Second Language Embodied Cognition: Automatic Activation or Native Language Mediation?

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Abstract

Embodied language cognition emphasizes that language processing is not merely the internal representation of purely abstract symbols; rather, the body and environment also play important roles. Most existing research has originated from the native language (L1) domain, and whether this effect exists in second language (L2) cognition and its underlying mechanism remain controversial. Based on a summary of evidence for the existence of L2 embodied effects from behavioral and neuroelectrophysiological perspectives, combined with related research, we propose two hypotheses—"automatic activation" and "native language mediation" —and analyze and evaluate the advantages, disadvantages, and influencing factors of these two hypotheses. Finally, we discuss existing problems in this field and provide prospects for future research directions, hoping to contribute to refining the theory of embodied language cognition, enhancing understanding of bilingual representation mechanisms, and effectively improving L2 instruction.

Full Text

The Embodied Cognition Effect in Second Language: Automatic Activation or Native Language Mediation?

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Abstract: Embodied language cognition emphasizes that language processing is not merely an internal representation of purely abstract symbols; rather, the body and environment play crucial roles as well. While most evidence for this effect comes from the first language (L1) domain, whether such an effect exists in second language (L2) cognition and its underlying mechanisms remain controversial. After summarizing behavioral and neurophysiological evidence for L2 embodiment effects, we propose two hypotheses— "automatic activation" and "native language mediation" —and analyze the advantages, disadvantages,

and influencing factors of each. Finally, we discuss existing problems in this field and outline future research directions, hoping to enrich the theory of embodied language cognition, enhance understanding of bilingual representation mechanisms, and effectively improve L2 teaching.

Keywords: embodied cognition, automatic activation, native language mediation, L2 processing
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Recently, embodied language cognition has attracted widespread attention and interest in academia. This perspective holds that language processing is not a purely cognitive activity based entirely on abstract symbols; rather, sensory, emotional, and motor neural systems, bodily states, and physical environments play important roles. Processing language related to perception and action activates brain regions involved in perception and motor control, meaning that language processing is grounded in action and perception. Current evidence for embodied cognition effects primarily comes from the L1 domain, with relatively few studies on L2. Is the embodied cognition effect universal across languages? Does L2 cognition exhibit embodiment effects? What differences exist between embodiment effects in L2 and L1? Is embodied cognition theory, constructed based on L1, applicable to L2 processing? This paper aims to analyze and summarize existing L2 embodied cognition research to address these questions, hoping to reveal L2 representation and processing mechanisms and improve L2 teaching.

1.1 Behavioral Evidence for L2 Embodied Cognition Effects

Using a picture-word matching paradigm, Bergen et al. (2010) examined performance in English lexical cognition among native English speakers and L2 English learners. Results showed that participants' reaction times were significantly faster in picture-word matching conditions than in mismatching conditions, with both L1 and L2 speakers showing similar behavioral patterns. Based on these findings, the researchers argued that both groups activated corresponding sensorimotor systems during verb comprehension. In another study with Italian-English bilinguals (Buccino et al., 2017), researchers employed a go/no-go paradigm. In the go task, participants were presented with English words and pictures of graspable or non-graspable objects as stimuli (meaningful stimuli in go conditions, meaningless stimuli like "pseudowords" or scrambled line pictures in no-go conditions). Results showed that in go conditions, participants' responses were significantly slower when processing words and pictures representing graspable objects. This occurred because performing hand actions and processing target stimuli activated the same sensorimotor system, competing for cognitive resources and thus slowing lexical decision responses.

Dudschig et al. (2014) used a vertical Stroop paradigm, asking participants to respond to the colors of words containing upward/downward spatial or positive/negative emotional information. Results revealed that when the spatial

orientation or emotional valence of words matched participants' response direction (e.g., pressing an upper response key for "star" or "happy" words), both L1 German speakers and L2 English speakers responded faster, demonstrating clear embodiment effects. L2 embodiment effects are not limited to motion-related words; abstract words such as time, emotion, power, and morality show similar effects. Using L1 German speakers and L2 German learners (whose L1s contained spatial words similar to or different from German, such as English or Turkish), Ahlberg et al. (2018) employed a modified Stroop paradigm where participants made upward or downward hand movements based on the color of German spatial prepositions (e.g., *auf* "on," *über* "above," and *unter* "under/below"). Both groups showed significant compatibility effects, indicating that L2 German learners also recruited corresponding perceptual experiences when processing German spatial prepositions.

