



REVIEW ARTICLE



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Emotional processing in bilinguals: a systematic review aimed at identifying future trends in neurolinguistics

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This review is one of the first studies to discuss the status of research on emotional processing in a healthy bilingual brain. Few articles about emotion and cognition coupling have examined how the bilingual brain differs in processing emotional stimuli from the monolingual brain in neuroimaging studies. Having diverse perspectives, tools, and methodologies in interdisciplinary research can help build our understanding of the connection between the mind, language, and emotions. This systematic review uses Moher et al., (2015) PRISMA-P to synthesize relevant publications. In this review study, we discuss common discrepancies, the techniques used to elicit data and the objectives of the emotion and cognition interaction in neuroimaging, psychophysiological and cognitive paradigms. Our findings suggest the focus of future research on simultaneous bilinguals, extended narratives instead of decontextualized stimuli and comparison of different modalities. We provide valuable insight for neurolinguistic researchers in regard to the various limitations in the existing literature that hinder the successful integration of emotion and language studies into the field of neurolinguistics.

Introduction

Emotions are a fundamental aspect of human characteristics, and they are intertwined with social meanings and shared public practices (Goodwin et al., 2012; Robillard et al., 2019). Emotional processing can be observed through instinctive facial body responses, countenance, and physiological and cognitive factors. How emotional stimuli are processed has been studied extensively by various disciplines, including physiology, cognitive science, and neuroscience. Altarriba (2013) emphasized the importance of psychological and linguistic factors in examining the affect-language interface. Hinojosa et al. (2019) conducted a systematic review of the neural basis of emotional processing during emotion-language comprehension. Still, it left the need to investigate how affective neurolinguistics might guide future trends in emotion-language interaction research in bilinguals.

Bilinguals outnumber monolinguals (Grosjean, 2010). First and second languages in bilingual speakers' brains frequently compete for emotional input, and research has shown that one language may supersede the other in eliciting emotions. Sometimes, bilinguals may even outperform monolingual peers in recognizing emotional inputs (Altarriba & Morier, 2004). With globalization leading to more diversified, multicultural societies and bilingual families, it has

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become crucial to investigate how emotional stimuli affect language processing in the bilingual brain.

The impact of bilingual experience on human behavior and neurological function has been extensively studied (Caldwell-Harris, 2014). However, more research is needed on how emotions are processed in the brain when a bilingual or multilingual individual receives verbal inputs that support emotional inducements. A substantial connection between cognitive control and overall L2 proficiency has been observed in various research. In late bilinguals, respective languages may be differentially embodied (Pavlenko, 2005). There is a significant connection between cognitive control and overall second language proficiency, and bilingualism enhances cognitive flexibility and communicative capacity. Additionally, bilingualism boosts cognitive reserves and productivity as people age (Bialystok et al., 2012).

Given the interdisciplinary nature of research on affective processing in bilinguals, studies might differ in stimuli, theoretical approaches, and techniques, leading to inconsistent findings regarding emotional processing. Moreover, publications on this topic may appear in different domains and journals, making it challenging to keep track of all the research. Therefore, this review aims to synthesize up-to-date findings on affective processing in healthy bilinguals across three paradigms: cognitive, psychophysiological, and neuroimaging. Further cross-disciplinary studies with different techniques and populations are necessary to advance our understanding of this complex topic. The goal is to lay out directions for future research in neuro-linguistics and investigate how advancements in the behavioral sciences can benefit research on neurolinguistics.

To limit the scope of this review, we focused on receptive language processing (reading and listening) and excluded studies on affective processing influencing language production and those on second-language learning and the emotion-language interface (DeDios-Stern & Ventura, 2021; Antia et al., 2021; Brouwer, 2021; Jones et al., 2021; Zarbafi, 2020; Corrêa et al., 2020; Cumbe et al., 2020; Bemath et al., 2020; Nidoo & Gokool, 2020; Ravaldi et al., 2020 and many others from 2010 to 2019).

Emotion and cognition. Emotion and cognition do not embody separate neurological systems; brain regions involved in emotional processing are also involved in cognition, and vice versa (Pessoa, 2008). Mondal (2022) conceptualizes the formal similarities between linguistic representations of emotion and perception for integrating perceptual and cognitive representations. According to Connell and Lynott (2014), cognitive representations are structures and schemas realized as collections of neural circuits essential for assessing things, events, and circumstances in the outside world. Hence, cognitive depictions incorporate experiences and ideas and can initiate again with the same experience beforehand, consequently affecting other neural functions. Perceptual and linguistic illustrations denote cognitive depictions coded and embodied in language and sensory systems; moreover, emotions are depicted in linguistic codes when expressed in language.

Meanwhile, the pertinence between emotions and perception can help reveal their characteristics and attributes. On the one hand, perception is frequently separated from the rest of cognition in a hefty portion of modern-day cognitive science. Conversely, Pessoa (2022) showed that perception and cognition have significant linkages and connections. The linguistic encoding of emotive representations plays a distinct part in elucidating trends of interactions between perception and cognition, provided that linguistically encoded representations of emotion are cognitive representations. These representations also exert a sensory character due to comparisons between emotion and

perception. The processing and referential dimensions in cognitive processes that regulate the computational complexity of attending to only pertinent points from within a quagmire of unnecessary detail in the perceptual surroundings can be better comprehended by studying differences across the perception and cognition continuum (Phelps, 2006). This process becomes challenging for bilinguals.

The ability to speak more than one language alters an individual's perspective and understanding of events occurring in their surroundings (Robinson & Altarriba, 2014). Bilingual brains are encoded with two languages: one language dominates the other one in most cases. By examining findings from reaction time, eye-tracking, functional magnetic resonance imaging, and event-related potential research, previous studies have investigated how language proficiency in one of two languages influences cognitive control and emotion, both of which are essential components of human interaction (Hinojosa et al., 2019; Hsu et al., 2015 and Imbault et al., 2021). We suggest that managing multiple languages has a profound effect not only on cognitive control and emotion separately but also on the interplay between the two. Language-cognition interaction is pertinent; the presence of two languages may drive different cognitive abilities. Processing and referential dimensions of cognition attend readily available linguistic codes on the threshold continuum (Paradis, 2004), such as responding to a stressful event becoming a different experience for bilinguals than monolinguals. Thus, examining the role of proficient and non-proficient linguistic codes guiding emotional perception becomes essential.

