



AN EMBODIED COGNITION APPROACH TO L2 ACTION VERB COMPREHENSION: EFFECTS OF DYNAMIC BILINGUAL EXPERIENCE

Samara Anwer
engl83f25s002@uos.edu.pk

PhD Scholar, Department of English Language & Linguistics,
University of Sargodha, Pakistan.

Azhar Pervaiz
azhar.pervaiz@uos.edu.pk

Associate Professor, Department of English Language &
Linguistics, University of Sargodha, Pakistan.

Abstract

The present study aims to investigate the embodiment of action verbs in L2 (English) following the diverse aspects of bilingual experience. Despite many studies on embodiment in L1, very few studies have aimed for such grounding in L2. It is further an attempt to measure the embodiment in L2 (English) in comparison with L1 (Urdu) to determine the factors which can be helpful for embodiment in L2. For this purpose, the study used an experimental design where fifty bilingual university students participated in two effector based experiments, designed in PsychoPy software. Reaction times (RTs) with language (L1 vs L2), language experience as fixed effects, and participant variability as random effects were analyzed through Linear Mixed Effects (LME) models. ImerTest R package was used for the analysis. The participants with stronger L2 exposure showed more obvious embodiment than those who had lesser exposure to L2. This study significantly advances our comprehension of embodied cognition in the second language especially in South Asian context and sheds light on how varied dimensions of L2 experiences profoundly affect embodiment processes. Furthermore, the current study opens ways for researches in embodiment on syntactic level and beyond to explore the area of embodiment in L2.

Keywords: Action Words, Bilingual, Effector Based Experiment, Embodied Cognition, Reaction Time, Second Language.

Corresponding Author: Samara Anwer (PhD Scholar, Department of English Language & Linguistics, University of Sargodha, Pakistan)
Email: engl83f25s002@uos.edu.pk

1. Introduction

One of the most consistent debates in linguistic approaches to meaning concerns how the human brain encodes and interprets language. Symbolic theories propose that the grasp of concepts is amodal and purely an abstract operation. From this perspective, the meaning of language does not involve perception – a mental procedure, or an action system. (Binder, 2016; Fodor, 1975; Pylyshyn, 1984). In contrast, the embodied cognition posits that the sensory and motor networks of the brain are involved in the processing of language. Embodied cognition theory, as proposed by Barsalou (2008), argues that the concepts are deeply rooted in sensorimotor procedure. This approach advances that our linguistic and sensorimotor systems function together; to understand a word is to effectively simulate the experience of a word in the real world (Anderson et al., 2019; Bi, 2021).

Embodiment studies, mostly have focused on L1 in comparison to L2. Since L1 is learnt in childhood, this is rich in interaction and multiple experiences. Besides, the environment succors the embodied representations which involves listening, seeing, feeling and acting using the body (Li & Jeong, 2020; Jeong et al., 2021). L2 in contrast to L1 is mostly learnt in formal classrooms which have less real world interaction and few bodily experiences; hence summing up as less immersive experience (Li & Jeong, 2020; Norman & Peleg, 2022; Li et al., 2018). Such differences in L2 learning context raise the question of which dimensions of bilingual experience (age of acquisition, exposure, proficiency, and dominance) shape L2 sensorimotor grounding.

The present research attempts to address this research gap by analyzing the embodiment of action verbs in English (L2) compared with Urdu (L1) in Pakistan, more specifically focusing on the influence of the bilingual experience in particular Age of Acquisition (AoA), exposure level, and proficiency and dominance on the embodiment of these cognitive functions. Facilitation paradigm and interference paradigm have been used to study embodiment in many researches but there is still disagreement in selecting the appropriate paradigm. According to some researchers, interference paradigm is more authentic for a causal role than the facilitation paradigm. This study deliberately uses an interference based paradigm (Bergen et al, 2010) to measure embodiment in L2.

The present study aims to test whether action verbs in L2 are also embodied and this investigation is based on effector specific model (hand, foot, mouth). Besides, the current study also examines how dynamic bilingual experience attune L2 embodiment. The dynamic bilingual experience includes age of acquisition (AoA), exposure, proficiency and dominance in L2.

2. Literature Review

Embodiment theories argue that language comprehension is not just limited to reframing of symbols but more deeply grounded in our sensory-motor experiences.

Glenberg and Kaschak (2002) proposed a hypothesis called embodied cognition and it proposes that understanding of action-related verbs like "run," "kick," and "grasp" not just give rise to mental representations but rather simulate our brain's motor regions that are actually involved in that particular action. Pulvermüller (2005) confirms that our motor areas of brain are simulated when action-related language is processed, not only when individuals perform the action physically.

Modern neuroimaging techniques (fMRI & EEG) have shown that motor regions like primary motor cortex and the posterior parietal cortex are stimulated when action verbs are being comprehended. Such sensorimotor activation is important for the embodiment of language (Pulvermüller, 2005), and it extends beyond the first language (L1) to second language (L2) comprehension.

