either positive or negative in L1. Additionally, the positive effect may expand the scope of attention, hinder cognitive performance, and enhance word associations, leading to more widespread semantic activation (Phillips et al., 2002). Consequently, no significant emotion effect was observed between neutral words and positive emotion-laden words.

In L2, the emotional advantage, reflected by faster RTs, was observed for all emotion words except for negative emotion-laden words. Concretely, while no marked difference in RTs was found between negative emotion-laden words and neutral words, the other three groups of emotion words were categorized more quickly than neutral words. This suggests that negative emotion-laden words in a nonnative language may evoke similar levels of emotional arousal as neutral words. Regarding the analysis of ACCs, L2 negative emotion-laden words led to more errors than neutral words, whereas no significant differences in accuracy were found for the other three groups of emotion words compared to neutral words. This leads us to speculate that processing the emotional content of L2 negative emotion-laden words may require additional cognitive resources. As previously mentioned, there are challenges in accessing the emotional content of emotion-laden words, as they require a mediated event to link their conceptual meanings with relevant emotional experiences. Moreover, in the L2 context, this process may be further influenced by negative valence, leading to a narrowed focus and enhanced selective attention (Finucane, 2011). For these reasons, L2 negative emotion-laden words showed an emotional disadvantage, as evidenced by similar RTs but lower ACCs compared to neutral words.

In Article II, RTs were not considered due to the fixed duration of stimulus presentation. ACCs were also excluded from analysis because the high accuracy of lexical decisions led to a ceiling effect. For ERP results, during the early word processing stages, the emotion effect was observed for L1 negative emotion-laden words and L2 negative emotion-label words, as evidenced by larger N170 amplitudes associated with these words relative to neutral words at the left parieto-occipital sites. However, there was no evident difference between neutral words and the other three groups of emotion words in L1 and L2. Some researchers have reported that N170 exhibits a high sensitivity to the differentiation between emotional and non-emotional information, with enhanced N170 responses for emotion words compared to neutral words (D. Zhang et al., 2014; J. Zhang et al., 2017). In this context, our findings suggest that L1 negative emotion-laden words and L2 negative emotion-label words may be more effective in conveying emotions. Prior research has demonstrated that negative words, especially those conveying threatening information, occupy a significant place in the mental lexicon (see Kauschke et al., 2019, for a review). Given the differing associations of the two kinds of emotion words with emotional states, emotion-label words with negative valence are likely perceived more readily as words containing affective information, which aligns with our finding in L2. This observation echoes previous studies showing that L2 negative emotion-label words elicited larger early brain activation (J. Zhang et al., 2019, 2020). Contrary to our hypothesis, in L1, it is negative emotion-laden words that induced larger N170. A possible explanation for this observation is that, although L1 negative emotion-laden words do not straightforwardly label individuals' emotional states, they may carry greater adaptive or social significance than negative emption-label words. For example, L1 negative emotion-laden words like "危急" (meaning "dangerous") or "可耻" (meaning "shameful") are more relevant in terms of biological adaptation. Consequently, the detection of emotional connotations in L1 negative emotion-laden words may be more rapid, resulting in a larger N170 emotion effect.

Temporally following N170, it was found that the EPN emotion effect did not emerge for positive emotion-label words at the parieto-occipital brain sites, irrespective of language. Concretely, in both L1 and L2, significant differences in EPN amplitudes were observed between emotion words and neutral words, except for positive emotion-label words. Previous research has identified the EPN as a marker of spontaneous and unintentional attention allocation to emotionally charged words (Chen et al., 2015; Citron, 2012; Hinojosa et al., 2020a). From this perspective, our findings indicate that neutral and positive emotion-label words captured similar levels of attention. However, the other three groups of emotion words were more salient than neutral words, resulting in greater attentional resources being allocated to them. These findings support our hypothesis that emotion-label words directly convey emotional meanings, without demanding additional cognitive effort. Furthermore, prior research suggested that words with positive valence might activate fewer neural resources (Espuny et al., 2018; Liu, Fan, Tian, et al., 2022). For these reasons, no EPN emotion effect was observed between positive emotion-label words and neutral words across languages.

At the later stages of word processing, the N400 emotion effect was observed for L1 emotion words, except for positive emotion-laden words. Specifically, in L1, neutral words generated N400 amplitudes similar to those of positive emotion-laden words but elicited increased N400 amplitudes compared to the other three groups of emotion words. The N400 presumably reflects higher-order lexico-semantic processing, with decreased N400 amplitudes for emotion words suggesting easier lexical access and semantic integration relative to neutral words (Citron, 2012). This finding in L1 implies that positive emotion-laden words may require elevated processing effort, consistent with the results of Article I, which showed that this word group elicited response accuracy similar to that of neutral words in L1. Additionally, this interpretation is supported by a previous study demonstrating an attentional preference for L1 positive emotion-laden words (Liu, Fan, Tian, et al., 2022). As elucidated earlier, the ambiguity of emotion-laden words, stemming from their multiple affective associations with the general lexicons, may complicate lexical access and semantic integration. In addition to that, positive emotions are known to broaden attention and weaken selective focus (Finucane, 2011), which could further contribute to the observed N400 pattern. Notably, while the N400 component is typically observed at centro-parietal sites, our results, though focused on a different ROI, are consistent with previous research that reported N400 emotion effects over anterior sites (Kanske & Kotz, 2007; Wang et al., 2019).

Regarding the LPC component, our results showed that in L1, while negative emotion-laden words evoked greater amplitudes compared to neutral words over centro-parietal sites, the other three groups of emotion words did not manifest any differences in LPC amplitudes relative to neutral words. The LPC component typically reflects elaborate processing of focused information (Espuny et al., 2018). In this sense, L1 negative emotion-laden words may necessitate more extensive cognitive elaboration, in consonance with the observed N170 findings during the early word processing stage. Collectively, these results imply that L1 negative emotion-laden words might impose a greater cognitive overload or working memory burden. The lack of significant differences in LPC responses to neutral words and the other three groups of emotion words may be attributed to the nature of the LDT, which does not explicitly direct attention to the emotional dimension of words. This might have resulted in less cognitive engagement with the emotional content of these words during lexical judgment.

In L2, only positive emotion-label words among the four groups of emotion words elicited larger LPC amplitudes compared to neutral words. This suggests that processing L2 positive emotion-label words likely demands more cognitive effort. This phenomenon could be interpreted by two possible explanations. For one thing, it may be attributed to the "positivity offset" effect (D. Zhang et al., 2014). Specifically, the diminished attention allocation to L2 positive emotion-label words during early processing stages, as evidenced by reduced EPN compared to the other three groups of emotion words, might necessitate more elaborate reevaluation, attention capture, or memory encoding in later stages. For another, this finding suggests that in L2, positive emotion-label words might be more salient in conveying emotions, thereby capturing more attention for more elaborate processing and resulting in more pronounced positive LPC amplitudes.

However, this second explanation is tentative and warrants further investigation to verify its validity.

4.2 Emotion word type effect on word processing in L1 and L2

The emotion word type effect, which refers to the variations in how emotion-label words and emotion-laden words are processed has been highlighted in prior studies (Wu et al., 2021b; J. Zhang et al., 2024). In this part, we discuss this effect, along with the valence effect on L1 and L2 word processing by comparing the four groups of emotion words with different valence from Articles I and II (after excluding neutral words) and Article III.

In Article I, the comparison of the four groups of emotion words showed that positive words were processed more quickly than negative words, irrespective of the languages. This observation is consistent with earlier behavioral results from research on emotion word type, which have reported a positivity bias in emotion word processing (e.g., Bromberek-Dyzman et al., 2021; Liu, Fan, Tian, et al., 2022). This suggests that words conveying positive information tend to facilitate word processing more effectively than their negative counterparts (Hofmann et al., 2009; Kauschke et al., 2019). This phenomenon might be accounted for from the perspective of the density hypothesis, which posits that words with positive valence may be more densely interconnected in memory relative to negative words, facilitating faster processing (Chen et al., 2015; Liao & Ni, 2021; Unkelbach et al., 2008). Alternatively, from a survival perspective, negative words may freeze ongoing cognitive responses when individuals encounter negative or threatening materials, potentially delaying the processing speed (Algom et al., 2004). As a result, our results support a processing preference for positive words in emotion research, even after separating emotion-label words from emotion-laden words in our experimental stimuli.

In addition, Article I revealed that emotion-label words and emotion-laden words are processed divergently when presented in L1 and L2, supporting the presence of the emotion word type effect in both speakers' dominant and non-dominant languages. Specifically, a processing superiority was noticed for emotion-label words compared to emotion-laden words, which correlated with faster responses. This finding aligns with previous research on emotion word type (Kazanas & Altarriba, 2015, 2016b, 2016a; H. Knickerbocker & Altarriba, 2013). The mediated account proposes that the affective charge of emotion-laden words could be mediated through emotion-label words, which link their lexical forms and associated affective experiences (J. Altarriba & Basnight-Brown, 2011; Wu et al., 2021a). It can thus be inferred that such a contextualized and individualized approach would decrease the retrieval of affective content from emotion-laden words. In contrast, emotion-label words more directly convey their affective meaning, as they describe or name emotional states. This direct linkage enables emotion-label words to create an experiential setting to trigger related emotions more automatically and efficiently. As an alternative, the emotion duality model provides further insight into this distinction. This model suggests that emotion-label words induce emotions in an autonomic and biologically rooted manner, whereas emotion-laden words trigger emotions in a more reflective and effortful way (Imbir et al., 2019). From this perspective, emotion words that directly label emotions are believed to have a stronger connection to affective experiences. Consequently, emotion words that indirectly name emotional states are related to longer RTs in both L1 and L2. Notably, the analysis of ACCs revealed a triple interaction among valence, emotion word type and language, showing that negative emotion-laden words induce higher error rates in comparison to negative emotion-label words and positive emotion-laden words in L2 only. This finding supports our previous assumption that in L2, the representation of negative emotion-laden words may be associated with greater emotional distance, extending earlier studies that reported L2 negative words might exhibit more affective disengagement (Sheikh & Titone, 2016).

In Article II, both the effects of valence and emotion word type were noticed during the early word processing stage in both dominant and non-dominant languages, as indicated by the EPN effect detected over parieto-occipital sites. Specifically, regardless of language, positively valenced words produced smaller EPN amplitudes relative to negatively valenced words, while emotion-laden words evoked larger EPN amplitudes compared to emotion-label words. Since the EPN is considered to be an indicator of attention allocation (Chen et al., 2015), our results suggest that negative words and emotion-laden words drew more attentional resources than their respective counterparts. Regarding the valence effect, our finding mirrors previous research showing that less brain activation is associated with positive words (Espuny et al., 2018; Liu, Fan, Tian, et al., 2022). With regard to the emotion word type effect, the results further support the idea that processing emotion-laden words may demand greater perceptual relevance, as their affective meanings are accessed through mediated events. In contrast, the emotional meanings of emotion-label words are accessed more automatically and effortlessly, leading to decreased EPN for these words compared to emotion-laden words. This finding aligns with our hypothesis and supports the mediated account.

At the later processing stages, it was found that enhanced N400 amplitudes were associated with positive words compared to negative words in both languages. This indicates that positive valence may facilitate lexical access or semantic integration, which contrasts with the finding of Herbert et al. (2008). However, it aligns with one prior study (Moreno & Vázquez, 2011), which speculated that negative words, possibly due to their pronounced survival significance, enable quicker and more automatic access to lexical and semantic meanings during the later processing stages. As a result, in a lexical decision task, participants might require less cognitive effort to access and integrate the semantic content of negative words. Furthermore, negative words were found to be associated with larger LPC amplitudes relative to positive words. This finding further corroborates our assumptions that negative words can facilitate lexical access, semantic integration and reevaluation due to their more discrete nature and survival-related significance.

In Article III, the influence of both emotion word type and valence on L2 word processing was exclusively detected in the explicit ECT condition. The behavioral analysis did not include accuracy rates due to the presence of a ceiling effect. However, the analysis of reaction times revealed a positive bias toward emotion-laden words, as they elicited faster responses. This finding aligns with what we found in Article I. In addition, this valence effect interacted with the emotion word type in the ECT, which demonstrated that in the negative condition, emotion-label words prompted faster response times than emotion-laden words. Interestingly, no significant difference was observed in how positive words were processed, regardless of whether they evoked emotions directly or indirectly. We speculate that the absence of difference in the processing speed for positive emotion words may be attributed to the predominance of the positive valence effect relative to the emotion word type effect, which aligns with the behavioral results from the EEG study of J. Zhang et al. (2020). In terms of the difference in responding to negative emotion-label words and negative emotion-laden words, our finding supports the mediated account (Wu et al., 2021a), suggesting that the direct affective descriptions provided by emotion-label words enhance emotion categorization. More critically, these findings imply the emotional disadvantage of L2 negative emotion-laden words, which resonates with what we found in Article I.