Emotion cognition and brain structures

Emotions affect various cognitive processes, including working memory, cognitive control, learning, episodic memory, decision-making, spontaneous thought, and attention (Todd et al., (2020)). An unpleasant emotional state can also reduce working memory, and individuals with depressive symptoms may have difficulty regulating their emotions effectively. Emotional arousal can enhance associative memories for features, colors, and location and lead to spontaneous thoughts and quick decisions without using rationale. Positive emotions involve a broadening of emotions.

Phelps (2006) suggests that animal neural models of emotion indicate that brain structures connected to emotional processes also heavily interrelate with other brain systems associated with cognition. One of these structures is the amygdala, an almond-shaped structure located in the medial temporal lobe next to the hippocampus. Klüver and Bucy (1937) proposed that lesions in the medial temporal lobe played a role in displaying odd behaviors while observing monkeys. Later, Weiskrantz (1956) demonstrated that damage to the amygdala within the medial temporal lobe caused various behaviors, known as Klüver-Bucy syndrome.

It is clear that the amygdala automatically processes emotions and can stimulate numerous cognitive functions. Research on animals has shown that specific subcortical pathways can detect emotion and alert the amygdala before the actual response. These findings suggest that emotions are processed before comprehension (Zajonc, 1984).

According to de Mendoza (2008), the amygdala can modify facial expressions in response to emotional words. Furthermore, task demands can also affect how the amygdala responds to social groupings defined by race (Kuchinke et al., 2005). This research highlights the importance of examining cognitive abilities to understand brain systems and emotion processing (Skrandies, 2011).

Methodology

We systematically reviewed the current literature to answer the following question:

RQ. How can current studies on bilingualism and emotion coupling investigated in multiple disciplines influence future research in neurolinguistics?

We further set the following objectives concerning this research question:

- To identify various recent advances assessing emotional processing in healthy bilinguals in psychophysiological, cognitive and neuroimaging research paradigms,
- To investigate the stimuli, the objectives and techniques used to assess emotion- language interaction in healthy bilinguals,
- To identify the gap for future research agenda for emotion and bilingualism in neurolinguistics.

Literature search and study selection. We followed a research strategy based on Moher et al., (2015) PRISMA-P checklist, using systematic and explicit methods. Our methodology included defining a search strategy, eligibility criteria, screening process, and plans for data synthesis. We collected administrative data such as title, publication date/year, authors, and introduction data, including study objectives, stimuli, sample/participants, and outcomes.

Search strategy. Initially, we queried the WorldCat database. We chose it because it is the most extensive database for all the research papers published in well-reputed journals indexed by Web of Science and Scopus. Then, we selected PubMed because it was needed in our area of interest. Neurolinguistics integrates the disciplines of Language and Neuroscience (purely medical), so we ensured that all the relevant studies to answer our questions were gathered published from 2010 to 2022, considering the recent developments and current focus of inquiries in other paradigms; the reason was to avoid the risk factor of suppressing our focus on neurolinguistics by relying too much on other paradigms.

Eligibility criteria. Guided by our research question, we selected only the research articles focused on emotion processing and cognition in bilinguals while perceiving a language and excluded the studies related to speech production or speaking abilities. The research articles about language disabilities were also excluded. We also excluded the affective studies employing introspective approaches and other review articles in behavioral research and emotion studies on foreign/second language learning investigating the role of emotions in language learning. Articles on inhibitory control were excluded to avoid excessive cognitive paradigms. Only memory recall studies were considered, as the given definition (pg# 10) described it as an essential component of the cognitive paradigm. We only selected the articles that implicitly and explicitly included the key terms (emotion, cognition/neuroscience, bilingualism). We set the search strings such as emotion, cognition and bilinguals; emotion, cognition and EEG; emotion, cognition and neuroimaging and emotion, neuroscience, and bilinguals.

Data and outcome articles. Two hundred ninety studies were gathered from the WorldCat database with the variable neuroscience and the 338 studies when neuroscience was replaced by cognition. Twenty-three studies were yielded on PubMed when neuroscience was used, and the variable cognition produced 105 results. The initial search yielded a total of 756 results. A careful screening excluded all the repeated articles, and 756 were reduced

to 457. Further screening after reading the titles excluded all the book chapters, review studies, the studies missing any one or all of the variables from the search strings, and studies about language disorders and acquired the refined number 122.

A detailed screening was done by reading abstracts and articles in detail. The articles explicitly addressing emotion-language coupling in bilinguals received further scrutiny. The articles with no primary focus on emotional processing or bilingualism were excluded. Hence, the final number scrutinized for the review was 37: 19 from the cognitive, 07 from psychophysiological and 11 from neuroimaging studies. A cross-check and review by the second author suggested 16 more articles to consider for the review because their contribution to investigating the answers to the current study's objectives seemed significant. These articles belonged to the introspective paradigm, executive functions and two review studies. Nevertheless, considering the exceeding word limit of the current review, we added only a table summarizing the findings of these 16 studies with various themes (Table 1). All in all, the total number of articles reviewed in this study was 53 (Fig. 1).

Data collection and coding process. The data was collected by a PhD scholar in neurolinguistics. The data was coded by hand, and an associate professor in applied linguistics cross-checked the initial screening. He also re-examined the detailed review and critical evaluation. The suggestions were considered and incorporated after discussing the reliability of the agreements and disagreements between them.

Review of different approaches

Psychophysiological approaches. Physiological measures can provide valuable insights into behaviour, cognition, and health interaction. One of the most commonly used approaches is the psychophysiological approach, which relies on physiological markers of autonomic arousal such as electrical conductivity of the skin, activation of smile or anger muscles, heart rate, and others (Palvenko, 2012).