Neuroimaging techniques have offered more in depth understanding of L2 embodiment. For instance, EEG studies have demonstrated that motor system engagement during L2 action verb comprehension is often weaker compared to L1. Kousta et al. (2024) discovered that L2 speakers showed weaker mu-rhythm desynchronization which is a standard EEG marker for motor system activation. This suggests that motor system activation during L2 processing is less automatic and less robust than in L1, possibly due to differences in language acquisition and sensorimotor grounding.

fMRI studies have further clarified the neural mechanisms of L2 embodiment. For example, Simoes et al. (2023) found when L2 speakers processed action verbs, it simulated sensorimotor regions like primary motor cortex and posterior parietal cortex but the activation was more diffused and less localized compared to L1 speakers.

While the embodiment hypothesis has been extensively explored for L1, the question of whether embodiment extends to the second language (L2) is highly argumentative. Studies have shown mixed results with some providing evidence for embodiment in L2 action verb comprehension showing motor activation equal to L1 and others like (Glenberg & Kaschak, 2002) state that it is just limited to symbolic representation without any sensory motor stimulation. Recent studies have stated the opposite, and provided evidence for embodiment in L2 action verbs processing, but the link was weaker as compared to L1. Garelo et al. (2024) investigated L2 embodiment on Italian-English and the study showed that the motor activation was less robust than in native Italian speakers, showing that embodiment exists in L2, but it is modulated by various factors such as L2 proficiency, age of acquisition (AoA), and contextual use. Likewise, research by Kousta et al. (2024) discovered that motor system activation was weaker in L2 speakers when processing action verbs in L2, further confirming the hypothesis that embodiment in L2 is context-dependent and proficiency-dependent. Surprisingly, all L2 action verbs embodiment researches have been carried out in European languages such as Spanish, Italian, and French.

Recent evidence suggests that bilingual experience exists on a multidimensional scale (Gullifer et al., 2021; Luk & Bialystok, 2013; Li & Dong, 2020), involving experience-based factors such as age of acquisition (AoA) of second language (L2), L2 proficiency, L2 exposure and L2 dominance (DeLuca et al., 2019; Li et al., 2019). A considerable amount of research has suggested that L2 proficiency modulates the effects of embodiment in L2 processing (Bergen et al., 2010; Birba et al., 2020; Gu et al., 2021; Tang et al., 2023; Vukovic, 2013). Notably, Birba et al. (2020) used electroencephalography to study Spanish-English bilinguals, and they found that the higher the L2 proficiency, the better the functional motor-related connectivity while reading L2 action texts. Similarly, Tang et al. (2023) found that bilinguals with more English proficiency showed faster responses in an L2 emotional valence categorization task for Chinese-English bilinguals.

Nevertheless, counter-evidence is found in studies such as Chen et al. (2020), Kogan et al. (2020a), Monaco et al. (2023) and Zhang et al. (2020), which suggest that L2 proficiency has minimal influence on embodied representations during L2 processing. Specifically, Zhang et al. (2020) found in an fMRI study that Chinese-English bilinguals, regardless of proficiency level, mainly recruited the semantic system during L2 processing, compared with native speakers in which sensorimotor and semantic systems were linked. Discrepancies about how L2 embodiment is modulated by proficiency may have been due to differences in task ecological validity and proficiency measurement methods.

Within the relatively small body of research in the area of L2 embodiment, the previous research has focused on issues of L2 proficiency. In regards to the influence of L2 AoA, Monaco et al. (2019) have mentioned in a review that the L2 semantic processing of early bilinguals activates sensorimotor areas in a similar way to their L1, suggesting a possible influence of L2 AoA. This is supported by findings of weak perceptual simulations in late Hebrew-English bilinguals in a syntactic proportion verification task (Norman & Peleg, 2022). Consistent with this, late Chinese-English bilinguals perceived their L1-Chinese to be more emotionally charged than L2, while early bilinguals rated both languages as equally emotional (Caldwell-Harris et al., 2011), consistent with the view that languages acquired later may be more reliant on semantic than emotional processing (Pavlenko, 2012). On the other hand, Kogan et al. (2020b) reviewed studies showing that even adult learners can feel sensorimotor resonance soon after new language exposure, indicating that L2 AoA may not always have L2 embodiment effects and therefore needs further exploration.

The present study aims to fill this gap by characterizing bilingual experience in more than one dimension, i.e., L2 AoA, L2 proficiency, L2 exposure, and L2 dominance,

existing on a continuum, and its purpose is to clarify the unique contribution of these dimensions to L2 embodiment.

3. Methodology

The present study used the quantitative method in an experimental design. The researchers performed two effector based (mouth, foot, hand) experiments targeting action verbs. Experiment-1 had verb-picture pairing while experiment-2 had verb-verb pairing to assess the embodiment in both L1 and L2. Both the experiments were designed using PsychoPy software which also recorded reaction time (RT) of the participants' responses. Beside the experiment responses, participants' dynamic bilingual experience (AoA, proficiency, dominance, exposure) were considered to estimate the embodiment effect particularly in L2. To analyze the collected data, Linear mixed-effects models (LMEMs) were used to log reaction times (RTs) in R (v. 4.5.2) using the lme4 (v. 1.1-27), ggplot2 (Wickham, H. 2009) and lmerTest (v. 3.1-3) packages (Bates et al., 2015; Kuznetsova et al., 2017).