With respect to the ERP results in Article III, the time-window (350-595 ms) and localization (centro-parietal region) of electrophysiological activation showing significant differences among emotion word conditions align with the LPC component identified in earlier research (Citron, 2012; Liu, Fan, Tian, et al., 2022). In this context, in the explicit task, positive words were associated with augmented LPC amplitudes compared to their counterparts. These results suggest more elaborate processing of L2 positive emotion words during the later processing stages. Interestingly, while no marked difference in LPC amplitudes was observed for emotion words with negative valence, positive emotion words that directly describe or express feelings elicited larger LPC amplitudes than positive words that indirectly evoke emotions through connotations. This may suggest that the distinction between the two kinds of emotion words appears to be more robust for those with positive valence. In Article II, we also observed that positive emotion-label words produced larger LPC amplitudes compared to the other three groups of emotion words. A possible explanation for this is that emotion-label words are straightforwardly connected with affective states and possess a wider semantic network, with more synonyms and antonyms linked to them (J. Altarriba & Bauer, 2004; J. Zhang et al., 2024). Therefore, the affective contents of emotion-label words are more stable, contributing to the formation of their core meanings stored within the mental lexicon (Betancourt et al., 2024). This could account for our findings, which suggest that L2 positive emotion-label words may attract more attention and undergo elaborate processing. Notably, these effects were not observed in the implicit EST.

4.3 General discussion

Given the lack of consensus on emotion word processing in bilingual research, this thesis posits that the inconsistent results may stem from a failure to consider the emotion word type. Building on prior findings, it is found that although both kinds of emotion words are related to emotions and can evoke emotional responses, they are likely represented differently within the mental lexicons of bilingual individuals. However, the existing evidence for this distinction is also inconsistent. Therefore, this thesis endeavors to examine and compare whether and how these two sorts of emotion words are processed differently in late bilinguals' dominant and non-dominant languages, providing deeper insights into emotion word representations in bilinguals.

A notable strength of this thesis is its employment of a within-subject design, which provides both behavioral and electrophysiological evidence for comparing the processing of emotion-label and emotion-laden words in both dominant and non-dominant languages, as well as across shallow and deep processing tasks. To the author's knowledge, only a few behavioral studies have been conducted to explore the emotion word type effect between L1 and L2 (e.g., Bromberek-Dyzman et al., 2021; Kazanas & Altarriba, 2016a). Instead, this thesis provides a deeper and more thorough exploration of the emotion word type effect. Furthermore, it should be highlighted that the experimental stimuli used in this thesis were strictly controlled. In contrast, some previous research on emotion word type (e.g., Kazanas & Altarriba, 2015; J. Zhang et al., 2017, 2020) relied on the subjective intuition of researchers for selecting and classifying emotion-label and emotion-laden words. Additionally, the stimuli in these earlier studies were not always matched for concreteness and lexical categories, which may have contributed to the conflicting results observed in emotion word type research, whether at the behavioral or electrophysiological level. By contrast, this thesis included neutral words as a control condition and used a voting method to classify stimuli in both languages. This classification was based on definitions of emotion-label words, emotion-laden words, and neutral words, as determined by participants who did not take part in the formal behavioral and EEG measurements. The stimuli were also strictly controlled for linguistic and psychological variables. With objective selection and well-controlled stimuli, this thesis provides more reliable evidence. The following parts offer a summary of the findings from these three articles.

Firstly, this thesis supports the idea that late bilinguals experience greater affective engagement in their L1 compared to their L2. In Article I, we used an ECT involving deep processing to investigate potential processing dissimilarities between emotion-label and emotion-laden words in both dominant and non-dominant languages, as measured by RTs and ACCs. Our findings showed that late bilinguals made quicker and more accurate emotion categorizations to emotion words in L1 relative to those in L2. This suggests that L1 is processed more proficiently, which aligns with participants' dominance and immersion in their L1 environment. Previous studies have suggested that ACCs may not always be reliable in tasks like the ECT, the valence or affective decision/judgment task, where the affective dimension of stimuli is relevant to the cognitive task (Ferré et al., 2018). This is because subjective experience may influence the categorization of valence, resulting in emotion words being classified into a category distinct from the established values (González-Villar et al., 2014). Nevertheless, it is significant to emphasize that such responses should not be considered errors. This thesis addressed this concern by having participants rate the valence of experimental stimuli based on their feelings after the behavioral measurements. The offline rating results demonstrated a positive correlation with the referenced valence values, confirming the validity of their categorization. Overall, the better RTs and ACCs results suggest a stronger and more distinct representation of emotion words in L1, likely due to their deeper grounding in emotional experiences compared to those in L2.

Apart from that, in Article II, the emotion effect did not manifest for L2 emotion words, as they elicited N400 amplitudes comparable to those of neutral words. This finding suggests that the affective content of L2 words did not facilitate semantic integration, contrary to our initial hypothesis, which predicted that the emotion effect would also be observed in the nonnative language of late bilinguals. This leads us to assume that although the recognition accuracy for L2 words was similar to that for L1 words, it does not necessarily indicate that explicitly recognizing the form and meaning of emotion words in L2 triggers the same level of emotional resonance as in L1 (Dang et al., 2023; Degner et al., 2012), at least during the initial semantic integration stage. It aligns with the previous findings that decoding L2 emotion word often involves a blunted reactivation of associated emotional experiences, even when participants are aware of the words' affective properties (e.g., Bromberek-Dyzman et al., 2021; Ferré et al., 2022). This finding also supports the emotional context of learning theory, which highlights the importance of an immersive learning environment during foreign language learning.

More interestingly, Article II revealed that L1 emotion words were linked to enhanced N400 amplitudes relative to L2 emotion words. This result contrasts with our hypothesis, where we expected L2 emotion words to evoke more negative N400 amplitudes due to the greater demands and difficulties involved in semantic integration in a nonnative language. One prior study by Jończyk et al. (2016) offers insights into this finding, showing that L1 emotion words elicited increased N400 relative to L2 emotion words within a sentential context. As previously discussed, the environment in which language acquisition occurs significantly influences the integration of affective connotations into lexical forms (Harris et al., 2006). In L1 acquisition, affective experiences, along with multiple sensorimotor interactions with the physical world, become deeply embedded in lexical forms through an embodied process (P. Li & Jeong, 2020). In contrast, this integration may be less complete or even absent in L2 acquisition. Furthermore, the LDT employed in Article II involved relatively shallow semantic processing of stimuli, which likely contributed to the reduced activation of semantic and affective meanings in L2 relative to L1 for the late bilingual group. As a result, the lexical access to words with emotional information in L2 may not achieve the same level of completeness in the early period of semantic integration as it does in L1 (Jończyk et al., 2016). Subsequently, this incomplete access to L2 emotion words during the early semantic integration stage likely necessitated more elaborate processing in the later processing stages. This is reflected in the enhanced LPC amplitudes observed for emotion words in L2 compared to those in L1, particularly for those with positive valence. As a result, we assume that this reduced N400 amplitudes may reflect the shallower processing depth of L2, indicating attenuated emotionality in L2.

Secondly, this thesis disentangled emotion-label words from emotion-laden words by providing both behavioral and electrophysiological evidence. Specifically, Article I, employing an ECT, revealed a processing facilitation for emotion-label words compared emotion-laden words, with shorter reaction times in both languages. This result is in line with our hypothesis and supports the mediated account. From the perspective of embodied cognition of language, emotion-label words may be more profoundly constructed in emotional interactions and socialization, as they are more closely tied to affective states (Bromberek-Dyzman et al., 2021). As a result, they are processed more efficiently than emotion-laden words, which require mediated events to access their semantic and affective meanings. In addition, Article I revealed that L2 negative emotion-laden words were associated with reaction times similar to those of neutral words, but with fewer correct responses. Late bilinguals demonstrated lower accuracy when responding to negative emotion-laden words relative to negative emotion-label words and positive emotion-laden words in L2. Similarly, behavioral results from Article III demonstrated that L2 negative emotion-laden words were related to longer RTs. This pattern reflects the challenges bilinguals encounter in accessing and processing the affective connotations of these words in their later-acquired language. These findings jointly indicate that L2 negative emotion-laden words present a greater degree of emotional disadvantage.

In Article II, the findings revealed that during the early word processing stages, L1 negative emotion-laden words and L2 negative emotion-label words were associated with enhanced N170 emotion effects, suggesting that these two groups of emotion words are more readily perceived as conveying affective information. Furthermore, positive emotion-label words appeared to attract fewer attentional resources compared to neutral words, as evidenced by similar EPN emotion effects in both languages. More notably, the results revealed that processing emotion-laden words, whether in L1 or L2, engaged additional cognitive resources, as indicated by enhanced EPN amplitudes. Shifting to later processing stages, L1 positive emotion-laden words exhibited similar N400 emotion effects as neutral words, suggesting that positive emotion-laden words might be more challenging for semantic integration in L1. With regard to the LPC results, L1 negative emotion-laden words elicited larger LPC amplitudes, in consonance with larger N170 amplitudes observed for these words. In L2, Articles II (in the LDT) and III (in the ECT) converged to show that positive emotion-label words were linked to larger LPC amplitudes. These findings indicate that L2 positive emotion-label words may undergo more elaborate processing, potentially because they contain more salient affective information in the non-native context. Overall, the findings from these three articles demonstrate that the emotion word type and valence modulate word processing, at both behavioral and electrophysiological levels. Therefore, it is crucial to take into account the emotion word type when constructing emotional stimuli for future research in emotional language.

However, in the L2 context, the effects of emotion word type and valence tend to be influenced by the depth of cognitive processing tasks. Specifically, Article III employed both the implicit EST and explicit ECT to explore how emotion-label words and emotion-laden words with different valence are processed across shallow and deep processing tasks. The behavioral findings showed no marked effects of emotion word type, valence or their interactions on RTs in the implicit EST. The ERP results echo the behavioral findings, which showed similarly comparable LPC amplitudes for all conditions of emotion words in the EST. Prior studies have shown a null effect of valence on L2 word processing in shallow processing tasks, as evidenced by reaction times (e.g., Liao & Ni) and LPC amplitudes (e.g., Schacht & Sommer, 2009). Article III extends prior studies by showing that in the EST, where participants disengaged from the emotional properties of stimuli, emotion words, whether directly labeling emotions or indirectly conveying them, are processed similarly. Therefore, despite the established division between emotion-label words and emotion-laden words in L2 in experimental paradigms like the affective Simon task (J. Altarriba & Basnight-Brown, 2011), the LDT (J. Zhang et al., 2020), and the valence decision task (Bromberek-Dyzman et al., 2021), the effect of emotion word type may not be robust in tasks where participants focus primarily on non-emotional properties of stimuli.

Note that the absence of effects of emotion word type and valence on L2 word processing in the implicit task does not indicate that subjects were unable to perceive the task-irrelevant emotional content of the words or failed to activate emotions in the L2 context. This caution arises from two key considerations. First, it is posited that the meanings of emotion words are not likely to be entirely disregarded, as they are processed automatically and unconsciously, even when irrelevant to the task (Crossfield & Damian, 2021). Second, the exclusion of neutral words or non-words in Article III prevents us from establishing a control condition for the comparison. Consequently, we can only safely draw a conclusion that late bilinguals attend to or ignore the emotionality of these two kinds of emotion words to a similar extent in the EST (Algom et al., 2004). Taken together, Article III elucidated differences in the neural correlates of explicit versus implicit processing of emotional content of emotion-label and emotion-laden words in L2. The results suggest that the effects of emotion word type and valence may be sensitive to task type, at least in the L2 context.

Despite this, it is essential to address the varying effects of L2 proficiency on word processing observed in this thesis. Specifically, the ECT was employed in both Articles I and III. In Article I, higher L2 proficiency was associated with faster RTs when processing L2 words. This supports the notion that enhanced L2 proficiency reinforces the connection between L2 conceptual nodes and lexical nodes, facilitating L2 word processing (e.g., Kroll et al., 2010). However, Article III found that higher L2 proficiency correlated with slower RTs, which stands in contrast to the finding from Article I. The differences between these two articles may be attributed to variations in experimental design. Specifically, Article I included neutral words as a control condition, which may have intensified the emotional contrast, allowing participants to more rapidly classify emotional and non-emotional information. On the contrary, no neutral words were included in Article III, potentially making it more challenging for participants to distinguish between emotional categories. This lack of a control condition could explain the finding from Article III, particularly the heightened interference from the emotional content of words for bilinguals with higher L2 proficiency. Specifically, given the demands of the ECT, subjects with higher L2 proficiency may engage in more in-depth processing of emotion words without the control condition to anchor their responses. This could potentially contribute to longer reaction times.