Studies in the psychophysiological approach have focused on exploring the interaction between emotion and language cognition in late bilinguals. These studies examined emotional resonance through various techniques, such as comparing emotional response in self-report and psychophysiological arousal (Caldwell-Harris et al., (2011)), response in facial motor and skin conductance (Baumeister et al., 2017), galvanic skin response (Jankowiak & Korpala, 2018), pupil dilation (Toivo & Scheepers, 2019), and electrodermal activity (Grégoire & Greening, 2019). The findings of these studies suggest a consensus of reduced emotional resonance in L2. However, the reviewed research works utilized different stimuli, including listening to emotional phrases (Caldwell-Harris et al., (2011)), a stimuli corpus consisting of 345 words associated with the concept of happiness and anger (Baumeister et al., 2017), emotion-laden words in visual and auditory modalities (Jankowiak & Korpala, 2018), and high- versus low-arousing words in both L1 and L2 with lexical confounds such as length, frequency, emotional valence, and abstractness (Toivo & Scheepers, 2019).

These studies have concluded that there is weak emotional elicitation in L2; the main reason could be the less frequent use of L2 than L1 in its non-native setting. Late exposure to the second language requires an increased threshold to access L2 codes, resulting in reduced access of the cognitive set-up to emotional input in L2. Additionally, bilinguals in languages with the head-initial parameter (the head of a phrase precedes its complement) or vice versa may also drive emotional intensity differently than in languages with the same language-headedness parameter.

Table 1 A summary of the studies with different methodology in emotion cognition in bilinguals.

Sr #	Study	Focus	Technique/Task	Findings
1	Shin & Kim, 2017	Relationship between foreign language effects and psychological distance	Not mentioned	Reduced emotional response, deliberation of decisions and more ration of utilitarian decisions in L2
2	Hutchison et al., 2021	Factor structure, reliability and validity of emotion regulation questionnaire (ERQ) in Chinese and English language	Not mentioned	Both versions replicated the factor structure of original ERQ
3	Robinson & Altarriba, 2014	Reviews the ways in which emotion word types have been distinguished, and methodologies used to distinguish the types	A review paper	A review
4	Goshvarpour et al., (2019)	Evaluating and classifying emotions of mono-bilinguals	ECG & PR	the proposed methodology provided successful tools for discrimination of affective states
5	Stadthagen-González et al., 2018	Presenting norms for 10,491 Spanish words for five discrete emotion words	42 blocks with 249 and 250 words each	Show high rate of inter-rater reliability and confirm previous studies
6	Min & Schirmer, 2012	Integration of verbal & vocal emotional expression in speech is comparable or not when listeners are exposed to L1 & L2	Words were played over headphones	Similarity in the integration of verbal and vocal emotional expressions in L1 & L2
7	Matsumoto et al., (2008)	Bilinguals judge emotions of others differently	The Intercultural Adjustment Potential Scale	Participants judged emotions differently as a matter of language
8	Panayiotou, 2010	Verbal construction of emotions in bilinguals	Recording & transcription	Participants changed their social codes with the change in linguistic code.
9	Liu et al., 2022	Effects of L1 & L2 on decision making	Trials presented on a computer screen	More rational decision making in L2 high load negative condition
10	Weimer & Gasquoine, 2016	Measurement of belief reasoning & emotion understanding	Test questions and response	Balanced and unbalanced Bilinguals develop emotion understanding and belief reasoning similarly.
11	Gao et al., (2019)	Language-induced emotionality differences by presenting self-praising and criticizing statements	E-Prime 2.0 software	Criticism was rated more unpleasant than pleasant feelings of praising
12	Keysar et al., 2012	Decision making in L2	Bets appeared on computer screen	Foreign language provides greater cognitive and emotional distance.
13	Hayakawa et al., 2017	Foreign language affects moral choices	Process-dissociation task	Foreign language reduces deontological responding but does not increase utilitarian responding.
14	Ivaz et al., (2019)	Effects of foreign language on emotional response	Experiment Builder, version 1.10.1630 on a 19" cathode ray tube (CRT) screen	Smaller self-bias indicated emotional distance as necessary prerequisite in foreign language effects.
15	Abdolrezapour & Ghanbari, 2021	Implication of positive psychology to improve EFL learners' listening comprehension	1-h regular English lecture and 1-h PPI and the controlled group 2-h English lesson for six months	The experimental group experienced positive emotions more than twice as frequent as negative emotions
16	Wong et al., 2017	Perception of English connected speech under five adverse conditions:	Recorder using Open-source audio editing software Audacity (version 2.0.2) to reduce noise reduction	English native speech was recognized less under unfavourable conditions