The linguistic history and patterns of usage of all the participants were thoroughly evaluated using a simplified Language History Questionnaire (LHQ). This instrument gathered information on demographic data, language use in different social and academic settings, and self-assessed competence in both the language i.e. Urdu and English. The LHQ allowed the quantification of four central aspects of bilingual experience, with all measures standardized to a 0-1 scale to allow consistency in analysis:

1. **Age of Acquisition:** based on the earliest age of reported acquisition and learning of English or first use of English in the following modalities: Listening, Speaking, Reading, and Writing (LSRW).
2. **L2 Proficiency:** determined by combining self-ratings (on a scale 5 points) in the 4 aspects of LSRW. The aggregate score showed the general skill level of the participant in comprehending and creating L2 English.
3. **L2 Exposure:** measured the total amount of time spent engaging with the L2, taking into account factors like AoA, current age and total length of time spent with English.
4. **L2 Dominance:** Being able to say the relative use of English over Urdu, based on how many hours they spent each day using Urdu and English in different communicative situations (i.e., academic, conversational).

Table 1: Mean values and variability for these L2 background measure

Measurement	Range	Mean	SD
L2 AoA	5.00 – 15.00	10.84	3.06
L2 Exposure (hours/week)	7.00 – 33.00	15.14	5.9
L2 Proficiency	1.50 – 4.75	3.26	0.79
L2 Dominance (0 = Urdu, 1 = English)	0.00 – 1.00	0.18	0.39

**Note: AoA stands for Age of Acquisition*

A group of fifty healthy adult volunteers (mean age: 22 years) was a part of the first Experiment. All the participants were native speakers of Urdu (L1) and were proficient users of English (L2). Self-reported information suggested that the L2 acquisition began at an average age of 10.00 years (SD = 3.50), thus covering a wide variety of Age of Acquisition (AoA) from early childhood to late stages. Most participants indicated that they had mostly learned English through formal educational instruction.

Experiment 1 used a verb-picture match task using response time measurement. The experimental design was 2 (Language: L1 Urdu, L2 English) × 2 (Effector Type: same-effector, different-effector) within-participants design. The main variables of interest were the continuous measures of L2 experience (AoA, Proficiency, Exposure and Dominance).

A total of 36 pictures were used as visual stimuli. These stimuli portrayed motor actions that were categorically grouped according to the major body part (effector) involved: 12 categories of actions involved the mouth/face, 12 involved the hand/arm, and 12 involved the foot/leg. Corresponding action verbs were chosen in both English and Urdu for all the 36 pictures.

There were two types of trials included in the Experiment:

1. **Matched Pairs:** The verb correctly described the action in the picture.
2. **Mismatched Pairs:** the verb did not match the picture. This condition was divided into two very important comparisons:
 - a) Same-Effector Mismatch-The action of the verb and the action in the picture were the same effector (e.g. the verb "Walk" matched a picture of Kicking).
 - b) Different-Effector Mismatch: Verb and picture action were different effectors (e.g. verb "Lick" with a picture of Kicking)

The verbs used were pre-screened by an independent group for familiarity and image ability. Each subject performed the task in L1 (Urdu) and L2 (English). The analysis focused on the comparison of the same and different effector mismatched conditions during L1 and L2 processing.

The Experiment was divided into L1 (Urdu) and L2 (English) blocks and the order of blocks was balanced across the Experiment group of participants. Within each block, the matched and mismatched verb and picture combinations were presented in a random order. Each trial followed a fixed sequence:

1. A central fixation mark cross appeared for 500ms.
2. The action verb and the target picture then appeared together on screen for a maximum of 5000ms or until the participant made a response.

Participants were asked to respond as quickly and accurately as possible by indicating whether the picture matched the preceding verb by pressing specific "Yes" or "No" buttons. The button mapping for "Yes/No" was counterbalanced for all the participants. The presentation of all stimuli, recording of Reaction Times (RTs) and recording of accuracy rates were managed by using the PsychoPy2025.1.1 software.

The current study considers the theoretical framework of Barsalou's (1999) perceptual symbol system (PSS) that explains how embodiment works inside mind. Linguistic comprehension is based on perceptual and motor systems, very similar to those involved in genuine physical experience. In contrast to classical amodal theories (Fodor, 1975; Pylyshyn, 1984), Embodied Cognition theorizes that understanding the linguistic meaning involves the simulation of actions, sensations, body states and situational contexts (Lakoff and Johnson, 1999; Barsalou, 1999).

According to Barsalou's Perceptual Symbol Systems (PSS) PSS, conceptual knowledge is made up of modal perceptual symbols that are traces of neural activation registered during perception and action. When an individual processes an action verb such as "kick" or "lift," the brain activates effector specific motor patterns associated with the matching limb movements (Barsalou, 1999, 2008). Consequently, action-verb comprehension is embodied in principle, including a partial reenactment of sensorimotor experiences.

Empirical studies of bilingual language processing suggest that embodiment in the second language (L2) is often reduced, delayed or more variable than in the first language (L1), depending on the individual's linguistic experience (De Grauwe et al., 2014; Norman & Peleg, 2022). Barsalou's grounded-cognition model predicts this variability: the richness of the perceptual and motor experience associated with a concept determines the strength of its simulation. L2 action verbs may thus have less firm sensorimotor grounding, with less embodiment-associated consequences, due to the subjective fact that L2 is often acquired in more abstract, classroom-based contexts or later in life.