4.4 Limitations and future directions

There are several limitations that need to be addressed. To begin with, the processing of emotional information could be modulated by individual emotional states, which may lead to different outcomes in word learning and processing, even within a healthy population (see Naranowicz et al., 2022, for a review). However, this factor was not controlled for in this thesis. Additionally, the age at which a word is acquired may affect the processing of emotion words (Hinojosa et al., 2020a; Wu et al., 2023). Research on the emotion word type has suggested that emotion-label words may be acquired at an earlier age compared to emotion-laden words (Basnight-Brown & Altarriba, 2018). Nevertheless, this relevant variable was also not controlled for in this thesis, which may impact the observed results. Furthermore, the emotional Stroop effect, which involves the automatic interference of the emotional content in words with color naming, was not fully explored in Article III due to the exclusion of neutral words, which precluded a comprehensive examination of the temporal dynamics of this effect in the L2 context.

For future directions, it would be interesting and informative to conduct studies involving participants from diverse linguistic backgrounds to explore the mental representation of emotion words that trigger emotions directly or indirectly across various languages. It has been shown that emotions may be conceptualized and expressed uniquely within a given language, and some emotions may be difficult to translate into concepts in another language (Basnight-Brown & Altarriba, 2018; Zhou et al., 2022). Additionally, employing other neuroimaging techniques, such as fMRI or MEG, could provide insights into the spatial dynamics underpinning the processing of these two different kinds of emotion words. Furthermore, in existing research on the emotion word type, the selection of emotion-label words and emotion-laden words is often based on the authors' intuition (e.g., Kazanas & Altarriba, 2015, 2016b, 2016a; J. Zhang et al., 2024), which lacks objectivity (Hinojosa et al., 2020b). In addition to the voting method employed in this thesis and other prior studies (Liu, Fan, Jiang, et al., 2022; Liu, Fan, Tian, et al., 2022; Wang et al., 2019), normative studies employing more objective approaches are needed. To the author's knowledge, two established databases in Spanish (Pérez-Sánchez et al., 2021) and Chinese (Zheng et al., 2023) have utilized the approach of emotional prototypicality, which measures how strongly an emotion word denotes an emotion. The higher the emotional prototypicality of a word, the greater the likelihood that it will be categorized as an emotion-label word (Wu et al., 2021a). Future exploration could benefit from developing normative databases for English and other languages.

YHTEENVETO (SUMMARY IN FINNISH)

Tunteita kuvaavien ja tunteita sisältävien sanojen käsittelymekanismit L1- ja L2 kielissä: Käyttäytymis- ja elektrofysiologinen näyttö

Tunne läpäisee ihmisten tavan tuottaa ja käsitellä kieltä. Tämä herättää seuraavan kysymyksen: Onko tunteilla universaali vaikutus kielen prosessointiin ja näkyykö tämä yksilöiden toisessa kielessä (L2) samalla tavoin kuin heidän äidinkielessään (L1)? Tämä kysymys on käynnistänyt tutkimuksia siitä, kuinka kaksikieliset käsittelevät tunneladattuja sanoja. Tulokset tämän alueen tutkimuksissa ovat kuitenkin ristiriitaisia. Vaikka jotkut tutkimukset viittaavat affektiivisen aktivaation automatisoitumisen häviämiseen, heikkenemiseen tai hidastumiseen toisen kielen (L2) affektiivisen sisällön käsittelyssä, toiset tutkimukset ovat havainneet, että tunteiden vaikutukset sanan prosessointiin ovat samanlaisia L1 ja L2-kielessä tai jopa voimakkaampia L2- kielessä L1-kieleen verrattuna. Huomionarvoista on, että aiemmat tutkimukset ovat usein sivuuttaneet ja laiminlyöneet eron tunteita kuvaavien sanojen (esim. iloinen, vihainen) ja tunteita sisältävien sanojen (esim. varakas, köyhä) välillä, mikä saattaa osaltaan selittää nykyisiä ristiriitaisia tuloksia. Tässä väitöskirjassa selvitettiin, voiko tällä tunnesanan tyypillä olla merkitystä aiempien tulosten ristiriitaisuuksien selittämisessä.

Tunteisiin liittyvien sanatyyppien tutkimuksessa ei ole löydetty yksiselitteistä näyttöä, joka selkeästi erottelisi tunteita kuvaavien sanojen ja tunteita sisältävien sanojen käsittelyn toisistaan. Vaikka jotkut tutkimukset ovat löytäneet tunnesanatyypin vaikutuksen L1- ja/tai L2-kielissä, on toisissa tutkimuksissa havaittu, että näiden kahden tunnesanatyypin prosessointimekanismit ovat samankaltaisia. Nämä ristiriitaisuudet voivat johtua joistakin tutkimusmenetelmällisistä ongelmista. Esimerkiksi konkreettisuuden ja leksikaalisen kategorian muuttujia ei ole joissakin tunnesanatyyppejä käsittelevissä tutkimuksissa kontrolloitu riittävän tarkasti, mikä on saattanut vaikuttaa ristiriitaisiin tuloksiin. Lisäksi tunnesanatyypin vaikutus saattaa olla tehtävästä riippuva. Tässä väitöskirjassa tutkittiin, käsitelläänkö näitä kahta tunnesanaluokkaa eri tavoin L1- ja L2-kielissä myöhäiskaksikielisten käyttäytymisvasteiden ja tapahtumasidonnaisten herätevasteiden (ERP) avulla.

Tämä väitöskirja koostuu yhdestä käyttäytymistutkimuksesta (artikkeli I) ja kahdesta EEG-tutkimuksesta (artikkelit II ja III). Artikkeli I pyrkii selvittämään, eroavatko näiden kahden tunnesanatyyppien prosessointi niiden erilaisista assosiaatioista emotionaalisiin tiloihin. Tunteiden kategorisointitehtävässä osallistujien tuli päättää ärsykkeiden valenssi sekä L1- että L2-kielissä. Tulokset osoittivat, että L1-tunnesanat herättivät nopeampia ja tarkempia vastauksia verrattuna L2-tunnesanoihin. L2-kielen negatiiviset emootioladatut sanat osoittivat emotionaalista haittaa, mikä ilmenee vastausaikojen ja tarkkuusprosenttien samankaltaisuudesta neutraalien sanojen kanssa. Lisäksi tunteita kuvaavien sanojen ja tunteita sisältävien sanojen erottelu vahvistettiin, ja tunteita kuvaavien sanojen käsittelyssä havaittiin helpotusta. Kaiken kaikkiaan artikkelin I tulokset viittaavat siihen, että myöhäiskaksikieliset kokevat vähemmän emotionaalista sitoutumista

L2-kielen tunnesanoihin, erityisesti negatiivisiin emootioladattuihin sanoihin. Tärkeämpää on, että erottelu tunteita kuvaavien sanojen ja tunteita sisältävien sanojen välillä tulisi ottaa huomioon tulevassa tunteita käsittelevässä tutkimuksessa.

Artikkeli II tarkasteli näiden kahden tunnesanatyypin erilaisten prosessointimekanismien taustalla olevia hermostollisia tapahtumia L1- ja L2-kielissä rekisteröimällä aivojen herätevasteita, kun myöhäiskaksikieliset kiinaa ja englantia puhuvat suorittivat leksikaalisen päätöksenteon tehtävän. Tulokset osoittivat, että näitä kahta tunnesanaryhmää käsitellään eri tavoin L1- ja L2-kielissä sekä aivojen varhaisissa että myöhemmissä prosessointivaiheissa. Tarkemmin sanottuna varhaisessa sanan prosessointivaiheessa havaittiin, että L1 negatiivisia tunteita sisältävät sanat ja L2 negatiiviset tunteita kuvaavat sanat aiheuttivat voimakkaamman N170-komponentin, mikä viittaa siihen, että nämä sanat koettiin emotionaalisemmiksi. Lisäksi positiiviset tunteita kuvaavat sanat aiheuttivat pienemmän EPN-vasteen, ja tunteita sisältävät sanat voimistivat EPN:ää, mikä viittaa siihen, että positiiviset tunteita kuvaavat sanat herättävät vähiten huomiota, kun taas tunteita sisältävät sanat vaativat enemmän huomiota kuin tunteita kuvaavat sanat. Myöhäisemmissä prosessointivaiheissa L1-kielen tunnesanat aiheuttivat voimakkaamman N400-vasteen ja pienemmän LPC-vasteen verrattuna L2-tunnesanoihin. Nämä havainnot viittaavat siihen, että myöhäiskaksikielisten aivoissa tunnesanojen semanttinen ja emotionaalinen sisältö on heikommin saatavilla L2-kielessä. Kaiken kaikkiaan artikkelin II tulokset vahvistivat havaintoa, jonka mukaan L1-kieli on syvemmin juurtunut ja ruumiillistunut emotionaalisessa kokemuksessa verrattuna L2-kieleen. Lisäksi näitä kahta tunnesanaryhmää käsitellään eri tavoin sekä aivojen varhaisissa että myöhäisissä sanan prosessointivaiheissa sekä L1- että L2-kielissä.

Artikkeli III tarkasteli, onko tunnesanatyypin vaikutus universaali eri tehtävissä. Tutkimuksessa käytettiin emotionaalinen kategorisointitehtävää (ECT) ja emotionaalinen Stroop-tehtävää (EST) selvittämään, onko aivovasteissa eroja, kun näitä kahta tunnesanaryhmää käsitellään eksplisiittisesti ja implisiittisesti L2-kielessä ERP-tekniikan avulla. Tulokset osoittivat, että eksplisiittisessä ECT-tehtävässä L2 negatiiviset tunteita sisältävät sanat aiheuttivat hitaampia vasteita ja L2 positiiviset tunteita kuvaavat sanat aiheuttivat suurempia LPC-amplitudeja. Nämä havainnot viittaavat siihen, että L2 negatiiviset tunteita sisältävät sanat herättävät vähentynyttä affektiivista resonanssia, kun taas L2 positiivisten tunteita kuvaavien sanojen kohdalla emotionaaliset konnotaatiot ovat selvempiä. Huomionarvoista on, että kaikki nämä erot rajoittuivat eksplisiittiseen ECT-tehtävään, jossa ärsykkeiden emotionaalinen sisältö oli tehtävän kannalta merkityksellinen. Implisiittisessä EST-tehtävässä ei havaittu tunnesanatyypin tai valenssin vaikutuksia sanan prosessointiin. Yhteenvetona artikkelin III tulokset viittaavat siihen, että näiden kahden tunnesanatyypin implisiittisessä ja eksplisiittisessä prosessoinnissa L2 -kielessä on eroja aivovasteiden tasolla. Nämä havainnot korostavat, että tunnesanatyypin vaikutus voi olla tehtävästä riippuva, ainakin L2-kielen kontekstissa.

Tämä väitöskirja vahvistaa havaintoa, jonka mukaan L1-kieli on emotionaalisesti vahvemmin juurtunut kuin L2-kieli, mikä tukee tunteiden huomioimista oppimisen teorioissa. Merkittävämpää on kuitenkin se, että väitöskirja vahvistaa eron tunteita kuvaavien ja tunteita sisältävien sanojen välillä sekä L1- että L2-kielissä, pohjaten sekä käyttäytymismittareilla että elektrofysiologisilla menetelmillä saatuun näyttöön. Tulokset osoittavat, emotionaalisen kielen prosessointiin liittyvien kokeellisten ärsykkeiden rakentamisessa on välttämätöntä ottaa huomioon käytettävät tunnesanatyypit. On kuitenkin huomattava, että tunnesanatyypin ja valenssin vaikutukset voivat olla tehtävästä riippuvaisia, ainakin L2-kielen kontekstissa.

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ORIGINAL PAPERS

I

THE EMBODIMENT OF EMOTION-LABEL WORDS AND EMOTION-LADEN WORDS: EVIDENCE FROM LATE CHINESE–ENGLISH BILINGUALS

by

Dong Tang, Yang Fu, Huili Wang, Bo Liu, Anqi Zang,
& Tommi Kärkkäinen, 2023

Frontiers in Psychology 14

https://doi.org/10.3389/fpsyg.2023.1143064

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frontiers | Frontiers in Psychology

TYPE Original Research
PUBLISHED 22 March 2023
DOI 10.3389/fpsyg.2023.1143064

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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

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The embodiment of emotion-label words and emotion-laden words: Evidence from late Chinese–English bilinguals

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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: $r=0.56$, Crl [0.36, 0.74]; English: $r=0.44$, Crl [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

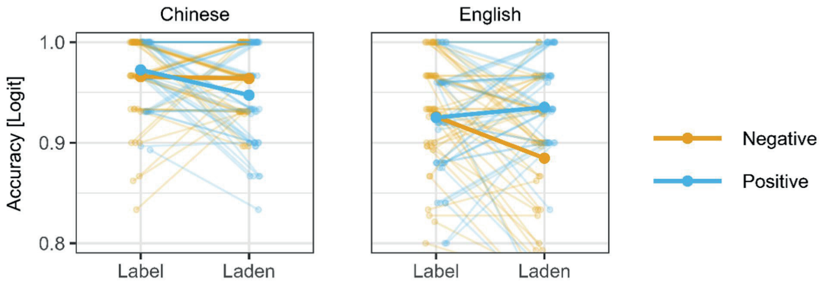

FIGURE 1
Triple interaction between valence (in color), language (L1 on the left, L2 right), and emotion word type (emotion-label and emotion-laden; on the x axis) reflected in ACCs (on the y axis). Single-subject indices (thin lines) are overlayed by group averages (thick lines).