Wang (2016) examined Chinese-English bilinguals processing power-related English and Chinese words, finding similar compatibility effects between power magnitude and spatial location in L2 learners. Feng and Zhou (2019) used a cue-priming paradigm to examine how priming cues affected the processing of high- and low-embodiment verbs. Results showed that at short stimulus onset asynchrony (SOA), priming cues only interfered with high-embodiment verb processing, but at long SOA, cues facilitated processing of both high- and low-embodiment verbs. However, this effect was primarily observed in high-proficiency L2 learners, with no effect found in low-proficiency learners. Beyond concrete nouns and verbs, abstract words such as emotion also show embodiment effects. Shen et al. (2014) used a spatial priming paradigm to investigate whether spatial information is activated during L2 emotional concept comprehension (spatial metaphor in emotion processing). Results showed that across languages and modalities, emotional word processing was influenced by spatial orientation, with L2 emotion words showing spatial metaphors in both single- and cross-modal conditions.

Given that most previous research used isolated single words as experimental materials, limiting ecological validity, some studies have adopted more ecologically valid sentences or texts to investigate L2 embodiment effects. Vukovic and Williams (2014) had Dutch L1 speakers and English L2 learners listen to English sentences describing spatial distances (e.g., "On the plate in front of you, you can see a bone" vs. "On the plate at the far end of the table, you can see a bone"). After hearing each sentence, the described object was presented at near or far distances, with near descriptions corresponding to large objects and far descriptions to small objects. Results showed that reaction times were significantly longer in mismatching conditions (near description with small object or far description with large object) than in matching conditions. Sheikh and Titone (2015) used eye-tracking technology to examine embodiment effects in natural reading of L2 emotion words among French-English bilinguals. Participants read sentences containing target words with different emotional valences (positive, negative, neutral). Unlike L1 emotion word processing, they found that L2 positive emotion words were processed faster than neutral words only

in first-pass reading time measures. Based on this, the researchers argued that L2 emotion word processing shows only partial emotional embodiment effects, a conclusion supported by Foroni (2015).

L1 research indicates that bodily simulation automatically and unconsciously participates in emotion word cognition (Fan et al., 2018). Does similar bodily simulation exist in L2 emotional language comprehension? To investigate this, Foroni presented participants with emotion-describing sentences while recording facial muscle activity with electromyography. Sentences described emotions that directly (e.g., "I am smiling") or indirectly (e.g., "I am frowning") corresponded to zygomatic muscle activity. Results similar to L1 cognition were obtained: when reading sentences describing positive emotions related to muscle activity, zygomatic muscles showed significant activation, though no similar effect was found for negative emotion materials.

1.2 Neurophysiological Evidence for L2 Embodied Cognition Effects

Although L2 embodiment effects have received partial support from behavioral studies, some experiments or conditions have failed to find these effects. To further investigate whether these effects exist and their neurophysiological basis, some scholars have employed neurophysiological techniques. de Grauwe et al. (2014) first used functional magnetic resonance imaging (fMRI) to examine brain activation patterns in German (L1)-Dutch (L2) bilinguals. Participants performed lexical decisions on Dutch materials including cognate verbs (present in both languages) and non-cognate verbs. Region-of-interest and whole-brain analyses showed that regardless of cognate status, both groups showed significant activation in motor and somatosensory brain regions when processing simple motion-related verbs. Based on this, the researchers argued that L2 cognition can exhibit embodiment effects similar to L1. Moreover, the degree of motor brain region activation was also influenced by language abstractness and proficiency (Tian et al., 2020).