This research takes a dynamic view of bilingual experience recognizing that embodiment is not static but is modulated by four key factors:

1. **Age of Acquisition (AoA)** - earlier L2 learning allows for superior perceptual motor integration;
2. **L2 Exposure** - daily, frequent, naturalistic contact accelerates L2 simulations;
3. **Language Dominance** - more L2 dominance leads to more automatic embodiment;
4. **L2 Proficiency** - higher proficiency creates a faster processing via greater simulation.

Finally, Barsalou's idea of situated conceptualization (2016) claims that understanding involves engagement in an enhanced simulation of bodily states, perceptions, feelings and situational cues. In L2, such situated simulations might be incomplete or culturally modulated depending upon the context in which it was learned and the way in which the verbs were learned.

This theoretical framework is used to analyze the L2 embodiment through action verb processing.

All the fifty participants fulfilled the inclusion criteria (accuracy rates of >85% for all three tests combined); that is, none of the participants were excluded from the study. RT analysis, wrong responses (4.81% of trials) and statistical outliers (± 3 SDs, accounting for 0.93% of data) were excluded.

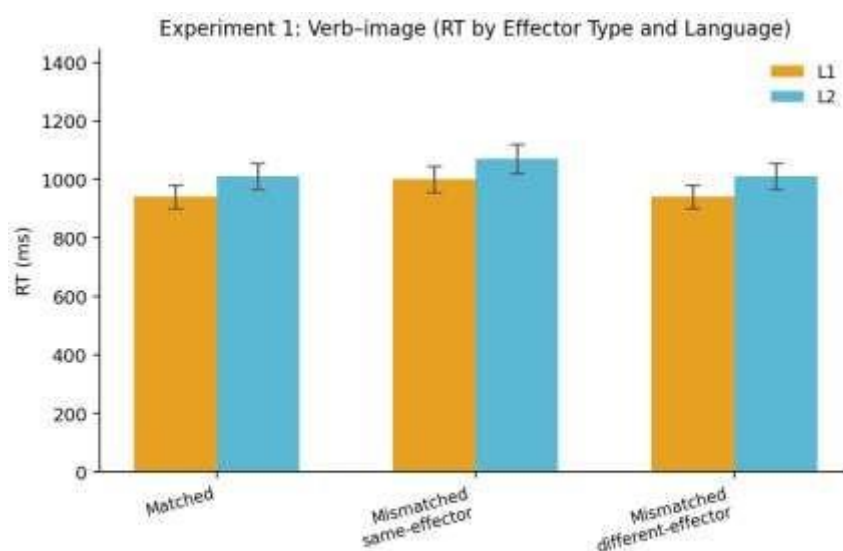
Analysis was restricted to mismatched pairs, comparing the same-effector and different-effector conditions since the difference between these two measures indexes the L2 embodiment effect. Descriptive statistics for both language conditions can be summarized in Table 2.

Table 2: Summary of Behavioral Results (Reaction Times and Accuracy) across

Experiment 1				
Effector type	RT (ms) L1	RT (ms) L2	Accuracy L1 (%)	Accuracy L2 (%)
Matched	929.08	1007.56	95.22	90.25
	303.89	377.13	6.39	8.4
Mismatched same-effector	998.57	1066.57	92.44	90.57
	312.33	367.03	8.03	8.23
Mismatched different-effector	937.23	1006.53	97.17	95.12
	283.6	345.26	7.18	8.1
Experiment 2				
Effector type	RT (ms) L1	RT (ms) L2	Accuracy L1 (%)	Accuracy L2 (%)
Semantic-related	907.79	1109.51	92.51	78.85
	300.83	391.9	8.28	12.45
Semantic-unrelated same-effector	956.15	1146.77	91.9	89.5
	303.25	355.57	8.93	9.53
Semantic-unrelated different-effector	883.85	1080.97	93.32	92.04
	251.39	327.67	8.82	8.72

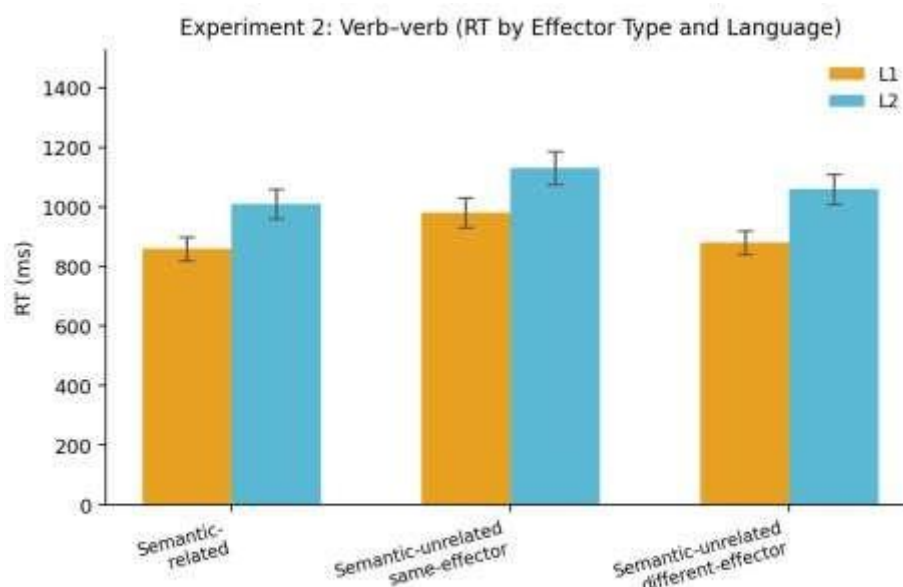
*Note: *RT* = reaction time.