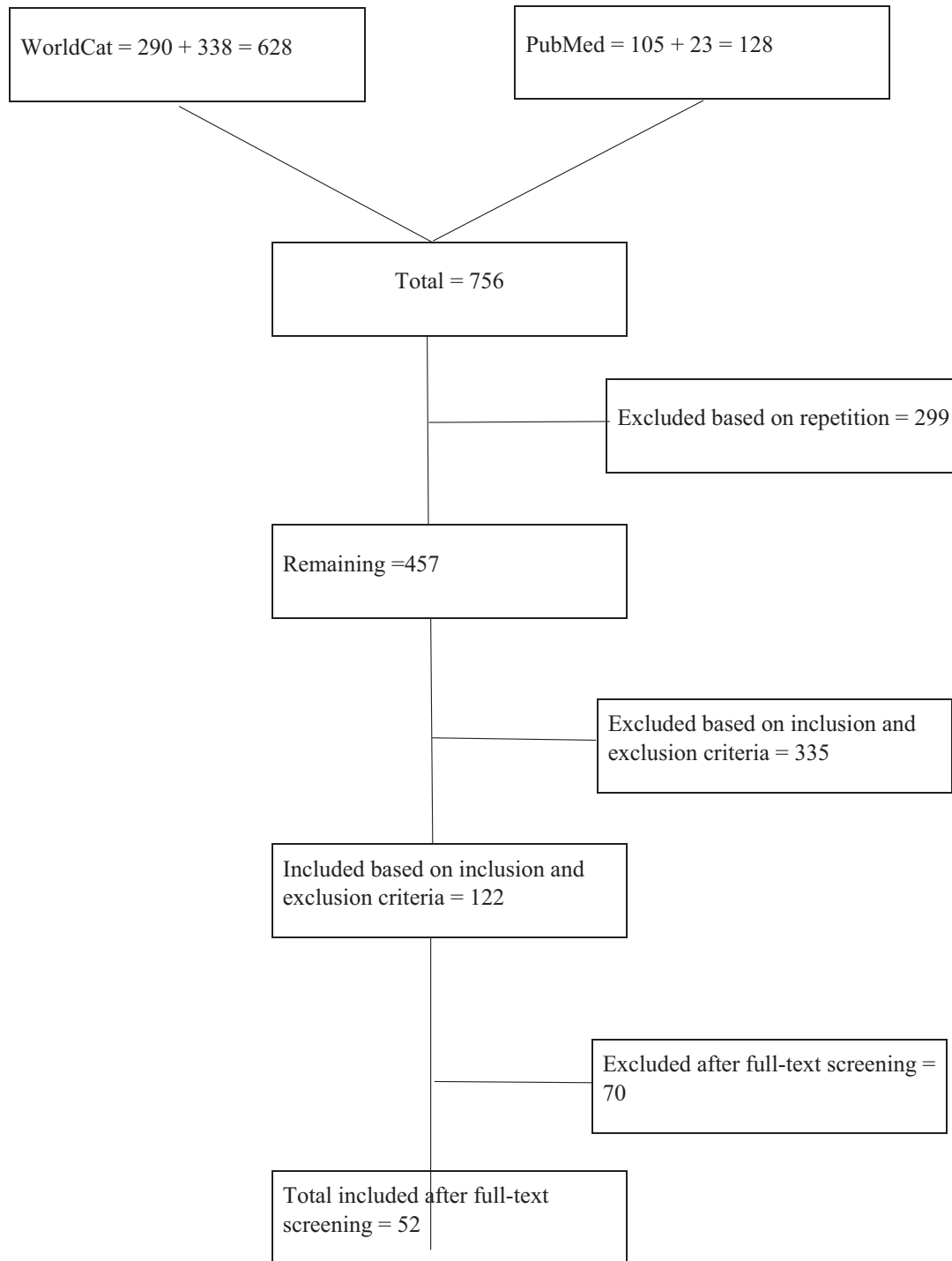


Fig. 1 An overview of search protocol based on PRISMA recommendation statement.

Examining this phenomenon with the same objectives and techniques but with different populations born and raised in different sociocultural settings is necessary.

Baumeister et al., 2017 study partially supported decreased facial motor and skin conductance responses to emotional words in L2. However, the study did not consider how different modalities and distinctions between emotion-laden and emotion-label words influence emotional response in L2. The study results of Jankowiak and Korpál (2018) suggested investigating the question that emotional processing may have been modulated by both language and modality, leaving the gap in their study with an unaddressed area of emotion-label narratives processing

emotions in bilinguals. Toivo & Scheepers, 2019 findings suggest that the results might have changed by changing the stimuli of single words with a cohesive narrative.

The section discusses the use of physiological measures in studying the interaction of behaviour, cognition, and health. The studies reviewed in this paragraph focus on emotion and language cognition interaction in late bilinguals. The studies utilized different stimuli and techniques to examine emotional responses in L2, which resulted in a consensus of reduced emotional resonance in L2. The studies suggest that reduced access of the cognitive set-up to emotional input in L2 might be the reason. The paragraph also highlights the need to examine this

phenomenon with different populations born and raised in different sociocultural settings and languages with different language-headedness parameters. The studies reviewed need to address specific areas of emotion-label narratives processing emotions in bilinguals.

Cognitive approach. The cognitive theory asserts that how we think guides our feelings and behaviors, encompassing memory, comprehension, motivation, and perception. This paradigm encompasses memory recall, congruence effects, and interference effects (Pavlenko, 2005).

Memory. Cognitive psychology research focuses on memory recall of emotional words in L1 and L2. Ferré et al. (2010) found that emotional words were recalled better than neutral words to a similar degree in both languages of bilinguals. It differed from a previous study by Ayçiçeği and Harris (2004), who observed greater recall of emotional words in L2. Ferré et al.'s Spanish-English bilinguals (2010) were mixed-context learners. They claimed that neither context of acquisition (CoA) nor typological distance and age of acquisition (AoA) reduced the recall of emotion words in L1 and L2. However, they did not control for the type of emotional words, such as positive, negative, and neutral, and mixed them up. Short- and long-term memory remained unaddressed variables in both studies.

Bridging this gap, Sun et al. (2018) used L2 emotional words in the context of pictures and associated monetary rewards and punishments with positive and negative emotions, respectively. The positive words and rewards were better recalled in short intervals, and punishment and negative emotions were more associated with long-term memory recall. The results could have been explained in terms of abstract and concrete nouns, which may have been a factor driving the results. The vital aspects of language proficiency and working memory interaction were explored in all three studies.

Ma et al. (2020) focused on the difference in emotional working memory by examining the performance of Chinese-English proficient vs non-proficient bilinguals on the delayed matching-to-sample task. Proficient bilinguals scored higher in matching sets of numbers (the emotional letter) to the letter displayed on the previous screen in an E (emotional) N-back test. In an N-back test, a sample letter appears first, and then the comparison set appears later on the screen; participants must match the emotional stimuli from the set of comparison stimuli to the sample stimuli. The findings supported the notion that proficient bilinguals may have an advantage in their cognitive abilities. The second language also has a significant role in decreasing and lowering negative emotions.

Jansson and Dylman (2021) investigated second-language effects on emotionality by examining experienced vividness. Emotionality was reduced when negative experiences were recalled in L1 and L2, whereas experience vividness was decreased only in the second language. Their findings contradict Dylman and Bjarta (2018), who observed increased distress when participants read and answered the negative text after reading in L1. It might be due to memory recall control in their study, so it becomes crucial to observe the associated experiences in future studies.

In conclusion, the recall of emotional words in bilinguals is a complex phenomenon affected by various factors such as emotional word type, short- and long-term memory, language proficiency, working memory, and the context of acquisition. While some studies suggest that emotional words are recalled better than neutral words in both L1 and L2, others suggest that emotional word recall may be influenced by the emotional

context in which they are presented. Additionally, language proficiency plays a significant role in emotional word recall, with proficient bilinguals performing better on emotional working memory tasks. Further research is needed to clarify the impact of these variables on emotional word recall and better understand the underlying mechanisms of emotional processing in bilinguals.