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.

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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

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II

NEURAL CORRELATES OF EMOTION-LABEL VS. EMOTION-LADEN WORD PROCESSING IN LATE BILINGUALS: EVIDENCE FROM AN ERP STUDY

by

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Cognition and Emotion, 1–18 (published online)

https://doi.org/10.1080/02699931.2024.2352584

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Neural correlates of emotion-label vs. emotion-laden word processing in late bilinguals: Evidence from an ERP study

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Neural correlates of emotion-label vs. emotion-laden word processing in late bilinguals: Evidence from an ERP study

Abstract

The brain processes underlying the distinction between emotion-label words (e.g., happy, sad) and emotion-laden words (e.g., successful, failed) remain inconclusive in bilingualism research. The present study aims to directly compare the processing of these two types of emotion words in both the first language (L1) and second language (L2) by recording event-related potentials (ERP) from late Chinese-English bilinguals during a lexical decision task. The results revealed that in the early word processing stages, the N170 emotion effect emerged only for L1 negative emotion-laden words and L2 negative emotion-label words. In addition, larger early posterior negativity (EPN) was elicited by emotion-laden words than emotion-label words in both L1 and L2. In the later processing stages, the N400 emotion effect was evident for L1 emotion words, excluding positive emotion-laden words, while it was absent in L2. Notably, L1 emotion words elicited enhanced N400 and attenuated late positive complex (LPC) compared to those in L2. Taken together, these findings confirmed the engagement of emotion, and highlighted the modulation of emotion word type and valence on word processing in both early and late processing stages. Different neural mechanisms between L1 and L2 in processing written emotion words were elucidated.

Keywords: emotion-label words, emotion-laden words, L1, L2, ERP

Introduction

Emotion and language, along with their interactions, are essential in the realm of human experience (Hinojosa et al., 2020a). Regarding research on human emotion processing, written emotion words with both affective and conceptual information have emerged as a focal point in understanding how language can trigger emotions. Generally, emotion words are characterized along two main dimensions: valence, reflecting the pleasant or unpleasant nature of emotional stimuli, and arousal, indicating the level of word-evoking emotional activation, ranging from calm to excited. Studies of emotion word processing have reported that emotionality-charged words tend to display higher or different automatic emotional arousal in comparison to neutral words, a phenomenon referred to as emotion effect (Citron, 2012).

Building on this understanding, there has been an increasing interest in the study of bilingualism, particularly whether the emotional content of words activates intensive emotions within bilingual speakers who have access to mental lexicons of two languages. So far, there is a commonly held notion that bilinguals exhibit more salient automatic reactions to emotion words presented in their native language (L1) when compared to those in their second language (L2). This is particularly the case for late bilinguals, characterized by their initial exposure to and acquisition of L2 at a later course of linguistic development (Toivo & Scheepers, 2019). For instance, late Polish-English bilinguals demonstrated decreased galvanic skin response to L2 emotional texts compared to those in L1 (Jankowiak & Korpal, 2018). This phenomenon gives rise to the theory of "emotion context-of-learning" (Harris et al., 2006), positing that language becomes imbued with emotionality when it is learned and used within an emotional or social context. From this perspective, L2 tends to be less emotionally grounded since late bilingual speakers typically acquire L2 in a non-natural learning context (formal settings such as classroom environment), devoid of immersive and emotional experiences of the physical world. Therefore, L1 is thought to be linked to a heightened sense of emotional embodiment, whereas L2 tends to be associated with a greater degree of emotional detachment (Pavlenko, 2012; Velez-Uribe & Rosselli, 2021).

There are, however, disagreements as some studies reported that emotional resonance afforded by L2 emotion words is compatible with that in L1. For example, a behavioral study has shown that the automatic motor responses to L1 and L2 emotional stimuli are comparable in late German-English bilinguals (Dudschig et al., 2014). One study even reported a larger emotion effect, reflected by larger skin conductance responses, in L2 relative to L1 (Caldwell-Harris et al., 2011). Considering the equivocal evidence in bilingualism research, it is necessary to conduct further investigation to ascertain whether affective word processing in L1 and L2 populations share the same neural mechanism. Notably, compared to research on the neural bases underlying emotion word processing that have been studied extensively in L1, the engagement of emotional content of L2 words is less investigated (Dang et al., 2023). It is worth noting that language plays a role not only in expressing and communicating about emotions, but also in shaping the feeling of emotions (Duñabeitia & García-Palacios, 2020), suggesting the need to investigate whether and how brain activity is modulated by emotion words in bilingual speakers.

In recent years, the event-related potentials (ERP) technique has been utilized, benefiting from its high temporal resolution, to establish the timing of brain activity related to emotion effect on word processing. Studies, as specified below, have identified that the emotional content of words is involved in both the lexical and lexico-semantic processing stages of written words. In the early processing stages associating with lexical access, recent research has demonstrated that N170, an occipital-temporally distributed negative deflection peaking at around 170 ms after stimulus onset, is sensitive to the category of emotional content (D. Zhang et al., 2014), with its amplitude being affected by attention (J. Zhang et al., 2017). Temporally after N170, an early posterior negativity (EPN) peaking between 200 and 300 ms over occipito-temporal sites has frequently been linked with the processing of emotion words. The more negative amplitudes of EPN for emotion words than neutral words were suggested to reflect implicit and automatic attention capture (Citron, 2012). These findings indicated that, to some extent, the emotional properties of words are processed parallelly with accessing the representations of word forms (Hinojosa et al., 2020a). Nevertheless, there is no consistent pattern of emotion effect in early period of word processing as those mentioned early ERP components were not always found (e.g., Schacht & Sommer, 2009; Wang et al., 2019).

In the later processing stages, on the contrary, the late positive complex (LPC) has been consistently reported in response to the emotional content of written words. LPC, a positive component peaking around 450-700 ms over centro-parietal sites, typically reflects elaborate processing of attended information like emotional features. ERP studies of emotion word processing frequently reported that, compared to neutral words, emotionally valenced words (negative and positive) evoke a more pronounced LPC (Citron, 2012). Furthermore, LPC is modulated by the depth of processing, exhibiting enhanced effects during tasks requiring certain degree of semantic processing, while diminishing or vanishing in tasks involving shallow processing (Hinojosa et al., 2020a). In addition, N400, typically peaking at approximately 400 ms post-stimulus with a centroparietal distribution, has been linked to the processing of emotion words. Prior research has shown that emotion words elicited attenuated N400 relative to neutral words, indicating facilitated semantic processing for emotional stimuli (Sass et al., 2010; Wang et al., 2019).

Crucially, there is a need to refine the features of emotion words, highlighted in the research into the interplay between language and emotion in the domain of affective neurolinguistics (Hinojosa et al., 2020b). In this sense, the effect of emotion word type has attracted strong interest. Specifically, it is proposed that, rather than being a homogeneous category that opposites to neural stimuli, emotion words can be categorized into two subtypes: emotion-label words, which straightforwardly label certain affective states, and emotion-laden words, which evoke emotional responses through their affective connotations (Pavlenko, 2008; C. Wu & Zhang, 2020). Behaviorally, previous studies using various cognitive paradigms have identified divergences between emotion-label and emotion-laden words across multiple languages, including English, Spanish, Romanian, Polish, Arabic and Chinese (Altarriba & Basnight-Brown, 2011; Bromberek-Dyzman et al., 2021; El-Dakhs & Altarriba, 2019; Kazanas & Altarriba, 2015; Tang et al., 2023). The majority of these studies reported a processing advantage for emotion-label words over emotion-laden words, with shorter response times or more pronounced priming effects (e.g., Kazanas & Altarriba, 2015; Tang et al., 2023). Conversely, a preferential processing for emotion-laden words over emotion-label words was also observed, as demonstrated in the study by Bromberek-Dyzman et al. (2021).

In addition, studies focusing on the brain processes related to the effect of emotion word type has uncovered distinctness between these two categories of emotion words. For instance, L1 research employing a lexical decision task (LDT), which requires subjects to determine whether a given stimulus is a word or not, has revealed that emotion-label words elicited larger N170 than emotion-laden words. Additionally, negative emotion-label words induced enhanced LPC on the right hemisphere (J. Zhang et al., 2017). In a similar vein, employing the same experimental design, J. Zhang et al. (2020) extended their investigation to L2 and reported interaction between emotion word type and valence concerning N170, and found smaller amplitudes of LPC for emotion-label words than emotion-laden words. These findings demonstrated the modulation of emotion word type at both early and late processing stages. As a result, it is suggested that the distinction between these two types of emotion words should be incorporated into the framework of affective neurolinguistics (C. Wu & Zhang, 2020).

Despite empirical evidence from the mentioned behavioral and ERP studies, the extant evidence for the effect of emotion word type is far from being conclusive. In L1 behavioral research, several studies failed to reveal differential processing between the two sorts of emotion words in an LDT (Martin & Altarriba, 2017; Vinson et al., 2014). Regarding ERP research in L1, findings that were reported were not replicated in the study by Wang et al. (2019) when controlling the concreteness and word class of stimuli and introducing neutral words as a contrast condition. Instead, they only observed differences in P200 between positive emotion-laden words and neutral words. In addition, Jia et al. (2022) detected that L1 emotion-label words produced reduced N170 compared to emotion-laden words in an LDT. Hence, a consensus on the neural correlates of the exact processing stages where sensitivity to these two kinds of emotion words emerge in L1 remains elusive. More importantly, it is suggested that the variable concreteness, signifying the extent to which a concept has clear referents to material objects, may be a potential factor contributing to the distinction between emotion-label and emotion-laden words (Kissler, 2020). However, the concreteness was not controlled in the L2 study by J. Zhang et al. (2020), and noteworthy is the exclusion of neutral words in their study, hindering the investigation into the temporal dynamics of the emotion effect in L2. Consequently, further investigation is needed to understand the divergences between these two types of emotion words in both L1 and L2 processing.

In summary, a consistent pattern of the emotion effect on word processing has yet to emerge in both L1 and L2 populations. Due to their varying associations with affective states, emotion-label and emotion-laden words may be lexicalized and embodied differently within and across L1 and L2, potentially contributing to the existing confounding evidence in both early and late word processing stages. Through a within-subject design, the present study aims to explore and directly compare whether and how these two types of emotion words are processed differently from neutral words and from each other in late Chinese-English bilinguals' L1 (Chinese) and L2 (English) using ERP. Based on prior research, we expect that in the early processing stages, emotion-label words would produce larger emotion activation (enhanced N170/ EPN) than emotion-laden words in both L1 and L2 (Liu, Fan, Tian, et al., 2022; J. Zhang et al., 2017, 2020), especially for those words bearing negative valence. In the later processing stages, we assume that emotion words, regardless of word type, would elicit attenuated N400 compared to neutral words (Wang et al., 2019), and the N400 amplitudes elicited by L2 emotion words should be larger than those in L1 due to greater semantic integration difficulty. Furthermore, we expect that emotion-laden words would induce a larger LPC compared to emotion-label words in both L1 and L2 (J. Zhang et al., 2020).

Methods

Participants

Thirty-two right-handed Chinese-English bilinguals with normal or corrected-to-normal vision participated in this study. None of them reported neurological or psychiatric disorders. ERP data of 4 subjects were discarded because of excessive EEG artifacts, resulting in a final sample of 28 participants (mean age: 28.25, SD = 3.03;10 males). Before the measurement started, all participants provided written informed consent. They then underwent the LexTALE (Lemhöfer & Broersma, 2012), an objective test for evaluating L2 proficiency, particularly vocabulary knowledge. The averaged LexTALE score was 68.61% (SD = 9.81%), indicating an upper intermediate L2 proficiency level (60%-80%). Additionally, participants completed three questions adapted from the Language History Questionnaire (Li et al., 2020). The results showed that they were late bilinguals who began learning L2 through classroom instruction at an average age of 8.61 (SD = 1.75); they had an average L2 exposure of 19.61 years (SD = 2.63); they rated their L1 proficiency as 90.56% (SD = 9.08%) and L2 proficiency as 66.58% (SD = 7.91%) on a 1-7 self-rating scale of their knowledge in listening, speaking, reading and writing in both L1 and L2 (7 = very excellent). The Ethics Committee of the University of Jyväskylä approved the experimental protocol.