L1 research has found that words frequently interacting with the body are easier to process, a phenomenon known as the Body-Object Interaction (BOI) effect. This occurs because objects establish connections with somatosensory systems and corresponding brain regions during interaction; when words representing these objects appear, the corresponding somatosensory systems and brain regions are easily activated. Does the BOI effect also exist in L2 cognition? Xue et al. (2015) manipulated the richness of sensorimotor context in sentences and the magnitude of BOI effects in target words, creating four types of English sentences for Chinese-English bilinguals to judge for semantic plausibility. Event-related potential (ERP) results showed that sensorimotor context facilitated BOI word processing, as evidenced by stronger N400 in frontal, central-parietal, and occipital regions for high sensorimotor context/low BOI word conditions, and significant P200 effects in sensorimotor brain regions. These results suggest that sensorimotor context facilitates L2 BOI word processing and that processing behavior- and perception-related language can activate sensorimotor systems

and brain regions.

Two recent electroencephalography (EEG) studies found similar effects. Using a priming-probe paradigm with neural oscillation desynchronization as an index of somatosensory-motor cortex activation, Vukovic and Shtyrov (2014) examined the involvement of sensorimotor cortex in L2 processing among German (L1)-English (L2) bilinguals. Results showed language-motor coupling effects as early as 150ms after stimulus presentation. Although the effect strength was less pronounced than in L1, it still indicated that somatosensory-motor cortex participates in L2 processing. Similar results were found in Birba et al. (2020). To enhance ecological validity, researchers had Spanish (L1)-English (L2) bilinguals read naturally occurring narrative texts describing action behaviors under relatively natural conditions, then performed functional connectivity analysis on collected EEG signals using spatial clustering. Results showed that compared to texts describing non-action behaviors, L1 readers showed enhanced connectivity between left and right hemisphere electrodes in central-parietal regions when reading action-describing texts, while L2 readers did not show similar patterns. However, correlation analysis revealed that connection strength in motor cortex-related regions was positively correlated with L2 proficiency and negatively correlated with L2 acquisition age, suggesting that sensorimotor systems and brain regions participate in L2 motion language processing to some extent.

Despite substantial behavioral and neurophysiological evidence confirming L2 embodied cognition effects, some research suggests L2 cognition is "disembodied." The framing effect is a common cognitive bias in L1 decision-making, primarily caused by the interaction between systematic rational analysis of decision materials and decision-makers' intuitive and emotional experiences during the decision process. However, Keysar et al. (2012) found the disappearance of this framing effect in L2 contexts, leading researchers to argue that high cognitive load in L2 cognition and the disembodied nature of L2 emotional representation are the main reasons for the disappearance of decision biases. Additionally, Foroni' s research on emotion word processing in affirmative and negative contexts found that L2 and L1 showed similar embodiment effects in affirmative contexts, but L2 emotion word processing showed disembodied effects in negative contexts. Sheikh and Titone found similar effects in negative emotion word processing, arguing that compared to positive emotion words, negative emotion words lack sufficient opportunities for embodied experience, thus showing more disembodied characteristics in processing. Wang et al. (2017) used a vertical Stroop paradigm to examine embodiment effects in spatial word processing among high-proficiency L2 learners, finding weak connections between L2 word processing and spatial responses, with less obvious motor response activation than in L1 word processing. Based on this, they argued that L2 spatial word processing does not evoke corresponding sensorimotor system participation.

Current explanations for the lack of embodiment effects in L2 cognition mainly include two perspectives. One view holds that L2 representation is less refined and profound than L1, with a "gap" between L2 symbols and their referents,

like an relationship between "oil" and "water" that is difficult to integrate. The other view suggests that due to proficiency issues, L2 symbol processing consumes more cognitive resources, leaving bilingual individuals with insufficient resources to activate embodied information such as sensorimotor systems (Keysar et al., 2012). Of course, processing tasks also affect the manifestation of L2 embodiment effects. A recent study on spatial metaphor effects in L2 time word processing found that low-proficiency L2 learners showed clear embodiment effects in semantic category tasks (SCT) but not in lexical decision tasks (LDT) (He & Bai, under review).