Congruence effects: affective priming. The processing of affective valence is observed when word/nonword match primes and targets in valence, and it is known as congruent because it is expected that congruent conditions, such as negative-negative, would produce faster reaction times. Congruence effects are examined in a lexical decision task.

Alvarado and Jameson (2011) concluded their study with a consensus of about 15 emotion terms, but they found a difference in terms of "shame" and "anguish." The results showed similarity in the structure of emotional space across highly diverse cultures, suggesting that the sociocultural setting may be less important than other factors, such as linguistic factors, which may lead to differences in emotional processing. These findings support the critical evaluation of psychophysiological approaches for the role of language headedness (the head of a phrase position concerning its complement) as more important.

Ponari et al. (2015) selected highly proficient bilinguals in their second language (English) to examine affective priming. The participants were of different ages of English acquisition and contexts of English language use and varied in frequency. The results indicated that the participants showed the same facilitation in processing emotionally valenced words as native English speakers, which contradicts previous studies concluding that the age of language acquisition affects affective processing. This finding suggests that affective processing is directly related to language proficiency and dominance and not to age of acquisition (AoA), the context of language learning (CoLL), frequency, or native language background, which directly affect language proficiency but not emotional processing.

El-Dakhs and Altarriba (2019) investigated this assumption by presenting auditory stimuli through classroom computers. They found that participants with increased L2 exposure outperformed non-proficient bilinguals in processing emotionally valenced content and emotional word types, which suggests that the context of language learning also affects emotional processing. Seniors who studied English as the mode of instruction for four years and used English for communication even outside the class outperformed Arabic students. The significance of sociolinguistic context to better understand the root of cognitive differences was attempted in the study of López et al. (2021) on a language brokering experience tied with L1 proficiency. Their study supported the theory of language embodiment (Palvenko, 2002), suggesting that low L1 proficiency coupled with negative feelings tied to language brokering experience moderated the Simon Task. These findings suggest that bilingualism with socio-contextual and socio-emotional language experiences induces differences in performance and emotional processing.

Imbault et al. (2021) investigated the priming effect using a large dataset of 2628 English valenced and arousal words. Their findings were consistent with previous studies (Ponari et al., 2015; El-Dakhs & Altarriba, 2019), and they argued that there is a significant relationship between word frequency and L2 proficiency. All three studies agreed on the time spent in the native language context. It is not a direct emotional processing factor; it somewhat improves language proficiency, which may influence emotional processing.

In Altarriba and Basnight-Brown's (2011) study, an affective Simon task was administered to both English-speaking monolinguals and Spanish-English bilinguals to investigate the

processing of valence and emotionality. The results indicated that bilinguals showed an advantage in congruency effects on negative emotions only, whereas both positive and negative emotion-laden words exhibited significant Simon effects. Additionally, Incera et al. (2020) found that bilinguals had an advantage in processing taboo words compared to neutral words, despite monolinguals outperforming bilinguals in emotional processing. However, it is worth noting that their study only used emotion-laden words, which may yield different results than emotion-label terms.

Morawetz et al. (2017) discovered an advantage of L2 in emotional regulation using images with content and emotion labelling. While there were differences in the stimuli used in these studies, the consistency in findings suggests the robustness of bilinguals' advantage in emotional regulation and less emotional processing. Kazanas and Altarriba (2016) suggested that this distinction of word types might be most pronounced in a person's dominant language. Their study on Spanish-English bilinguals found that negative words elicit emotions slower than positive ones.

Another study conducted by Bromberek-Dyzman (2021) investigated the difference in word type operation between two groups of bilinguals: Polish-English and Romanian-English. The results indicated facilitation for emotion-laden words (adjectives as chosen stimuli) in processing and established that the lexical proximity between two languages modulates affective responsiveness.

In order to confirm the results of these paradigms, further research on a comprehensive discourse consisting of strings of lines is necessary. It should be counter-checked with studies using neuroimaging techniques in the paradigm of neurolinguistics.

In conclusion, the processing of affective valence in bilinguals is a complex phenomenon influenced by various factors such as language proficiency, age of acquisition, frequency of language use, sociolinguistic context, and word type. Previous studies have yielded conflicting results regarding the effects of these factors on emotional processing in bilinguals. However, recent research suggests that language proficiency and dominance may be more crucial in affective processing than the age of acquisition or sociocultural context. Additionally, the type of emotional stimuli presented, whether emotion-laden words or emotion labels, may play a role in bilingual emotional processing. More research is needed to fully understand the complexities of affective processing in bilinguals and how different factors contribute to these processes.

Neuroimaging studies. Neuroimaging studies use functional magnetic resonance imaging (fMRI), positron emission tomography (PET), or event-related potential (ERP). Latencies measure the time course of processing, with shorter latencies indicating early processing. The letters N and P indicate the polarity of the component, with N indicating a negative peak and P denoting a positive peak, followed by a number suggesting a particular peak. N400 is observed during language comprehension for semantic processing and integration. The numerical value such as 100, 200, or 400 with N and P suggests that the responses are calculated at the peak value of 100, 200, or 400 ms.

EEG measures the brain's pro-electric activity caused by neurons' oscillation in response to emotional stimuli. Pavlenko (2005) reported that, until then, all neuroimaging studies of affective processing in bilinguals relied on ERP, trusting on early posterior negativity. A few studies published between 2015 and 2021 (Chen et al., 2015; Jeong et al., 2016; He et al., 2021) relied on fMRI or both fMRI and ERP. The ERP studies depended more on recording EEG than resting state EEG (Conrad et al., 2011; Sianipar et al., 2015; Jończyk, 2016; Vélez-Uribe, 2018; Vélez-Uribe & Rosselli, 2021; Sendek et al., 2021; Barker & Bialystok, 2019; Wu & Zhang, 2019).

Conrad et al. (2011) recorded the EEG of German-Spanish bilinguals to examine their sensitivity to their L2 by using decontextualized words. Results indicated no qualitative difference between positive and negative emotional stimuli, regardless of their L1 and L2. These findings were insufficient to establish a hypothesis about the role of L1 and L2 in emotional language cognition. So, another contribution came from Sianipar et al. (2015), who examined word processing effectively and semantically in L2 learners in four sessions employing a primed lexical decision paradigm spanning half a year of L2 learning. They observed improved sensitivity rates, accuracy rates, RTs, and N400 amplitude across sessions. The ERP data exhibited L2 valence effects more than neutral words across sessions. The findings also indicated a separate representation of the brain's semantic and affective processing. It also suggested that proficiency level in L2 affects semantic and affective processing of words or narratives in L2. All these studies addressed the affective cognition of balanced bilinguals.