Stimuli

Given that adjectives may be more related to emotional states (D. Zhang et al., 2014), and to better control the concreteness of stimuli, only adjective words were included in this study. A total of 408 Chinese two-character words were selected primarily from a Chinese database (Cai & Brysbaert, 2010), along with 296 English words obtained from an English emotional norm database (Warriner et al., 2013), establishing the initial word pools. Following the voting method adopted in prior research (Liu, Fan, Jiang, et al., 2022; Liu, Fan, Tian, et al., 2022; Wang et al., 2019), 20 participants for each language, who did not participate in the formal measurements, were instructed to classify these words into emotion-label, emotion-laden or neutral words according to their definitions. Words that achieved a consensus of at least about 80% among participants for the same category were included for further selection, leading to a final set of 276 L1 words and 240 L2 words. Then, for each language, four separate groups of participants not involved in the later formal measurements, were invited to evaluate the valence, arousal, concreteness, and familiarity of the selected L1 and L2 words on a 7-point Likert scale (7 = very pleasant, very excited, very abstract, and very familiar, respectively).

Table 1. Means (M) and Standard Deviation (SD) of the properties of neutral, emotion-label, and emotion-laden words in L1 (Chinese).

Word type	Valence	Arousal	Concreteness	Frequency	Familiarity	Strokes
Positive emotion-label	5.8 (0.96)	5.5 (1.27)	4.3 (1.96)	2.1 (1.19)	6.4 (1.09)	17.4 (4.19)
Positive emotion-laden	5.8 (0.94)	5.5 (0.95)	4.4 (2.02)	2.3 (0.71)	6.5 (1.14)	18.3 (4.73)
Negative emotion-label	2.5 (0.84)	5.6 (1.17)	4.2 (2.02)	2.3 (0.77)	6.5 (1.07)	16.7 (3.1)
Negative emotion-laden	2.4 (0.98)	5.5 (1.27)	4.2 (2.00)	2.2 (0.54)	6.4 (1.22)	18.1 (4.41)
Neutral	4.2 (0.74)	3.0 (1.58)	4.2 (1.70)	2.4 (0.65)	6.4 (1.09)	16.8 (4.69)

Finally, each language experiment consisted of 180 words, evenly distributed into three valence categories: positive words (30 emotion-label words and 30 emotion-laden words), negative words (30 emotion-label words and 30 emotion-laden words), and neutral words (60 words). Details for the matching of variables (see Table S1 for L1 stimuli and Table S2 for L2 stimuli) and all stimuli (see Table S3 for L1 and Table S4 for L2) employed in this study could be found in the supplementary materials. For L1 stimuli, strokes, frequency (Cai & Brysbaert, 2010), familiarity, and concreteness were matched across all five groups of words (*ps* > 0.411). Arousal ratings revealed a significant difference among the five groups of words [$F(1, 31) = 74.441$, $p < 0.001$]. However, paired tests showed that the positive emotion-label words, negative emotion-label words, positive emotion-laden words, and negative emotion-laden words did not differ significantly from each other (*ps* > 0.452). Regarding valence, neutral words received significantly higher ratings than negative words ($p < 0.001$), while neutral stimuli were rated significantly lower than positive words ($p < 0.001$). However, no significant differences were observed between emotion-label and emotion-laden words within the positive and negative valence categories (*ps* > 0.29). Additionally, 180 L1 nonwords were drawn from the Chinese Lexicon Project (Tse et al., 2017). The strokes of L1 nonwords (M = 17.6, SD = 2.14) were matched to the strokes of real words (M = 17.3, SD = 4.35), with no observed significant difference between them ($p = 0.444$). The attributes of the L1 stimuli used in this study are shown in Table 1.

Concerning the L2 stimuli, these five groups of words were matched in terms of length, frequency (Brysbaert & New, 2009), familiarity, and concreteness (*ps* > 0.1). For arousal, the differences among the five groups of words were significant [$F(1, 34) = 52.525$, $p < 0.001$]. However, paired test showed that differences between the four groups of emotion words did not reach a significance (*ps* > 0.1334). For valence, neutral words were rated significantly higher than negative words ($p < 0.001$) but significantly lower than positive words ($p < 0.001$). No significant differences were observed between emotion-laden words and emotion-label words in the positive and negative valence categories (*ps* > 0.1). In addition, 180 L2 nonwords were selected from the English Lexicon Project (Balota et al., 2007), with the length of L2 nonwords (M = 7.54, SD = 0.5) matching that of real words (M = 7.54, SD = 1.80). A significant difference between them was not observed ($p > 0.05$). The properties of the L2 stimuli employed in this study are presented in Table 2.

Table 2. Means (M) and Standard Deviation (SD) of the properties of neutral, emotion-label, and emotion-laden words in L2 (English).

Word type	Valence	Arousal	Concreteness	Frequency	Familiarity	Length
Positive emotion-label	5.4(1.15)	5.3 (1.16)	5.2 (1.3)	2.7 (0.73)	6.6 (0.84)	7.5 (2.01)
Positive emotion-laden	5.5 (1.10)	5.2 (1.13)	5.2 (1.37)	2.7 (0.71)	6.7 (0.75)	7.7 (1.54)
Negative emotion-label	2.6 (1.11)	5.4 (1.18)	5.2 (1.30)	2.8 (0.78)	6.6 (0.91)	7.5 (1.93)
Negative emotion-laden	2.5 (1.10)	5.2 (1.35)	5.1 (1.46)	2.9 (0.56)	6.6 (0.98)	7.5 (2.22)
Neutral	4.1 (0.75)	3.1 (1.45)	5.2 (1.55)	2.7 (0.60)	6.6 (0.91)	7.5 (1.57)

Procedure

Participants were instructed to sit comfortably in a chair in front of an LCD monitor (resolution: 1920 × 1080, refresh rate: 60 Hz) in a sound-attenuated and dimly lit room. Using the E-prime 2.0 software (Psychology Software Tools, Pittsburgh, PA), experimental stimuli were displayed in black (L1 in Song typeface font and L2 in Times New Roman font; size: 36) on a gray background, with a distance of 70 cm between participants and the computer screen. Stimuli in L1 and L2 were presented randomly and shared the same procedure in two separate language blocks. Notably, the L2 experiment preceded the L1 experiment to avoid the potential priming effect of L1 on L2 (Tian et al., 2020).

Each language experiment comprised three unrepeated blocks, with each block including 120 trials (10 words for each emotion word type-valence combination, i.e., positive emotion-label, negative emotion-label, positive emotion-laden and negative emotion-laden, 20 neutral words, and 60 nonwords). Later, these three blocks were presented again in a random order. In total, each language block consisted of 720 trials, evenly distributed across six blocks, each lasting for about 6 minutes. Breaks were arranged between blocks to allow participants to rest if needed. Additionally, a training session with 24 trials (12 real words, 12 nonwords) that were not included in the formal experiment preceded the measurements to familiarize participants with the experimental procedure. As shown in Figure 1, each trial started with a 500 ms fixation cross at the center of the screen, followed by a 200-400 ms long blank. Then, a stimulus appeared on the screen for 1,000 ms, and subsequently replaced by a question mark. Participants were instructed to decide whether the given stimulus was a real word or not as quickly and accurately as possible when they saw the question mark. Finally, a blank appeared for 200-400 ms. The corresponding keys "J" or "F" were counterbalanced across participants in each language block.

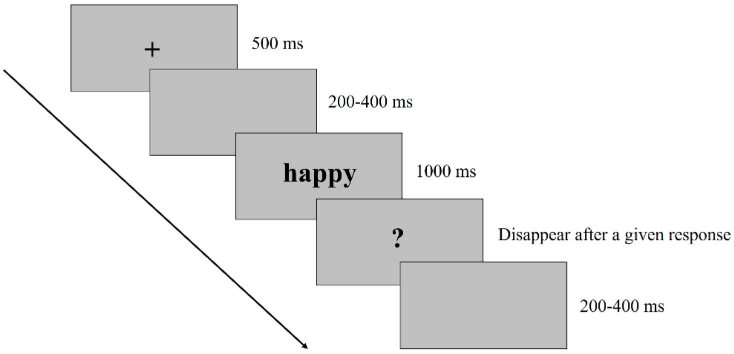

Figure 1. Schematic view of one experimental trial

EEG recording and data processing

EEG was recorded using a 128-channel net (Hydro Cel Geodesic Sensor), a high-impedance amplifier- the Net Amps 400 amplifier (Electrical Geodesics Inc., Eugene, OR, USA), and Net Station 4.5.7 software (Electrical Geodesic Inc., Eugene, OR, USA) at a sampling rate of 1,000 Hz. The online filters were set from 0.1 to 250 Hz and the online reference electrode was placed at a vertex electrode (Cz). During the measurement, electrode impedances were kept below 50 kΩ.

EEG data were processed with BrainVision Analyzer 2.2 (Brain Products GmbH, Munich, Germany). Firstly, the data were re-referenced offline to an average over all channels. Then, the EEG signals were filtered offline with a low cutoff at 0.1 Hz and a high cutoff at 30 Hz, and a notch 50 Hz filter was employed to remove the power line artifact. Bad channels were interpolated with the spherical splines method implemented in BrainVision Analyzer. Next, data were segmented into epochs, ranging from 200 ms before and 800 ms after the onset of stimuli. The 200 ms of the pre-stimulus period served as the baseline, which was corrected by calculating the mean value from -200 to 0 ms for each time point. Segments with artifacts caused by eye movements and eyeblinks were eliminated. Bad segments were identified using the automatic segment selection in BrainVision Analyzer. In each epoch, the absolute difference between two consecutive time points should not exceed 50 μV/ms. The maximum allowed voltage difference was set as 150 μV within a 200 ms interval, and the amplitude value should be between -150 μV and 150 μV. Additionally, the minimum threshold of activity allowed within a 100 ms interval was 0.5 μV. If any of the above criteria were violated within a 200 ms time frame before or after an event, the corresponding epoch would be marked as bad. Finally, for each participant, EEG segments were averaged separately for each stimulus type.

Only epochs with correct responses, and data from participants with more than two-thirds of accepted trials for each stimulus type (40 out of 60 for the four groups of emotion words, and 80 out of 120 for neutral words) were included for further analysis. This study focused on N170, EPN, N400 and LPC. Notably, a left-lateralized pattern for N170 has been observed (for a review: Nan et al., 2022), with the difference between emotion words and neutral words being evident exclusively within the left hemisphere (D. Zhang et al., 2014). Therefore, the investigation of N170 in this study was confined to the left hemisphere. Based on some previous studies, mean amplitude values of N170 from the time window of 120-170 ms over the left parieto-occipital sites (58, 64, 65, and 70) were applied (J. Zhang et al., 2017, 2020);

mean amplitude values of EPN from the time window of 180-290 ms over the parieto-occipital sites (58, 64, 65, 70, 75, 83, 90, 95, and 96) were applied (Liu, Fan, Tian, et al., 2022); mean amplitude values of N400 from the time window of 320-440 ms over the central-frontal sites (6, 7, 13, 29, 30, 36, 104, 105, 106, 111, 112 and 129) were applied (Wang et al., 2019); mean amplitude values of LPC from the time window of 440-680 ms over the central-parietal sites (37, 54, 55, 61, 62, 78, 79, 87) were applied (Liu, Fan, Tian, et al., 2022; Wang et al., 2019; J. Zhang et al., 2017, 2020). Further information about electrode pools applied in this study could be found in Figure S1 in the supplementary materials.

Statistical modeling

The resulting epoched EEG data were analyzed by Linear Mixed Effect Models (LMEMs) (Baayen et al., 2008) in R (Version 4.2.1; R Core Team, 2022), using the lmer4 1.1.31 package (Bates et al., 2015). The model considered the fixed effects of five groups of words, namely positive emotion-label words, positive emotion-laden words, negative emotion-label words, negative emotion-laden words, and neutral words, with random-effects terms for the intercept of participant and item. We called the hypr 1.2.1 package (Rabe et al., 2020) to design contrast matrices by repeated contrast coding to compare each type of emotion stimuli against neutral ones. This identical model structure was employed for both the L1 and L2 datasets. Subsequently, we excluded the neutral condition, and sequential contrast coding (1/2, -1/2) was defined, in a way that the intercept of the model represented the grand average of the fixed factors (Schad et al., 2020). This coding scheme allowed us to directly examine the main effect of and interaction among the factors of emotion word type (emotion-label vs. emotion-laden), valence (positive vs. negative), and language (L1 vs. L2). Proficiency, centered on its mean value, was included in the model as a covariate.