2 Mechanisms and Influencing Factors of L2 Embodied Cognition Effects

Although numerous studies have confirmed the existence of L2 embodiment effects, the cognitive mechanisms underlying these effects remain unclear. Some research suggests that L2 embodiment effects occur similarly to L1 (Ahlberg et al., 2018; Dudschig et al., 2014; Vukovic & Shtyrov, 2014), with language symbol manipulation and lexical semantic access directly triggering activation of corresponding brain regions and motor systems. This process is spontaneous and unconscious, which we term the Automatic Activation Theory (AAT). Other research argues that embodiment effects in L2 cognition are not direct effects of L2 processing but rather results of L1 activation during L2 processing (Ahlberg et al., 2018). That is, L2 embodiment effects are mediated by L1 activation, a hypothesis we call the Native Language Mediated Theory (NMT).

2.1 Automatic Activation: How Is It Possible? Evidence for automatic activation of L2 embodiment effects primarily comes from unconscious processing tasks. The theoretical assumption of these tasks is that if participants show embodiment effects without accessing L2 semantics, the effect occurs automatically. Dudschig et al. (2014) used a vertical Stroop task where participants only responded to word colors while ignoring word meaning. Results showed significant embodiment effects for both spatial and emotion words. To further confirm that L2 embodiment effects result from automatic activation rather than L1 mediation, researchers compared the time courses of L1 and L2 embodiment effects. If L2 embodiment effects were based on L1, they should lag behind L1 effects, but analyses showed no significant differences in onset times between L1 and L2 effects, with both showing high synchrony. Therefore, the study concluded that L2 embodiment effects are automatic.

de Grauwe et al. (2014) used fMRI to examine brain activation patterns in German (L1)-Dutch (L2) bilinguals during lexical decision tasks. Materials included cognate verbs present in both languages and non-cognate verbs. Region-of-interest and whole-brain analyses showed that regardless of cognate status, both groups showed similar activation patterns in motor and somatosensory brain regions when processing motion-related verbs. Based on this, the researchers argued that L2 embodiment effects represent the effect of L2 processing itself

rather than L1 cognitive transfer.

However, this conclusion remains questionable. First, most studies supporting automatic activation of L2 embodiment effects use unconscious processing tasks that require participants to focus on physical properties while ignoring semantic factors. But can participants effectively avoid L2 semantic activation in such paradigms? If the paradigm cannot effectively prevent L2 semantic activation, L1 semantics would necessarily be activated simultaneously, as numerous studies show that both languages are activated simultaneously during bilingual language processing. For example, the Revised Hierarchical Model (RHM) (Wu & Juffs, 2018) proposes that bilinguals have separate lexical representation systems for each language but share semantic representations. The Bilingual Interactive Activation Plus model (BIA+) further suggests that lexical representations of both languages are organically integrated to some extent (Lauro & Schwartz, 2017; Monaco et al., 2019).

Second, evidence for automatic activation of embodiment effects primarily comes from L1 research. Recent studies using time-locked neurophysiological techniques such as EEG, magnetoencephalography (MEG), and transcranial magnetic stimulation (TMS) have examined embodiment effects across visual, auditory, and olfactory channels, finding that 80-170ms after language stimulus presentation, somatosensory and sensorimotor cortices related to olfactory and motor language stimuli show significant activation even when participants are not attending to language stimuli but processing non-linguistic tasks (Xue et al., 2014). What causes automatic activation of sensorimotor cortex? The Immersed Experiencer Framework (IEF) (Adams, 2016) suggests that L1 acquisition and use occur primarily in real environments, with language symbols and their described objects, entities, or actions forming close connections that constitute an integrated experiential representation in the human brain. Therefore, when encountering language symbols, corresponding experiential representations are automatically activated, facilitating language processing. However, L2 acquisition occurs more often in classroom or relatively artificial environments, where learners perform more internal mental operations, and language symbols lack direct perceptual connections with the objects, events, or actions they describe, not forming a complete mental representation. Consequently, L2 embodiment effects are more likely based on simulation of concepts or mental images formed through language description.