A significant study finding was different language processing 'n balanced and unbalanced groups in both languages. Therefore, Vélez-Uribe (2018) investigated the effects of language proficiency in emotional content processing, comparing balanced and unbalanced Spanish-English bilinguals. The results of valence effects advantage over neutral words were consistent in both languages (Spanish and English) in balanced groups only. The Spanish unbalanced group showed a larger Latent Positive Complex (LPC) for positive than neutral and neutral than negative. Chen et al. (2015) found smaller Late Positive Complex (LPC) amplitudes for positive words compared to neutral words in L1 Spanish-English bilinguals. In a subsequent study, Vélez-Uribe and Rosselli (2021) compared balanced and unbalanced Spanish-English bilinguals and found that emotional words were processed more efficiently than neutral words, with the balanced group showing delayed ERP latencies for L2 emotional words and the unbalanced group showing shorter latencies for L2 emotional words. These findings suggest that language proficiency and the context of language learning and use may influence emotional word processing. Ma et al. (2020) reported similar results using a physiological paradigm, supporting the hypothesis of cognitive advantages for proficient bilinguals. However, cross-disciplinary studies using different techniques and populations are necessary to understand better the interaction between emotion, language, and cognition in bilinguals. Additionally, the role of language dominance should be examined to determine whether brain representation differs based on language dominance, regardless of the first language and other factors.

The studies discussed thus far only investigate emotional words; it remains unclear how different categories of emotional words, such as abstract and concrete affective words, emotion-label and emotion-laden words, and metaphorical and figurative words, affect bilinguals' emotional word processing. Wu and Zhang (2019) explored this question by examining the conflict processing of positive emotion-label and positive emotion-laden words in Chinese-English proficient bilinguals using a Flanker task. They found that positive emotion-laden words elicited different brain activations than positive emotion-label and neutral words. However, this study only investigated positive terms, and including negative words may yield different results. Furthermore, taboo words may also affect emotional word processing differently. Sendek et al. (2021) addressed this issue by using only taboo words in American and British English and found a significant difference in social threat perception between the two groups. However, the results may vary based on other contextual cues, such as pragmatic and motivational factors.

Barker and Bialystok (2019) investigated emotional and cognitive mechanisms using an n-back test to compare

monolinguals and bilinguals. They found that emotional distraction had a more significant effect on monolinguals than bilinguals. These results align with previous studies that have reported a bilingual advantage in affective processing across different paradigms (Baumeister et al., 2017; Jankowiak & Korpala, 2018; Ma et al., 2020; Sharif & Malik, 2022; Toivo & Scheepers, 2019). These findings provide a platform for future research to improve emotional discourse practices in therapy.

Wu and Zhang (2019) used positive emotion-label and positive emotion-laden words to investigate conflict processing in a Flanker task in Chinese-English bilinguals. They found that positive emotion-laden words elicited different brain activations than positive and neutral emotion-label words. These results were consistent with Bromberek-Dyzman et al. (2021), who investigated congruent effects using affective priming tasks. Chen et al. (2015) examined emotional processing using ERP and fMRI and reported a positive word processing advantage for neutral and negative words. In their study, the left superior frontal gyrus processed negative emotional words. Different brain activation patterns were involved in the reduced processing of positive emotional words in L1 and L2 (middle occipital gyrus and left cerebellum), revealing a complex picture of emotional word processing in bilinguals. Further investigation in this area may help neurosurgeons and physicians to decide on the brain areas engaged in emotional regulation to keep intact, considering patients' language dominance while removing tumours.

Jeong et al. (2016) examined the underlying neural mechanism involved in L2 communication vs L2 description, recruiting the left posterior supramarginal gyrus. The findings revealed that L2 communication was sensitive to oral proficiency and L2 anxiety, recruiting the left posterior supramarginal gyrus, indicating that L2 communication relies on social skills. Activation in the left middle temporal gyrus increased with L2 proficiency, and activation in the orbitofrontal cortex decreased as the L2 anxiety level increased. These results support the hypothesis of socio-cultural context involvement in the intersection of language, emotion and cognition. Further research in this area is required to improve foreign language teaching strategies and course design.

He et al. (2021) investigated the neural mechanisms underlying language and emotional interaction in decision-making during a gambling task. They observed avoidance mechanisms for negative feedback in L2 mediated by the dorsolateral prefrontal cortex and enhanced hippocampus activation for win feedback in L2. A significant limitation of the studies is their use of decontextualized stimuli consisting of only words. It calls for more research by adding extended narratives with different emotional valences.

Hsu et al. (2015) tried contrasting emotional responses to literary reading in L1 and L2 bilinguals with three emotional valences in an fMRI study. The study found that L1 bilinguals had a more robust hemodynamic response to 'happy' passages than neutral ones. Furthermore, it indicated that emotional processing was more substantial and differentiated in L1 than in L2, which was consistent with the findings of behavioural studies (Jankowiak & Korpala, 2018; Ma et al., 2020; Sharif & Malik, 2022). Jończyk et al. (2016) conducted a study in which Polish-English bilinguals and native English monolinguals were compared using

sentences that ended semantically and affectively with congruent and noncongruent adjectives. The study found that N400 amplitude was overall more negative in L1 than in L2 in bilinguals. In monolinguals, the N400 congruity affect appeared earlier at the onset, supporting previous results that negative information is suppressed in L2 at the earlier stage, thus requiring less evaluation at the later stage. Jończyk (2016) added a pragmatic twist to uncover differences in cortical activation to affective adjectives in L1 and L2 through an fMRI study. This study observed the difference between N400 and LPC modulations, indicating enhanced affective response in L1, which was again consistent with previous studies (Hsu et al., 2015; Jankowiak & Korpala, 2018; Ma et al., 2020; Sharif & Malik, 2022). These findings raise questions for multilingual and bilingual speakers raised in different social and cultural settings. Including and comparing different types of bilinguals and comparing bilinguals speaking languages with different Universal Grammar parameters will significantly contribute to the arena of affective neurolinguistics.