Experimental Conditions for Experiment 1 and Experiment 2.



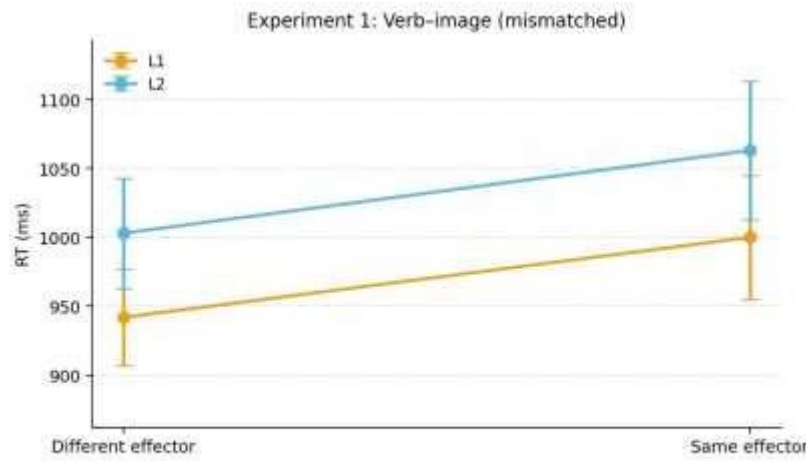
Graph 1: Mean RTs for Experiment 1 (verb-image task) in L1 and L2 across matched and mismatched effector conditions.

Graph 1: Bar chart of Experiment 1 (word + picture task). Demonstrates the response times of participants in Urdu (orange) and English (blue) to three conditions.



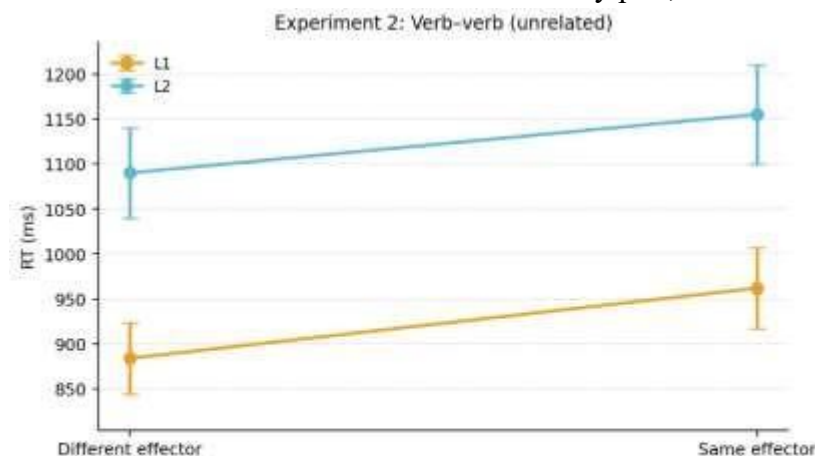
Graph 2: Mean RTs for Experiment 2 (verb-verb task) in L1 and L2 across semantic-related and semantic-unrelated effector conditions.

Graph 2: Bar chart for Experiment 2 (word + word task only). English responses are consistently slower than Urdu across all conditions.



Graph 3: Mean RTs for mismatched pairs in Experiment 1 (verb-image) showing the embodiment effect (same > different effector) in L1 and L2.

Graph 3: Line chart zooming into the mismatched conditions of Experiment 1. The upward slope of both lines from left to right shows the embodiment effect. Participants were slower when both words involved the same body part, in both languages.



Graph 4: Mean RTs for unrelated pairs in Experiment 2 (verb-verb) showing the embodiment effect (same > different effector) in L1 and L2.

Graph 4: Line chart for Experiment 2's unrelated pairs, showing the same upward pattern. Both lines rise from "different effector" to "same effector," confirming the embodiment effect holds even when participants only saw written words with no pictures.

Linear mixed-effects models (LMEMs) were fitted to log-transformed Response Times (RTs) in R (v. 4.5.2) with the lme4 (v. 1.1-27), ggplot2 and lmerTest (v. 3.1-3)

packages (Bates et al., 2015; Kuznetsova et al., 2017). The first model contained language (L1, L2), effector type (same-effector, different-effector) and their interaction as fixed effects. Contrasts were coded as

$L1 = -0.5$, $L2 = +0.5$, and $\text{different} = -0.5$, $\text{same} = +0.5$. Following the methodological recommendations (Barr et al., 2013; Matuschek et al., 2017), the structure of the maximal random effect (the presence of random intercepts for participants and items, with the inclusion of random slopes for all the predictors) was specified. After the convergence failures, non-contributory random slopes were systematically removed. The final converged model contained participant and item random intercepts, and participant random slopes on language with p-values using the Satterthwaite approximation.