Third, if L2 embodiment effects do show automatic activation, they should be influenced by L2 proficiency and age of acquisition (AOA). That is, for early, high-proficiency L2 learners, automatic embodiment effects may be more pronounced, while late, low-proficiency learners may need to rely on L1 to achieve these effects. According to the Revised Hierarchical Model, the connection strength between L2 words and their conceptual representations is modulated by L2 proficiency. For low-proficiency L2 learners, the weak association between words and conceptual representations requires L1 mediation for effective activation and access, while high-proficiency learners can directly activate and access

conceptual representations from words.

2.2 Native Language Mediation: How Does It Fare? Early evidence for native language mediation theory came from Vukovic and Williams (2014). As described in Section 1.1, researchers auditorily presented Dutch L1 speakers and English L2 learners with English sentences describing objects at different distances, embedding homophonic heterographs shared by both languages (e.g., English "bone" sounds similar to Dutch "boon" [beans]/bo:n/). Results showed that even when object size matched sentence-described distance, participants' reaction times significantly increased if the object mentioned in the L2 sentence had a homophonic heterograph in L1. This was interpreted as participants automatically simulating perceptual features from L1 homophonic heterographs during L2 processing. Therefore, the researchers argued that L2 embodiment effects result from automatic activation of L1 experiences.

Ahlberg et al. (2018) supported this view in their study of spatial prepositions, arguing that L2 processing automatically activates mental experience traces formed during L1 acquisition, and that activation of these traces facilitates L2 embodiment effects. If L2 embodiment effects are indeed mediated by L1, they should lag behind L1 effects in time. Baumeister et al. (2017) confirmed this hypothesis using neurophysiological techniques. The experiment consisted of encoding and retrieval phases. In the encoding phase, participants performed categorical judgments based on word emotional valence; in the retrieval phase, they judged whether words had been studied. An MP150 system recorded zygomatic and corrugator muscle electromyography (EMG) and skin conductance (SC). Results showed that EMG and SC responses were weaker during L2 than L1 emotion word processing, indicating differences between L1 and L2 embodiment effects. More importantly, comparison of zygomatic EMG showed that neural signals evoked by L2 emotion words lagged behind those evoked by L1 and lasted for shorter durations.

Analysis suggests that "differences in intensity and onset time between L1 and L2 embodiment effects" form the main foundation of native language mediation theory. Although this foundation has received empirical support, it remains questionable. First, the weaker intensity of L2 embodiment effects could result from either L1 mediation or simply lower L2 proficiency, as these factors are difficult to separate. Research shows that language proficiency positively correlates with embodiment effects (Bergen et al., 2010; Sheikh & Titone, 2015). For L1, rich language experience leads to more refined, profound, and comprehensive representations, where language symbols, their referents, and acquisition environments easily form an integrated whole in the brain. Therefore, minimal language cues can activate complete representations in L1 processing, producing strong embodiment effects. However, for L2, especially low-proficiency L2, representations are more abstract, with referents and acquisition environments dissociated from language symbols, resulting in weaker L2 embodiment effects.

Second, the temporal lag of L2 embodiment effects behind L1 does not necessar-

ily indicate native language mediation. Age of acquisition (AOA) and learning method may cause this phenomenon. L1 is acquired early, often through immersion, making its knowledge representation more like procedural knowledge, which relies on prefrontal cortex, inferior frontal gyrus, and basal ganglia, giving L1 retrieval and processing distinct "implicit" and "automatic" characteristics. L2, acquired later and primarily in classroom settings, resembles declarative knowledge, relying on medial temporal lobe and prefrontal cortex for "explicit" and "conscious" semantic extraction and processing (Chen & Caldwell-Harris, 2019; He, 2015). Due to differences in knowledge representation forms and brain regions between L1 and L2 semantic knowledge, L2 semantic access and extraction lag behind L1, making the temporal lag of embodiment effects understandable.