The studies reviewed in this text focus on the intersection of emotion, language, and cognition in bilingual individuals. They used various neuroimaging techniques, including fMRI and ERP, to investigate how language proficiency affects emotional word processing. The studies suggest that balanced bilinguals show better cognition for emotional words than neutral words, and language proficiency and context of language learning and use may influence emotional content processing. Additionally, studies have begun to explore how emotional words belonging to different categories, such as abstract and concrete affective words, emotion-label and emotion-laden words, and metaphorical and figurative words, affect cognitive processing in bilinguals. However, more cross-disciplinary research is needed to fully understand the complex relationship between emotion, language, and cognition in bilingual individuals. The studies reviewed here highlight the importance of examining language dominance and considering contextual cues in future research.

Discussion

In this section, we have discussed the findings summarized above to find precise answers to the objectives of this review study. The first four sections discuss research objectives one (Table 2) and two. Following these four sections, the last section lead to the final discussion on future works in bilingualism in neurolinguistics.

Language dominance to take over L1/L2 metaphor. The results demonstrate two distinct processing patterns: bilinguals outperforming monolinguals and proficient bilinguals displaying an advantage over non-proficient ones. These findings reveal two complementary patterns of interaction between emotion and cognition: L1 advantage in emotional processing and L2 advantage in emotional regulation. The L1 advantage is attributed to increased automaticity and more facilitation in emotional processing (Incera et al., 2020). Conversely, reading and processing a negative text in the L1 can increase distress (Dylman, Bjärtå (2019)). The parallel L2 advantage was found using L2 to decrease

Table 2 Summary of the reviewed literature answering the research objective 1.

Addressed factors	Gap
<ul style="list-style-type: none"> • L1 advantage over L2 in emotion processing • L2 advantage over L1 in emotion regulation • Bilinguals' advantage over monolinguals • Proficient bilinguals outperforming non-proficient bilinguals 	<ul style="list-style-type: none"> • Focus on language dominance • Same research by using different Modalities • Sequential and simultaneous bilinguals' performance in emotion processing

negative emotions (Tse & Pu, 2012). Reduced automaticity is believed to assist in emotional regulation, as demonstrated by decreased facial motor response and skin conductance response to emotional words in L2 (Baumeister et al., 2017), decreased Galvanic Skin Response (Jankowiak & Korpil, 2018), increased pupil dilation supporting reduced emotional resonance in L2 (Toivo & Scheepers, 2019), and reduced experienced vividness in L2 (Jansson & Dylman, 2021).

Bilinguals exhibit enhanced cognitive abilities that assist in reducing emotionality (Ferré et al., 2010). They demonstrate an advantage in congruency effects on negative emotions (Altarriba & Basnight-Brown, 2011), emotional regulation, and reduced automaticity (Morawetz et al., 2017). It is worth noting that trait anxiety decreases inhibitory control accuracy in bilinguals but not monolinguals (Ouzia et al., 2019). Monolinguals were observed to surpass bilinguals in detecting and identifying emotions (Incera et al., 2020).

Highly proficient bilinguals process emotions similarly to L1 speakers (Alvarado & Jameson, 2011), and proficient L2 learners outperform non-proficient bilinguals in processing emotions (Ponari et al., 2015; El-Dakhs & Altarriba, 2019). Additionally, bilinguals with native-like command process working memory better than less proficient ones (Ferré et al., 2010). An emotional word processing advantage has also been observed over neutral word processing (Ferré et al., 2010).

Psychophysiology and cognitive psychology studies agree that bilinguals outperform monolinguals in different cognitive tasks (Ferré et al., 2010; Altarriba & Basnight-Brown, 2011). L2 advantage is observed in reducing emotionality in decision-making tasks and regulating negative emotions to make rational choices. The language dominance of bilinguals can affect their moral dilemmas, as observed in the study by Ma et al. (2020). These findings suggest that stress should be shifted to language dominance, given that a person can be dominant in their L2 and not L1. The dominant language controls cognitive abilities. Hence, future research should rely on language dominance instead of the L1 and L2 debate (Table 2).

Considering the role of modality. Modality is another attention-demanding factor in research on the coupling between emotion and language. Modality refers to the sensory channel through which information is perceived or processed, such as visual, auditory, tactile, olfactory, or gustatory modalities. In language, modality refers to how information is expressed or communicated. For example, spoken language is an auditory modality, while sign language is a visual modality. In cognitive science, modality refers to the specific way in which information is processed, organized, and represented in the brain. It concerns how different modalities (e.g., visual, auditory, etc.) affect cognition and perception and how the brain integrates and processes information from different modalities.

Modality was identified as a limitation of the study conducted by Baumeister et al. (2017). Subsequently, only Ouzia et al. (2019) and Jankowiak & Korpil (2018) indicated that emotional processing might exhibit variation when examined using different modalities. However, due to the limited number of studies, further research is needed to confirm these findings.

Stimuli limitation. The reliance on single-word processing is a disadvantage in the studies documented above. Only Caldwell-Harris et al., (2011) utilized emotional phrases, Jankowiak and Korpil (2018) used emotion-laden narratives, and Hsu et al., (2015) included short passages from the Harry Potter books. Since these studies were limited in number, their findings cannot be generalized. Decontextualized single words elicit weak

emotions. In future research, there is a need to examine emotional processing using a cohesive discourse that represents a complete thought. Co-text, in interaction with context, evokes emotions within a naturalistic environment. The reason for neglecting emotion and cognition research is that it is challenging to simulate realistic interactions in the lab. The context can be manipulated using discourse with different modalities, such as pictorial or video representation.

Studies using emotion-label and emotion-laden stimuli are scarce, emphasizing the need for future work. Studies using valenced and arousal stimuli differ in their number and type of stimuli, lexical confounds, objectives, and methodological considerations (Altarriba & Basnight-Brown, 2011; Caldwell-Harris et al., (2011); Alvarado & Jameson, 2011; Toivo & Scheepers, 2019; Imbault et al., 2021). Therefore, their findings cannot be generalized. Also, inconsistent findings of memory-recall studies (Ferré et al., 2010; Ayçiçeği and Harris (2004)) indicate a broad spectrum for future research on stimulus types. It establishes the need for extensive research to establish a consensus-based theoretical foundation.