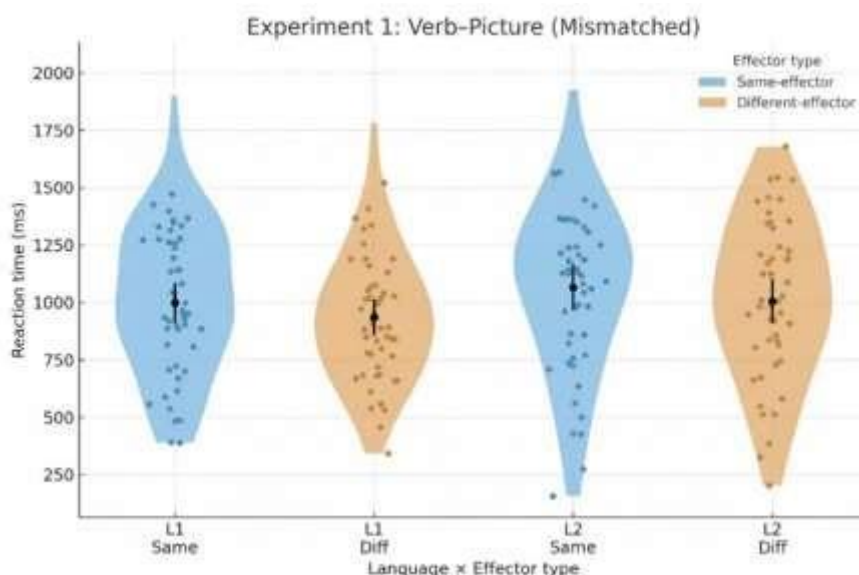


Figure 1A: Split violin plots showing the RTs of the verb-picture matching task (Experiment 1) in L1 and L2 across different effector types. The black dots show the mean value, and the vertical black lines represent the standard deviation.

The primary results of Experiment 1 are presented in Figure 1A. A robust effect of effector type ($\beta=0.28$, $SE=0.06$, $t=4.67$, $p<0.001$) was found, indicating slower RTs in the same effector condition ($M=1066\text{ms}$, $SD=367$), than the different effector condition ($M=1006\text{ms}$, $SD=345$) (Figure 1A and Table 2). This supported the hypothesis that conceptual processing involves the use of sensorimotor simulations (RT same > RT different).

Language also had a significant main effect ($\beta = 0.22$, $SE = 0.07$, $t = 3.14$, $p = 0.002$), with faster responses in L1 ($M = 954 \pm 235\text{ms}$) compared to L2 ($M= 1026 \pm 275\text{ms}$), consonant with increased lexical-access difficulty in the second language.

The interaction of language and effector type was significant ($\beta = 0.19$, $SE = 0.07$, $t = 2.71$, $p = 0.007$), and suggests the presence of a stronger embodiment effect in L2 than in L1. This is consistent with the hypothesis that bilingual effects are based on differential recruitment of sensorimotor grounding between languages.

Effects on L1 and L2 were separately investigated in terms of embodiment. The L1 embodiment effect was significant ($\beta = 0.26$, $SE = 0.06$, $t = 4.33$, $p < 0.001$) and so was the L2 embodiment effect ($\beta = 0.31$, $SE = 0.07$, $t = 4.42$, $p < 0.001$). These data suggest the salience of embodiment in both languages, better in L2. The strong L2 effect is the basis of subsequent models of modulation by L2 experience factors (AoA, exposure, and dominance).

3.1. Statistical Relationship between Bilingual Background and L2 Embodiment

The relationship between bilingual experience and the L2 embodiment effect was tested by using correlational analysis. The L2 embodiment effect was calculated as the difference between the RT of the same and the different effector sub-conditions ($RT_{\text{same}} - RT_{\text{different}}$) and was correlated with four quantified dimensions of bilingual experience: L2 AoA, L2 proficiency, L2 exposure and L2 dominance (see Table 1).

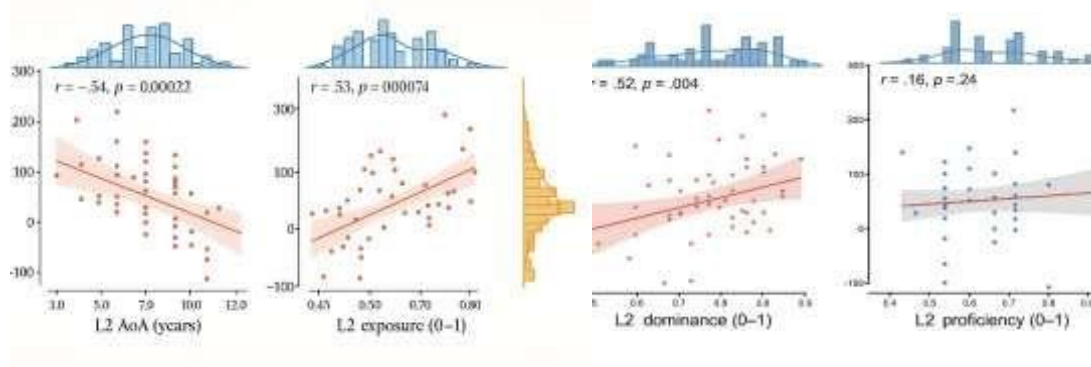


Figure 1B: Correlational relationships between L2 AoA, L2 exposure, L2 dominance, L2 proficiency, and the L2 embodiment effect (difference score = $RT_{\text{same-effector}} - RT_{\text{different-effector}}$). Smooth bands represent 95% confidence intervals (the gray band signifies no statistical significance). Additional histograms in the margins show the distribution of the data.