Third, native language mediation is a hypothesis built upon the Non-Selective Access Theory (NSAT) of bilingual processing. According to NSAT, bilinguals' two languages interact and activate in parallel during language processing (Lauro & Schwartz, 2017; Wu et al., 2013). However, whether parallel activation exists remains controversial. Early Selective Access Theory (SAT) argued that bilinguals' languages are independently represented and activated separately (Boudelaa, 2018). Recent research suggests that mental lexicon activation and access in bilinguals is not static but a dynamic language "continuum," where selective activation of one language or parallel activation of multiple languages depends on bilingual experience, task demands, and processing time (Morales et al., 2016). If so, the foundation of native language mediation theory is challenged.

3 Problems and Future Directions

Currently, research on L2 embodiment effects is still in its infancy both domestically and internationally. Although researchers have investigated manifestations, mechanisms, and influencing factors of L2 embodiment effects and obtained valuable conclusions, many issues remain to be addressed.

First, whether sensorimotor systems truly participate in L2 cognitive processing remains debated (Monaco et al., 2019). Due to differences in L2 acquisition time, method, and proficiency compared to L1, L2 lexical-semantic representations are less refined than L1, and connections between L2 words and sensorimotor systems are weaker than in L1. Therefore, some research suggests that L2 (especially low-proficiency L2) cognitive processing is "disembodied" (Pavlenko & Aneta, 2017). Studies using clinical, introspective, behavioral, and neurophysiological techniques with L2 learners have examined emotional semantics (Hsu et al., 2010), taboo word processing (Sulpizio et al., 2019), autobiographical memory (Pavlenko et al., 2017), cognitive decision-making, and moral judgment (Keysar et al., 2012). Results show that L2 participants exhibit more "disembodied cognition" in automatic coupling of emotional semantics, emotional involvement, autobiographical memory activation detail, and decision-making framing effects—they respond and judge more based on abstract language sym-

bol systems and are less influenced by embodied factors such as event contexts and personal life experiences.

Nevertheless, we argue that these findings cannot serve as effective evidence against L2 embodiment effects, as embodiment effects are not "all-or-none" (Tian et al., 2020) but should be considered a "continuum" process. Due to differences in L2 acquisition method, time, and proficiency compared to L1, L2 embodiment effects may lie at the beginning of this continuum, thus differing from L1 in intensity and manifestation. Additionally, L1 research shows bidirectional relationships between language cognition and embodied cognition: language cognition involves activation and participation of sensorimotor systems and embodied experiences, while pre-activation of sensorimotor systems and corresponding embodied experiences facilitates language cognition (Marmolejo-Ramos et al., 2020). Based on this, if embodiment effects are indeed intrinsic properties of L2 cognition, pre-activation of sensorimotor systems, emotional experiences, or contextual experiences should facilitate L2 cognition—a hypothesis awaiting future verification.

Second, automatic activation and native language mediation are the two main explanatory tendencies for L2 embodiment effects. While both theories have some validity, which provides more universal explanation remains uncertain. A key criterion for distinguishing the two theories is the onset time of L2 embodiment effects. Automatic activation theory posits that L1 and L2 embodiment effects occur synchronously, while native language mediation hypothesis argues that L2 embodiment effects should lag behind L1. To date, two studies have compared the time courses of L1 and L2 embodiment effects (Baumeister et al., 2017; Dudschig et al., 2014; Gianelli et al., 2020), both finding high synchrony between L1 and L2 effects, favoring automatic activation theory. However, participants supporting automatic activation theory were all high-proficiency L2 learners whose L2 representations were similar to L1, allowing direct semantic activation from L2 words and making automatic L2 embodiment effects possible. This conclusion cannot be generalized to all L2 populations, especially low-proficiency learners. According to the Revised Hierarchical Model (Wu et al., 2018), low-proficiency L2 learners have weak connections between lexical and conceptual levels, requiring L1 mediation for L2 semantic concept activation. Therefore, low-proficiency L2 embodiment effects are more likely results of L1 activation. Based on this, we argue that automatic activation and native language mediation hypotheses are not completely opposing or mutually exclusive theories. As L2 proficiency increases, embodiment effects gradually shift from native language mediation to automatic activation. The key questions are: At what proficiency level does this shift occur? Is this transition cliff-like or gradual? Besides proficiency, what roles do L2 acquisition age, language similarity, learning method, and task type play? These questions require in-depth investigation.