In line with the guidance of Scandola and Tidoni (2021), we sought to strike an optimal balance between specifying a maximal random structure, ensuring model convergence. Scandola and Tidoni (2021) demonstrated that computational efficiency is intricately tied to convergence and overfitting concerns, particularly in situations characterized by intricate model structures, such as ours. Hence, they recommended the utilization of Complex Random Intercepts (CRI) when dealing with high model complexity. In the context of a full-CRI model, random slopes are replaced with distinct random intercepts for each grouping factor, thereby mitigating the risk of Type-I errors. For each analysis, we initially fitted a maximal model, and in cases where convergence was not achieved, we systematically removed the CRI component accounting for the least variance, repeating this process until convergence was attained. During this iterative procedure, we conducted thorough scrutiny to assess model assumptions, including the distributional normality of residuals and homoscedasticity. Importantly, in the model trimming process, it was observed that the final models and their corresponding maximal counterparts yielded consistent outcomes, underscoring the notion that a parsimonious and readily interpretable model offered the best alignment with the empirical data. T-values above 1.96 can be treated as approximating the two-tailed 5% significance level since a t-distribution with a high degree of freedom approaches the *z* distribution (Baayen et al., 2008). The reported models were fit based on Kenward-Roger estimation (McNeish, 2017).

Results

Behavioral results

Due to the fixed duration of the stimuli presentation, response times were not analyzed in this study. For the analysis of accuracy rates, participants responded accurately to both L1 and L2 stimuli (> 90%).

ERP results

ERP components with observed differences across all conditions in both L1 and L2 are shown as follows. Summaries of linear mixed model for the comparison of observed ERP components between the four groups of emotion words and neutral words (see Table S5 for L1, and Table S6 for L2), and for the comparison among the four groups of emotion words in both L1 and L2 (see Table S7) can be seen in the supplementary materials.

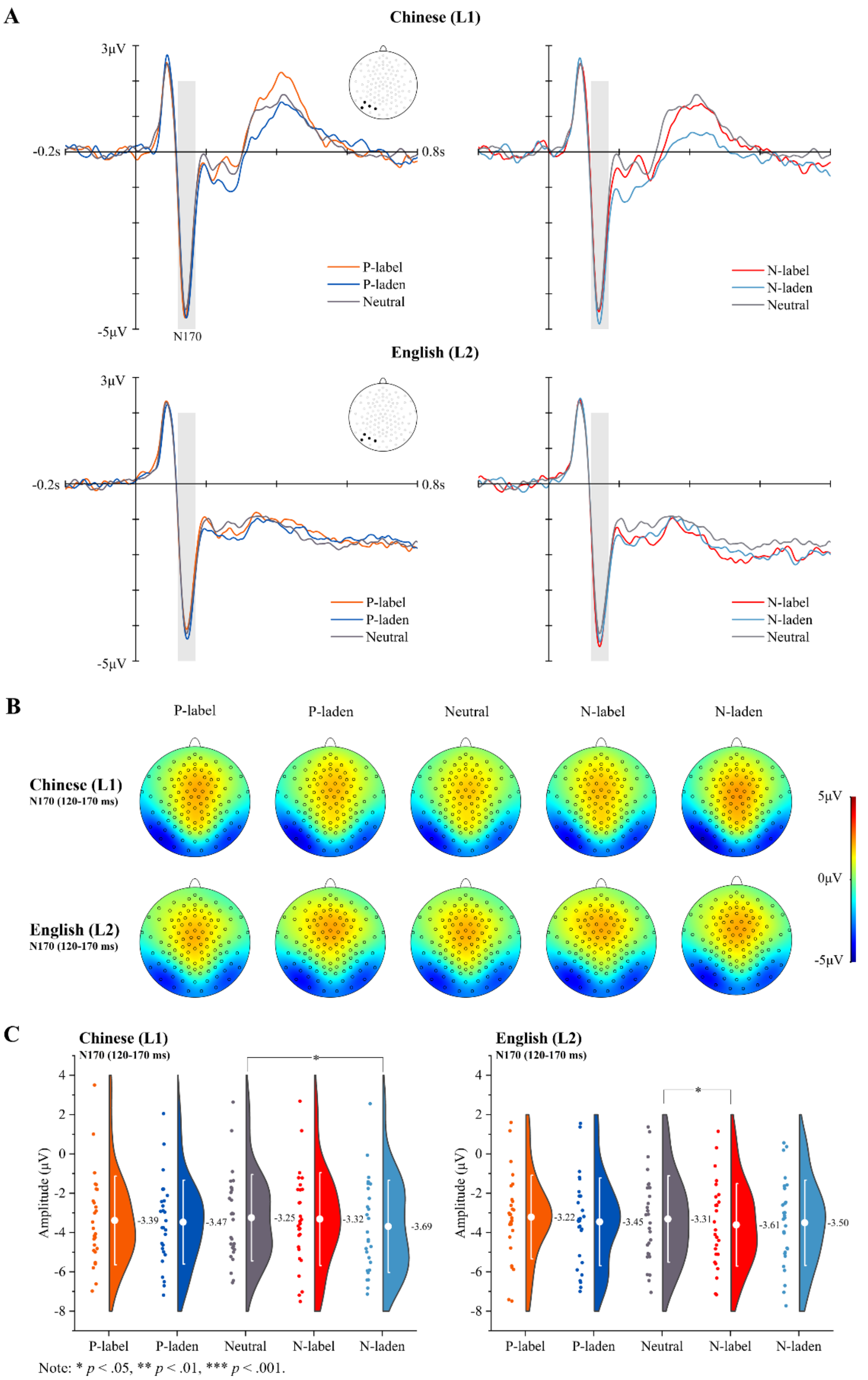

Figure 2. Grand average ERP waveforms (A), topographic maps (B) and raincloud plots (C) of N170 responses to all conditions of words in L1 and L2 on a cluster over parieto-occipital sites in left hemisphere. The gray shadows in all four waveforms indicate the time window (120-170 ms) applied in the analysis. The colored dots and area with mean value in the raincloud plots represent the distribution of electrophysiological data from a participant-based level (note: hereafter "P-label" means "Positive emotion-label words", "P-laden" means "Positive emotion-laden words", "N-label" means "Negative emotion-label words", and "N-laden" means "Negative emotion-laden words").

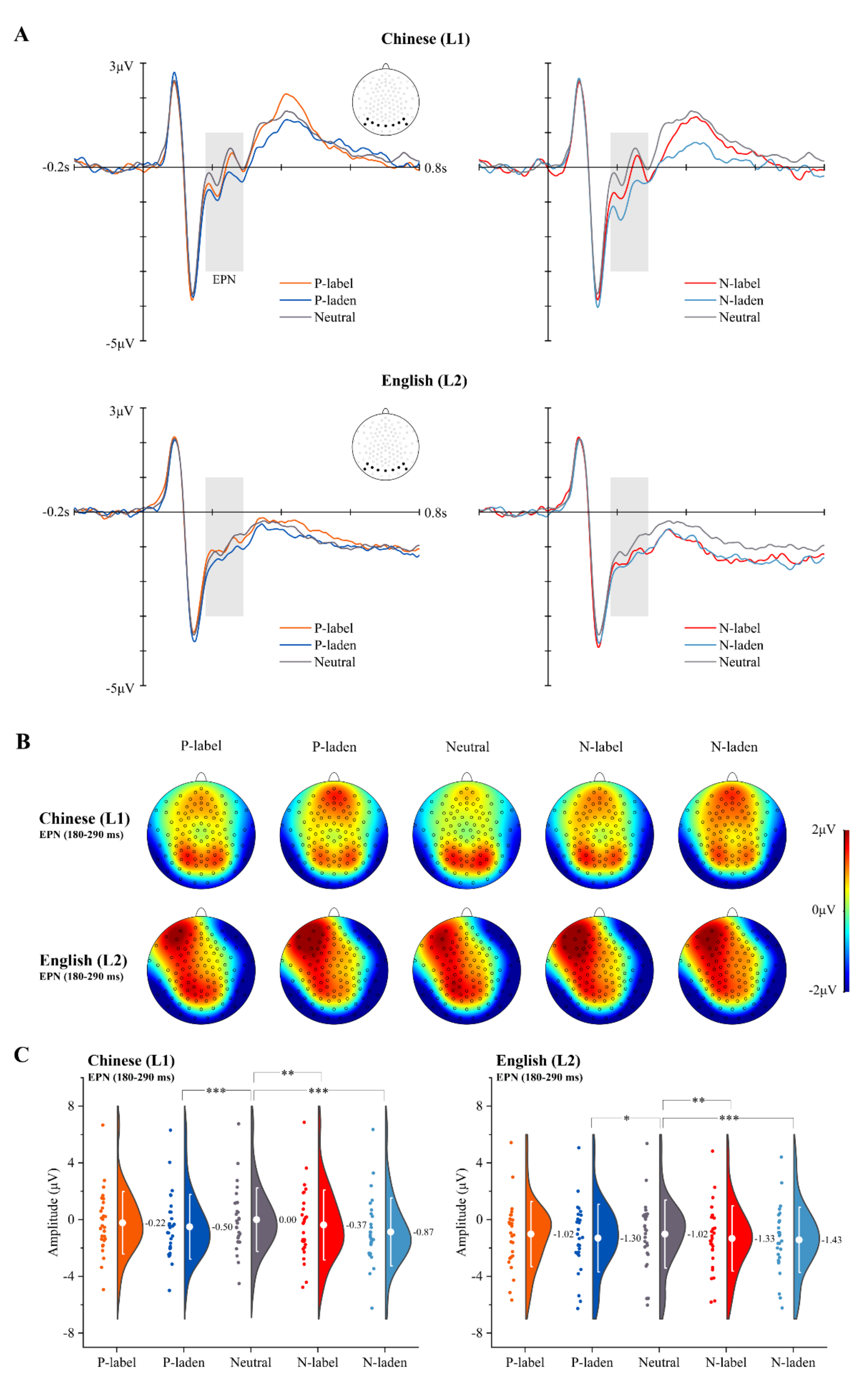

Figure 3. Grand average ERP waveforms (A), topographic maps (B) and raincloud plots (C) of EPN responses to all conditions of words in L1 and L2 on a cluster over parieto-occipital. The gray shadows in all four waveforms indicate the time window (180-290 ms) applied in the analysis. The colored dots and area with mean value in the raincloud plots represent the distribution of electrophysiological data from a participant-based level.