The findings discussed in these sections are from the paradigms of psychophysiological and cognitive studies, explaining that regardless of the stimuli used and their focus and population, they all investigated behavioural and physiological responses in the groups of L1 and L2. Cross-task neuroimaging studies should examine these processes with the same procedural characteristics to see whether they differ in findings or if the results remain the same. Few studies in recent works have taken up this area of inquiry, as summarized in the section on neuroimaging studies and discussed in the next section.

Neuroimaging from the perspective of neurolinguistics. The neuroimaging studies in this review addressed different questions. The studies included techniques of ERP and fMRI to obtain brain images during emotional processing. FMRI measures hemodynamic changes induced by regional changes in neural activity with high spatial resolution. These techniques help identify the brain regions activated during emotional processing. Electroencephalogram (EEG) in ERP studies measures electric signals with high temporal resolution. It calculates the potential generated by the neurons in the brain in response to an event (external stimuli).

Chen et al. (2015) addressed the factor of language dominance in emotion content processing in their study. This study sets a comparison between decontextualized positive emotional words and neutral words. It seeks attention from future researchers to investigate the role of language dominance in emotional processing in a possible naturalistic setting and by utilizing stimuli consisting of cohesive discourse and complete thought. Only one study tried to bridge the gap and used passages from literary reading to compare the processing of happy and neutral stimuli (Hsu et al., 2015). It concluded that there was a more robust hemodynamic response to happy words than neutral ones. Among all three paradigms, only one study compared balanced and unbalanced groups to examine emotional processing, and only one study compared balanced and unbalanced bilinguals in English and Spanish (Vélez-Urbe, 2018). More research is needed to investigate other languages to draw more conclusive results regarding emotional processing in the brain of balanced and unbalanced bilinguals. A much-needed area of inquiry is the processes underpinning emotion-language coupling and processing in the brain of balanced and unbalanced bilinguals.

Jeong et al. (2016) collected underlying neural mechanisms showing the effects of L2 proficiency and L2 anxiety in L2 communication compared to the L2 description. It highlights the

role of social skills in L2 communication. As stated above, L2 proficiency has been an essential key factor in examining neural processes in bilinguals, but this was the first study that focused on L2 anxiety to explore communication. It may produce significant results if set as a variable to address emotional processing in the bilingual brain.

All studies except one (Hsu et al., 2015) utilized isolated and decontextualized words to examine emotional processing in the brain. This major limitation calls for the dire need for future work to draw a comprehensive and detailed picture of brain functioning in bilinguals and language coupling processes by simulating the context in the lab. Only positive emotional words were compared with neutral words in all the summarized neuroimaging studies except Vélez-Urbe (2018). Arousal and emotional word types have been neglected except in the study of Wu and Zhang (2019), who utilized both positive emotion-label and positive emotion-laden words and concluded that emotion-laden words elicited different brain area activation. It conforms to the results of studies in other psychological paradigms, indicating that emotion-laden words show different physiological signs in emotion cognition. Neuroimaging studies need to examine the phenomenon under discussion by utilizing emotion-laden narratives.

A journey in neuroimaging studies through a microscopic lens revealed the need to read brain images of emotional processing with the theoretical perspectives of neurolinguistics. The vast gap drawn here confirms that affective neurolinguistics needs more attention from bilingualism and neuroscience, integrating their theoretical and methodological considerations to draw more conclusive results. Neuroimaging studies in emotional processing in bilinguals need to adopt the stimuli utilized in other psychological paradigms and broaden their research spectrum, benefiting from the gaps in those paradigms as indicated above. It will help academics and stakeholders design a better curriculum and provide better teaching and learning content, techniques, and environments focused on emotion cognition in L2 to gain native-like command.

Summary and future work recommendations

The most robust results on emotional processing in bilinguals across all three paradigms have been obtained with single words, mainly valenced ones, compared to neutrals, taboo words, and aversive words. However, we argue that emotional processing based on a single word is not convincing since language is not processed merely as a single decontextualized word, registered individually. Words in their co-text, pragmatic contexts, such as intentionality and relevance, social skills, previous experiences, and cultural usage, are hypothesized to produce visible effects in eliciting emotions. Appropriate identification patterns are not acquired by age; attributing affective qualities to verbal stimuli of words and narratives depends on proficiency in the language. All studies compiled in this review had participants with L1 as their dominant language, producing automaticity of emotional processing in L1 instead of L2. Therefore, future research in neurolinguistics focusing on language in context should primarily focus on language dominance rather than L1. It is because the ability to make cognitive judgments, the interplay of individual socialization skills, and language ideologies are the factors underpinning language dominance.

All the psychophysiological, cognitive, and neuroimaging studies reviewed here selected sequential bilinguals as their subjects of inquiry without describing any difference between the performance of simultaneous and sequential bilinguals. Therefore, future research in emotional processing in neurolinguistic bilinguals should focus on this aspect. We hypothesize that L2 may become the dominant language of a sequential bilingual,

depending on social and linguistic exposure. Thus, future research should examine questions such as whether sequential bilinguals with L2 dominance outperform simultaneous bilinguals with L2 dominance, whether sequential bilinguals with L1 dominance show any difference from simultaneous bilinguals with dominance in L1 in affective processing, and whether overall language dominance matters in emotional processing, overcoming the differences in simultaneous and sequential bilinguals.

In summary, the studies on emotion-label/emotion-laden words and valenced attributes reviewed above do not describe any underlying processes driving the differences in emotional processing. These processes may be further affected by replacing single-word stimuli with cohesive narratives, configuring them with parallel linguistic processes, simulating the lab's context, the role of language dominance, and the difference between simultaneous and sequential bilinguals. Working on this broad canvas of multiple pitfalls will help neurolinguistics evolve from infancy to maturity.

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Competing interests

The authors declare no competing interests.

Ethical approval

The research did not require any ethical approval as it did not include human participants.

Informed consent

The informed consent was irrelevant as the research did not include any human participants.

Additional information

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