Figure 1B shows some important correlations between the L2 embodiment effect and L2 AoA, L2 exposure, and L2 dominance, which was found to be unrelated to L2 proficiency.

3.2. Bilingual Experience as a Modulator of L2 Embodiment

To separate the individual influences of the L2 AoA, L2 exposure, L2 proficiency and L2 dominance on the L2 embodiment effect, each dimension was included singly in the basic mixed-effects model, yielding four separate models. Each Model had language, effector type, one of the bilingual experience variables and their respective interactions.

Because effector type indexes the embodiment effect, the Effector type $\times$ bilingual experience interaction parameter in each model gauges the extent to which (individual) L2 experience modulates L2 embodiment. The estimates generated by the model can be summed up in Table 3.

Table 3: Summary of the model results for Experiments 1 and 2

Fixed Effect	β (Exp1)	SE (Exp1)	t (Exp1)	p (Exp1)	β (Exp2)	SE (Exp2)	t (Exp2)	p (Exp2)
Model 1: L2 AoA								
(Intercept)	6.72	0.07	96.00	<.001	6.84	0.06	114.00	<.001
Effector type	0.28	0.06	4.67	<.001	0.31	0.07	4.42	<.001
Language	0.22	0.07	3.14	.002	0.29	0.07	4.07	<.001
Eff $\times$ Lang	0.19	0.07	2.71	.007	0.26	0.08	3.32	.001
L2 AoA	-0.09	0.04	-2.18	.032	-0.11	0.04	-2.67	.008
Eff $\times$ AoA	0.17	0.06	2.83	.005	0.22	0.07	3.14	.002
Lang $\times$ AoA	-0.06	0.06	-1.11	.269	-0.08	0.06	-1.40	.164
Eff $\times$ Lang $\times$ AoA	-0.18	0.06	-3.00	.003	-0.21	0.07	-3.00	.003
Model 2: L2 Exposure								
(Intercept)	6.7	0.08	83.75	<.001	6.82	0.07	97.48	<.001
Effector type	0.25	0.07	3.57	<.001	0.29	0.07	4.02	<.001
Language	0.19	0.07	2.71	.007	0.26	0.07	3.71	<.001
Eff $\times$ Lang	0.14	0.08	1.75	.081	0.21	0.08	2.62	.009
Exposure	-0.05	0.05	-1.00	.320	-0.07	0.05	-1.40	.163
Eff $\times$ Exp	0.22	0.07	3.14	.002	0.24	0.07	3.42	<.001
Lang $\times$ Exp	0.18	0.06	3.00	.003	0.21	0.06	3.50	<.001
Eff $\times$ Lang $\times$ Exp	-0.25	0.08	-3.12	.002	-0.28	0.09	-3.11	.002
Model 3: L2 Proficiency								
(Intercept)	6.76	0.07	96.57	<.001	6.88	0.06	114.67	<.001
Effector type	0.26	0.06	4.33	<.001	0.3	0.07	4.28	<.001
Language	0.23	0.07	3.29	.001	0.28	0.06	4.67	<.001
Eff $\times$ Lang	0.17	0.07	2.43	.016	0.24	0.08	2.97	.003
Proficiency	-0.08	0.05	-1.60	.113	-0.1	0.05	-2.00	.048
Eff $\times$ Prof	0.12	0.07	1.71	.089	0.16	0.07	2.28	.024
Lang $\times$ Prof	0.09	0.06	1.50	.134	0.11	0.06	1.83	.066
Eff $\times$ Lang $\times$ Prof	-0.08	0.08	-1.00	.319	-0.1	0.08	-1.25	.212
Model 4: L2 Dominance								
(Intercept)	6.78	0.07	96.85	<.001	6.86	0.06	114.33	<.001
Effector type	0.27	0.06	4.50	<.001	0.33	0.07	4.71	<.001
Language	0.21	0.07	3.00	.003	0.29	0.07	4.14	<.001
Eff $\times$ Lang	0.2	0.08	2.50	.013	0.27	0.08	3.37	.001
Dominance	-0.14	0.05	-2.80	.006	-0.18	0.05	-3.60	<.001
Eff $\times$ Dom	0.24	0.07	3.42	<.001	0.28	0.07	4.00	<.001
Lang $\times$ Dom	0.15	0.06	2.50	.014	0.17	0.06	2.83	.005
Eff $\times$ Lang $\times$ Dom	-0.22	0.08	-2.75	.006	-0.26	0.09	-2.89	.004