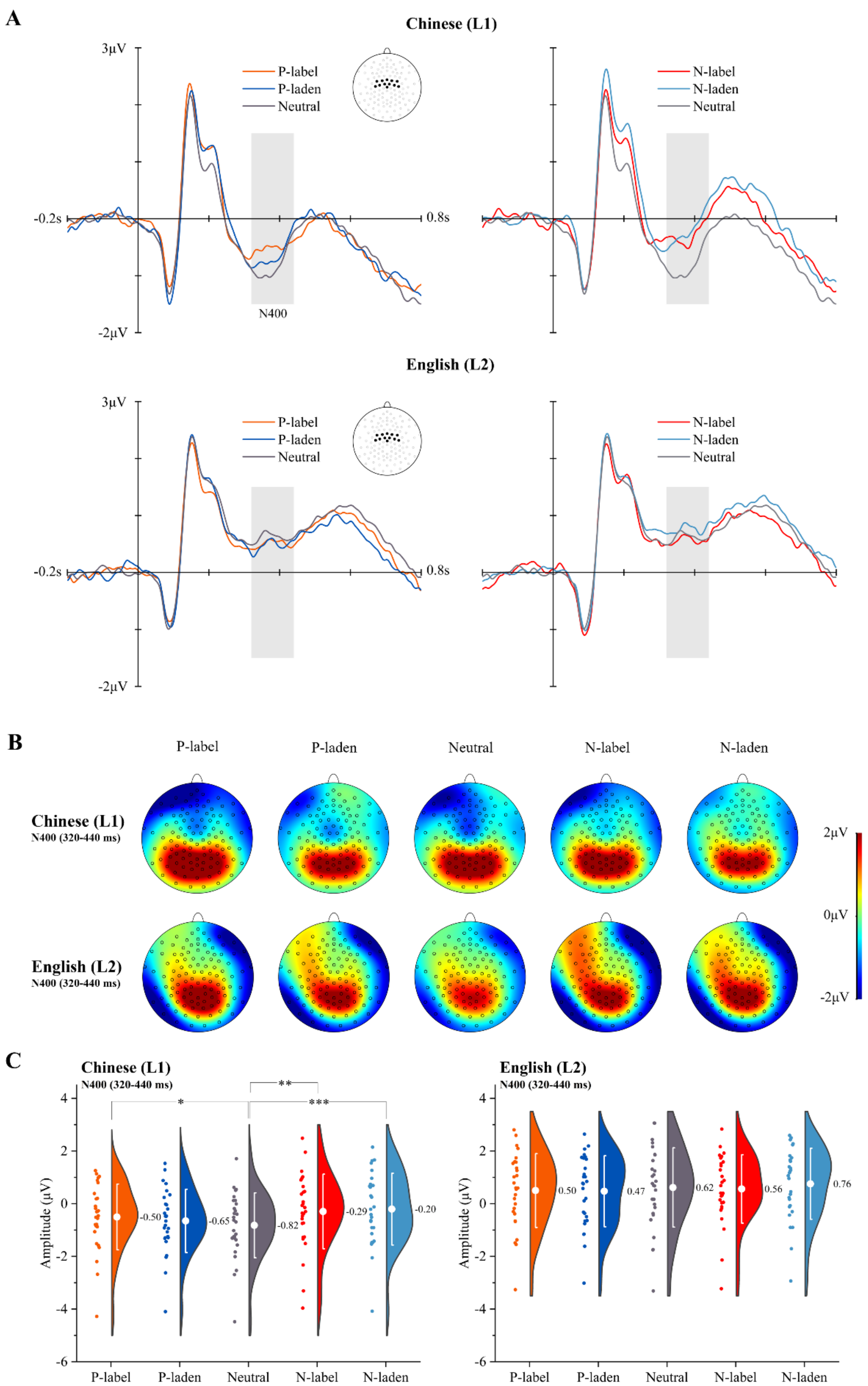

Figure 4. Grand average ERP waveforms (A), topographic maps (B) and raincloud plots (C) of N400 responses to all conditions of words in L1 and L2 on a cluster over centro-frontal sites. The gray shadows in all four waveforms indicate the time window (320-440 ms) applied in the analysis. The colored dots and area with mean value in the raincloud plots represent the distribution of electrophysiological data from a participant-based level.

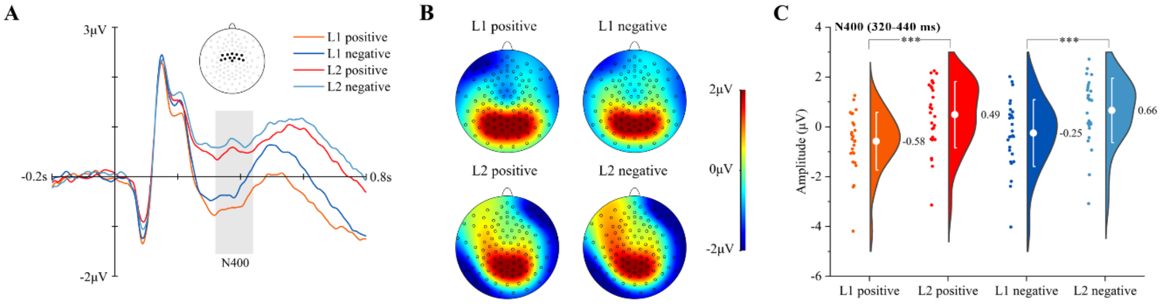

Figure 5. Grand average ERP waveforms (A), topographic maps (B) and raincloud plots (C) of N400 responses to positive and negative words in L1 and L2 on a cluster over centro-frontal sites. The gray shadow in the waveform indicates the time window (320-440 ms) applied in the analysis. The colored dots and area with mean value in the raincloud plots represent the distribution of electrophysiological data from a participant-based level.

N170. The mean grand-average of the waveforms, topographic maps and raincloud plots of N170 for each condition of words in L1 and L2 are illustrated in Figure 2. L1 negative emotion-laden words evoked enhanced N170 than neutral words (β = -0.44, t = -2.6, p = 0.011). No significant difference was observed between neutral words and the other three groups of emotion words (ts < 1.3, ps > 0.2). In L2, negative emotion-label words elicited stronger N170 compared to neutral words (β = −0.3, t = -2.1, p = 0.032). The other three groups of emotion words elicited similar amplitudes to neutral words (ts < 1.4, ps > 0.17). After the removal of neutral words, no main effects or interactions were significant among the four groups of emotion words (ts < 1.7, ps > 0.092).

EPN. The mean grand-average of the waveforms, topographic maps and raincloud plots of EPN for each condition of words in L1 and L2 are illustrated in Figure 3. The EPN amplitudes evoked by positive emotion-label words did not differ from that of neutral words in both L1 (β = -0.21, t = -1.8, p = 0.077) and L2 (β = 0.0094, t = 0.08, p = 0.94), whereas the other three groups of emotion words elicited enhanced EPN than neutral words in both L1 (ts > 2.9, ps < 0.0035) and L2 (ts > 2.3, ps < 0.02). After the removal of neutral words, main effects of emotion word type and valence were significant. Specifically, positive words produced smaller EPN than negative words (β = 0.23, t = 3.9, p = 0.00011), and emotion-laden words elicited more negative-going EPN than emotion-label words (β = 0.3, t = 4.5, p < 0.0001).

N400. The mean grand-average of the waveforms, topographic maps and raincloud plots of N400 for each condition of words in L1 and L2 are illustrated in Figure 4. In L1, positive emotion-label words, as well as negative emotion-label and emotion-laden words elicited smaller N400 compared to neutral words (ts > 2.5, ps < 0.019). N400 amplitude did not differ between positive emotion-laden words and neutral words (β = -0.17, t = 1.5, p = 0.16). In L2, there were no significant differences between the four groups of emotion words and neutral words (ts < 1.3, ps > 0.21).

After removing neutral words, a two-way interaction between valence and language (β = -0.16, t = −2.1, p = 0.036) was detected. Post hoc analysis revealed that L1 positive words elicited larger N400 than negative words (β = -0.328, SE = 0.0834, z = -3.933, p = 0.0001), and a similar valence effect was found in L2 (β = -0.171, SE = 0.0834, z = -2.050, p = 0.0404). Additionally, L1 emotion words elicited amplified N400 compared to those in L2, with L1 positive words eliciting enhanced N400 compared to those in L2 (β = -1.065, SE = 0.053, z = -20.084, p < 0.0001) and L1 negative words eliciting enlarged N400 compared to those in L2 (β = -0.908, SE = 0.053, z = -17.123, p < 0.0001). The mean grand-average of the waveforms, topographic maps, and raincloud plots of N400 for positive and negative words in L1 and L2 are illustrated in Figure 5.

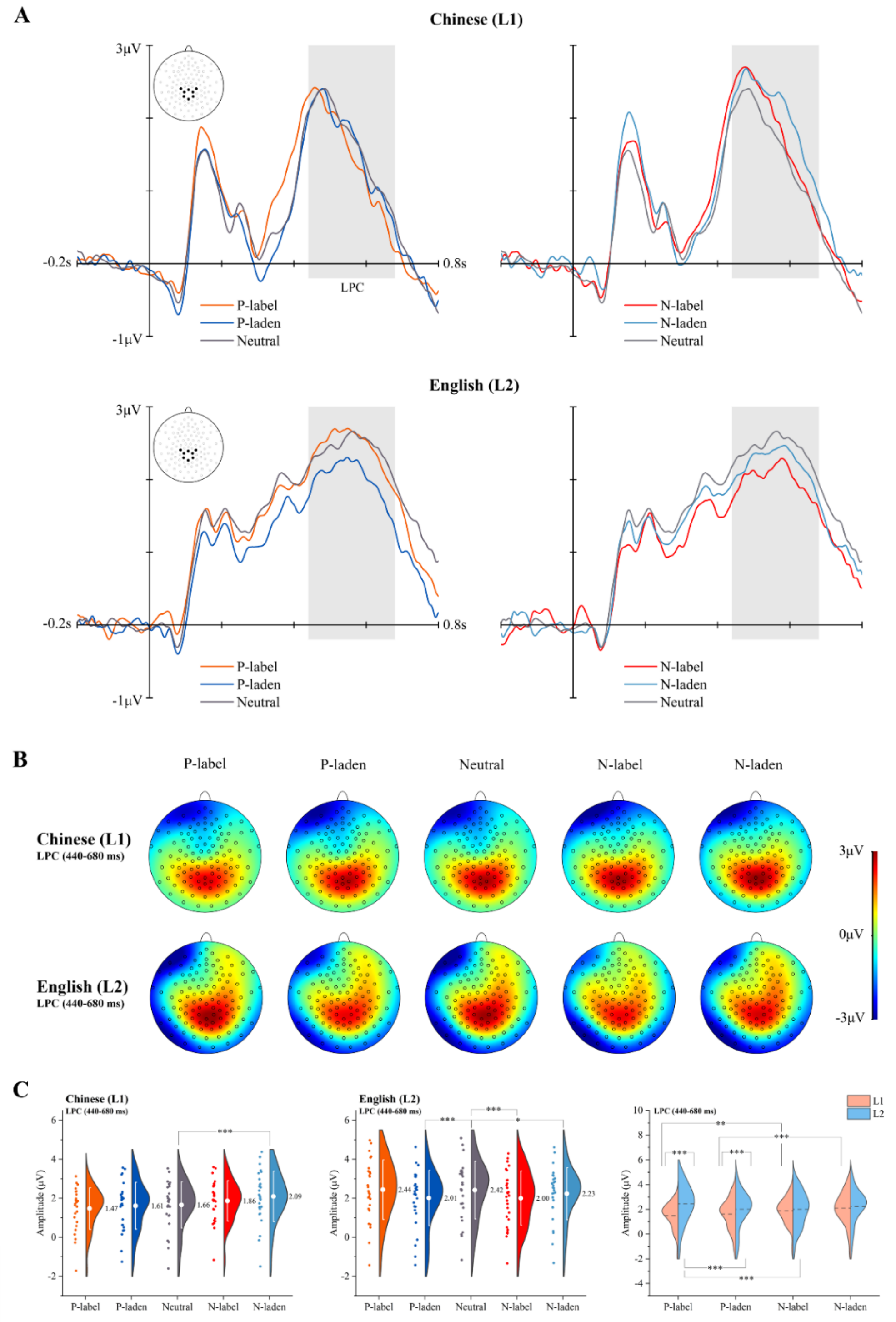

Figure 6. Grand average ERP waveforms (A), topographic maps (B) and raincloud plots (C) of LPC responses to all conditions of words in L1 and L2 on a cluster over centro-parietal sites. The gray shadows in all four waveforms indicate the time window (440-680 ms) applied in the analysis. The colored dots and area with mean value in the raincloud plots represent the distribution of electrophysiological data from a participant-based level.

LPC. The mean grand-average of the waveforms and topographic maps of LPC for each condition of words across two languages are illustrated in Figure 6. In L1, while negative emotion-laden words elicited larger LPC than neutral words (β = 0.43, t = 4.1, p = 0.00037), there were no differences between the other three groups of emotion words and neutral words (ts < 1.7, ps > 0.096). In L2, no significant difference between positive emotion-label and neutral words was observed (β = 0.019, t = 0.2, p = 0.84), while the other three groups of emotion words elicited larger LPC than neutral words (ts > 2.1, ps < 0.04).

After the removal of neutral words, main effect of language was observed, with L1 emotion words eliciting attenuated LPC than those in L2 (β = -0.41, t = -8.1, p < 0.0001). This mean effect was modulated by a three-way interaction among valence, emotion word type and language (β = -0.57, t = -2.8). Post hoc analysis revealed that in L1, negative emotion-label words elicited larger LPC than positive emotion-label words (β = -0.391, SE = 0.123, z = -3.186, p = 0.0014); negative emotion-laden words elicited larger LPC than positive emotion-laden words (β = -0.479, SE = 0.123, z = -3.909, p = 0.0001). In L2, positive emotion-label words elicited enhanced LPC than negative emotion-label words (β = 0.439, SE = 0.123, z = 3.585, p = 0.0003), and negative emotion-laden words (β = 0.428, SE = 0.127, z = 3.371, p = 0.0007). L1 positive emotion-label words elicited smaller LPC than those in L2 (β = -0.968, SE = 0.102, z = -9.518, p < 0.0001); L1 positive emotion-laden words elicited smaller LPC than those in L2 (β = -0.401, SE = 0.102, z = -3.940, p = 0.0001).

Effect of L2 proficiency on ERP results

No significant effect of L2 proficiency on N170 (β = -0.57, t = -1.5), EPN (β = 0.048, t = 0.11), N400 (β = -0.057, t = -0.24) or LPC (β = -0.068, t = -0.32) was observed in L2 processing (see Table S7).