Furthermore, examining L2 embodiment effects in bilinguals with different reading and writing habits may help resolve these debates. Research shows that par-

ticipants from left-to-right writing systems (e.g., English, Chinese) tend to associate left space with the past and right space with the future, while those from right-to-left systems (e.g., Hebrew, Uyghur) show the opposite pattern (Grasso et al., 2021; Li & Wang, 2015; Ulrich & Maienborn, 2010). If a participant masters two languages with different reading/writing habits, what embodiment effects will appear in L2 processing? According to automatic activation theory, L2 temporal word processing will be influenced by L2 reading/writing habits, while native language mediation hypothesis predicts influence from L1 habits.

Third, if native language mediation theory applies to low-proficiency L2 learners, does this mediation operate at the lexical or semantic-conceptual level? According to the Revised Hierarchical Model, low-proficiency L2 words access semantic-conceptual levels through L1 lexical levels. With L1 lexical activation, mental representations such as sensorimotor experiences, emotional experiences, and environmental information integrated during word acquisition are automatically activated, manifesting as L2 embodiment effects (Dudschig et al., 2014). However, some research suggests that L2 embodiment effects result more from "intentional imagination" following semantic concept activation rather than automatic lexical activation. As Meteyard et al. (2012) noted, access to semantic-conceptual representations is a prerequisite for sensorimotor system and corresponding cortical activation. Since semantic access lags behind identification of lexical physical properties and involves different brain regions—primarily left temporal lobe, temporo-occipital junction, left inferior frontal gyrus, and supramarginal gyrus for semantics (Shafto & Tyler, 2014), versus left fusiform gyrus (temporo-occipital junction), left striatum, primary visual cortex pathways, and longitudinal fasciculus for physical properties (Centanni et al., 2017; Vukovic et al., 2017; Yeatman et al., 2013)—high temporal and spatial resolution methods should help resolve this issue.

As a newly emerging research orientation in language and cognitive science, L2 embodiment effects have not yet attracted sufficient academic attention, so questions about manifestations, mechanisms, influencing factors, and neural bases remain exploratory and controversial. Nevertheless, attention to L2 embodiment effects has important theoretical and practical significance. Theoretically, it first helps enrich embodied language cognition theory. Since the 1980s, debates between "disembodied cognition" and "embodied cognition" have emerged in abstract symbol processing domains like language (Miller et al., 2017). Disembodied cognition views language processing as amodal, internal, purely logical symbol operations independent of the body, while embodied cognition sees cognition as modal, 主张认知是语言符号、身体经验、社会情境等综合作用的结果. Although recent studies have found embodiment effects in elderly (Vallet, 2015), children (Desai et al., 2019), and patients with cognitive disorders (Gallese & Cuccio, 2018), these findings all come from L1 domains, making it difficult to demonstrate language universality of embodiment effects. The discovery of L2 embodiment effects undoubtedly provides support for universality. Second, L2 embodiment effects help reveal bilingual representation mechanisms. Traditional views hold that L2 acquisition age and method critically affect L2 representation; even

high-proficiency L2 learners with late acquisition ages and classroom learning cannot achieve L1-like representation, instead relying on abstract symbol representation with perceptual experiences and contextual factors dissociated from representation (Pavlenko et al., 2017). The discovery of L2 embodiment effects, especially automatic activation phenomena, challenges this view.

Practically, L2 embodiment effects provide theoretical support for L2 teaching. Since language cognition is embodied and sensorimotor experiences, emotions, and environmental factors play important roles, learning environments similar to L1 should be created, fully integrating sensorimotor experiences, emotions, and environmental factors to make L2 learning more modal. Porter (2016) found that gestures facilitate L2 vocabulary acquisition and representation, while Mayer et al. (2015) confirmed the effectiveness of L2 embodied learning at the neural level. As Macedonia (2014) stated: "By using the body as a tool for language learning, embodied learning becomes a watershed in L2 teaching."

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Note: Figure translations are in progress. See original paper for figures.