Discussion

In bilingualism research concerning emotion word processing, one unresolved issue pertains to the neural differentiation between emotion-label words and emotion-laden words. This study employed an LDT to directly compare and elucidate how these two types of emotion words are represented in late Chinese-English bilinguals' L1 and L2, respectively. The main findings suggested that the emotion word type along with valence, modulated ERP components at both early (N170 and EPN) and late processing stages (N400 and LPC) in both L1 and L2. In terms of behavioral results, participants exhibited high accuracy in responding to both L1 and L2 words, indicating a high level of familiarity with the stimuli and, consequently, resulting in ceiling effects.

Turning to the ERP results in the early processing stages, in L1, it was found that negative emotion-laden words elicited larger N170 amplitudes relative to neutral words over the left parieto-occipital sites, whereas the differences between the other three types of emotion words and neutral words were nonsignificant. In the previous study, D. Zhang et al. (2014) reported enhanced N170 amplitudes for both negative and positive words compared to neutral words in left hemisphere, indicating N170's sensitivity to the distinction between emotional and non-emotional word information. In this sense, the finding in this study suggests that L1 negative emotion-laden words may be more effective in provoking emotions than negative emotion-label words and positively valenced words, which is inconsistent with our hypothesis.

However, it is argued that negative words, due to their association with threatening information, may occupy a dominant position in the mental lexicon. Affective negative emotion-laden words such as “危急” (means dangerous) or “愚蠢” (means stupid), bear high adaptive or social significance, making them particularly relevant for biological adaptation. In addition, the affective content of negative emotion-laden words may be more closely connected to individuals’ interoceptive experiences (Ferré et al., 2022). For these reasons, L1 negative emotion-laden words may facilitate the rapid detection of salient events, capturing enhanced attention and yielding apparent early emotion effect.

In L2, the results showed that negative emotion-label words, rather than negative emotion-laden words, elicited a more enhanced N170 component than neutral words. This finding aligns with our hypothesis, indicating that L2 emotion-label words with negative valence may be easier to be perceived as words with affective information. Indeed, L2 emotion-label words may be more affectively embodied since they are encountered more frequently in daily life when describing or expressing individuals’ feelings or emotional states. Furthermore, considering the negative valence effect, it is plausible that L2 negative emotion-label words are more readily perceived as conveying affective information, thereby capturing heightened attention. The observed disparity in N170 between L1 and L2 could be attributed to the notion that L2 words might not be as strongly grounded in emotional experiences as L1 words (Dang et al., 2023), resulting in stronger emotional sensitivity to negative emotion-laden words in L1 and negative emotion-label words in L2. Here, we extend previous knowledge in emotion effect by showing that, in the early lexical processing stages, it is L1 negative emotion-laden words and L2 negative emotion-label words that may more readily evoke emotional resonance.

In addition to the N170 component, differences in emotion effect were observed in the subsequent EPN component at parieto-occipital electrodes. The results showed that the EPN emotion effect did not emerge for positive emotion-label words in both L1 and L2. Specifically, it was found that, except for positive emotion-label words, the EPN amplitudes for the other three groups of emotion words were significantly more pronounced than those for neutral words, irrespective of language operation. Past research has regarded the EPN component as an indicator reflecting task-independent and automatic attention allocation to the affective content of words (Citron, 2012; Hinojosa et al., 2020a), occurring at a lexico-semantic processing stage. The findings here suggest that positive emotion-label words and neutral words may capture similar attention resources. After removing the neutral words, the modulation of valence and the modulation of emotion word type on the EPN effect were observed. Concretely, negative words elicited boosted EPN relative to positive ones, and emotion-laden words produced pronounced EPN relative to emotion-label ones. The superior EPN response to negative words mirrors the previous results, indicating that words with positive valence might activate fewer neural resources than negative ones (Espuny et al., 2018; Liu, Fan, Tian, et al., 2022). The prioritized processing for emotion-laden words is consistent with the study by Liu, Fan, Tian, et al. (2022). It indicates that emotion-laden words may approach emotional meanings exclusively through mediation events, demanding more cognition resources as they bear complex conceptual information and correspond to one or more emotions. In contrast, emotion-label words can more easily access emotional meanings, by virtue of their explicit connection to emotional states. Hence, the EPN effect is particularly increased for negative words compared to positive words, and for emotion-laden words compared to emotion-label words. Given these considerations, it is likely that positive emotion-label words attract similar attentional resources as neutral words.

Shifting to the later processing stages in L1 processing, the results showed absent N400 emotion effect for positive emotion-laden words over centro-frontal sites. In contrast, the other three groups of emotion words demonstrated evident emotion effect, with a reduction in N400 amplitude relative to neutral words. The N400 component typically manifests facilitated higher-order lexico-semantic processing, and weaker N400 amplitudes in the context of emotion words relative to neutral words have been associated with easier lexical access and semantic integration (Citron, 2012). In this sense, our finding suggests elevated processing effort with L1 positive emotion-laden words, aligning with the study by Liu, Fan, Jiang, et al. (2022) where an attentional bias was reported for positive emotion-laden words. As mentioned earlier, emotion-laden words are associated with multiple connections with emotional states (Tang et al., 2023). For example, the word "successful" might simultaneously trigger multiple emotions like "happy", "proud" or "excited", introducing ambiguity that may weaken the lexical access and semantic integration of emotion-laden words. Additionally, compared to negative emotion words, positive emotion words may broaden one's mind and weaken selective attention (Finucane, 2011). Therefore, L1 positive emotion-laden words displayed a similar N400 effect to that of neutral words, implying increased processing effort and higher cognitive demands. It is noteworthy that N400 component is typically distributed at the centro-parietal region, which is different from the cluster site examined in our study. Nevertheless, our results corroborate some previous research demonstrating stronger N400 emotion effect over anterior sites (Kanske & Kotz, 2007; Wang et al., 2019).

In L2, however, no such N400 emotion effect was identified. The results showed that L2 emotion words evoked comparable N400 amplitudes to neutral words, indicating that L2 emotion words, regardless of valence and emotion word type, could not facilitate semantic processing. One may thus speculate that explicitly knowing the meaning of L2 emotion words does not necessarily lead to intensive emotional resonance and faster semantic integration as observed in L1 (Ahn & Jiang, 2022), at least during the initial stages of semantic integration. This aligns with the idea that, for late bilinguals, the encoding of L2 emotion words entails fewer accompanied reactivation of associated emotional experiences, even though they understand that these words convey emotional meanings (Ferré et al., 2022). After excluding neutral words, an enhancement in N400 amplitudes in response to positive words relative to negative words was observed in both L1 and L2, suggesting that negative valence, rather than positive, can facilitate semantic integration. This finding corroborates with one previous study (Moreno & Vázquez, 2011), and we ascribe this finding to the fact that affectively negative words could acquire repaid semantic access because of their significant survival significance. Consequently, late Chinese-English bilinguals appear to access and integrate semantic content more effortlessly when the emotional content is negative.

Interestingly, amplified N400 evoked by L1 emotion words relative to L2 emotion words was observed. This finding stands in contrast to our hypothesis, which assumed a more pronounced N400 in L2 due to greater semantic integration difficulty. Existing research on bilingual emotion research provides insights into interpreting this result. A study by Jończyk et al. (2016) revealed that bilinguals exhibited a more robust N400 effect in L1 than in L2 when tasked with processing sentences ending with emotion words. As previously stated, the context of language acquisition matters. Hence, affective connotations may become integrated into the lexical form of L1 words through a language embodiment process, whereas this integration may does not occur in the process of L2 acquisition. Given the nature of the LDT employed in the present study involving relatively shallower processing, late bilinguals might not effectively activate the semantic and emotional meanings of L2 words to the same extent as words in their native language during online processing. As a result, for late bilinguals, the lexical access to emotional words presented in a non-native language might not be fully completed at the early period of semantic integration (Jończyk et al., 2016). Importantly, unlike the typical way regarding N400 that indexes semantic integration difficulty, the marked N400 dissimilarities between L1 and L2 in this study might signify a shallower depth of word processing in the case of L2.

With regard to the LPC component, the results revealed that in L1, negative emotion-laden words elicited larger LPC than neutral words with a centro-parietal distribution. Conversely, the evoked LPC for neutral words and the other three groups of emotion words did not exhibit any significant disparities. LPC has been reported to be task-relevant and typically reflects late and deeper elaboration of focused information (Espuny et al., 2018). Our results suggest that negative emotion-laden words may bear a more working memory burden and cognitive overload compared to the other three groups of emotion words at the later processing stages. This is in consonance with the observed N170 difference between negative emotion-laden words and neutral words reported earlier in this study. Concerning the absent differences between neutral words and the other three types of emotion words, it might be due to the LDT involving no attention direction to words' emotional content, contributing to decreased or eliminated LPC emotion effect (Fischler & Bradley, 2006; Hinojosa et al., 2020a). Furthermore, the comparison among the four groups of emotion words showed that in L1, negative emotion words elicited enhanced LPC than positive words, corroborating the previous research on the effect of emotion word type (Jia et al., 2022; Liu, Fan, Tian, et al., 2022; J. Zhang et al., 2017). For example, Liu, Fan, Tian, et al. (2022) reported that L1 negative words evoked larger late LPC amplitudes than positive ones in an emotional categorization task. This finding might be interpreted from the view of density hypothesis (Unkelbach et al., 2008), according to which the negative words have a more discrete nature, thereby attracting more attention in the process of reevaluation in the late processing stages.

In terms of LPC results in L2, it was found that positive emotion-label words elicited comparable LPC with neutral words, and enhanced LPC than negative emotion-label words and positive emotion-laden words. However, the other three groups of emotion words elicited smaller LPC than neutral words. In contrast with our hypothesis, these results suggest that the processing of L2 positive emotion-label words may be more effortful, which might be attributed to the effect of "positivity offset" (D. Zhang et al., 2014). Concretely, our study revealed less allocation of attention to L2 positive emotion-label words in the early lexical processing stages, as indexed by decreased EPN. This diminished attention allocation may potentially enhance the elaboration of reevaluation, attention capture, or memory encoding in the later processing stages of L2. Therefore, more resources are dedicated to L2 positive emotion-label words and a larger LPC amplitude in response to them was observed. On the other hand, the decreased LPC for the other three types of emotion words relative to neutral words, may be an effect of delayed emotion modulation in the early semantic integration stages, indexed by absent N400 emotion effect in L2, which facilitates word processing in later processing stages. Nevertheless, this explanation remains tentative and calls for future validation.

Additionally, the overall LPC amplitude reported in this study was more prominent for L2 emotion words than for L1 emotion words, especially for the processing of positive words. Considering the previously reported smaller N400 amplitude in L2 compared to L1, this discrepancy may stem from the incomplete semantic access to L2 during the very early stages of semantic integration in late bilinguals. This incomplete access could, in turn, subsequently trigger more substantial reevaluation in the later processing stages, as evidenced by the larger LPC amplitudes of L2 emotion words. Last but not the least, it is argued that language proficiency may be a potential variable that would modulate emotion word processing (Velez-Uribe & Rosselli, 2021). In our study, late Chinese-English bilinguals are native Chinese speakers, and they are supposed to be highly proficient in L1. Considering their L2 proficiency, the results showed no significant modulation of L2 proficiency on the N170, EPN, N400 and LPC components reported in L2 in the present study.

Conclusion

This study compared the neural correlates in processing emotion-label and emotion-laden words in both L1 and L2 in late Chinese-English bilinguals. The findings demonstrated the presence of emotion effect in early lexical processing and highlighted dissimilar neural processing patterns for effects of emotion, and emotion type between L1 and L2. Specifically, the results suggested that in the early lexical processing stages, negative emotion-laden words in L1 and negative emotion-label words in L2 may be more readily perceived as conveying affective information. In addition, in both L1 and L2, positive emotion-label words appear to attract the least attentional resources, and access to emotion-laden words tend to engage additional resources compared to emotion-label words. In the late processing stages, the semantic integration of L1 positive emotion-laden words tend to require more processing effort. Furthermore, it is plausible that late bilingual speakers may have less complete access to the semantic and emotional contents of L2 emotion words compared to L1 emotion words. Altogether, results from this study suggest that emotion-label and emotion-laden words are represented differently in late bilinguals' L1 and L2 in both early and late processing stages. More importantly, L2 may not be as strongly grounded and embodied in emotional experiences as L1.

Disclosure statement

No potential conflict of interest was reported by the author.

Funding

This work was supported by the scholarship from China Scholarship Council (No. 201906060171).

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III

NEURAL CORRELATES OF EXPLICIT AND IMPLICIT PROCESSING OF EMOTION-LABEL VS. EMOTION-LADEN WORD IN L2: BEHAVIORAL AND ELECTROPHYSIOLOGICAL EVIDENCE

by

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