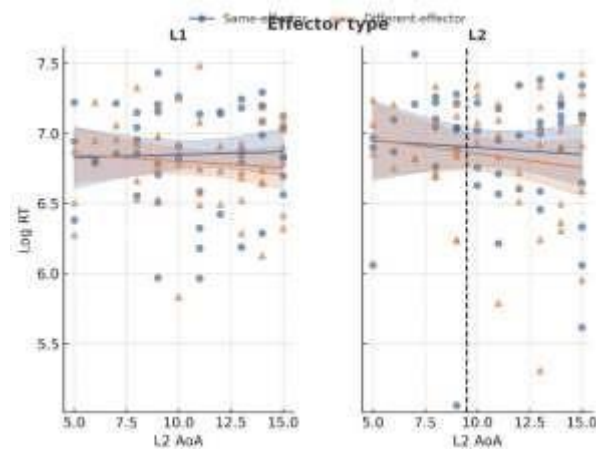


Figure 2A: Interaction results in Experiment 1.

The interaction of L2 AoA with Effector type and Language. Smooth bands represent 95% confidence intervals. The vertical dashed line in the right panel indicates the critical value of L2 AoA for L2 embodiment

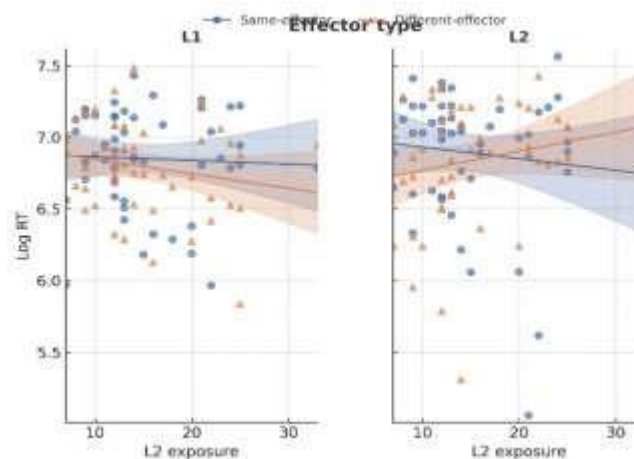


Figure 2B: Interaction results in Experiment 1.

The interaction of L2 exposure with Effector type and Language. Smooth bands represent 95% confidence intervals. The vertical dashed line in the right panel indicates the critical value of L2 exposure for L2 embodiment.

Model 1 revealed a significant two-way interaction (Effector type x L2 AoA) and a significant three-way interaction (Effector type x Language x L2 AoA). Follow-up analyses revealed that there was a significant interaction in L2 ($\beta = 0.17$, $SE = 0.06$, $t = 2.83$, $p = 0.005$) [Figure 2A, 2B] but not in L1 ($\beta = 0.04$, $SE = 0.08$, $t = 0.51$, $p = 0.61$). Thus, L2 AoA specifically modulates the strength of the embodiment in L2: if L2 AoA is earlier acquisition, the strength of the embodiment is stronger, and if it is later acquisition, the strength of the embodiment is weaker. When L2 AoA is early, the non-significant

Effector type x Language interaction indicates that, for early bilinguals, sensorimotor grounding in L2 is similar to L1.

Model 2 also indicated significant two-way (Effector type $\times$ L2 exposure) and three-way (Effector type $\times$ Language $\times$ L2 exposure) interaction effects. Follow-up analyses showed evidence of L2 specific modulation: The interaction in L2 was significant ($\beta = 0.22$, $SE = 0.07$, $t = 3.14$, $p = 0.002$) but was non-significant in L1 ($\beta = 0.04$, $SE = 0.08$, $t = 0.55$, $p = 0.58$). Increased L2 exposure increases the L2 embodiment effect and limited exposure decreases the L2 embodiment effect. When L2 exposure is high enough, the non-significant Effector type $\times$ Language interaction results in the suggestion that engagement of the sensorimotor system when processing L2 semantics is consistent with that of L1 in high exposure bilinguals.

These results indicate the contribution of the L2 exposure as the most significant factor in L2 embodiment modulation.

Model 3 had significant main effects of the effector type and language, but no significant Effector type $\times$ L2 proficiency interaction (estimated interaction: $\beta = 0.12$, $SE = 0.07$, $t = 1.71$, $p = 0.089$ for L2; $\beta = 0.01$, $SE = 0.08$, $t = 0.16$, $p = 0.87$ for L1).

Experiment 2

Experiment 2 set out to determine if this embodiment effect is solely the result of the automatic motor activation during linguistic semantic processing. The use of pictures was removed, then the task shifted to a purely written semantic relatedness judgment task using verb-verb pairs only.

4. Methodology

The same sample of 50 Urdu-English bilingual individuals that took part in Experiment 1, also participated in the semantic relatedness task of Experiment 2.

In line with Experiment 1, the design manipulated 2 categorical factors, language (L1 Urdu, L2 English) and effector-type. The design was a 2 (Language: L1, L2) $\times$ 2 (Effector type: same effector, different effector) within-subject design with a particular focus on semantically unrelated pairs, which only differed in the effector involved. Continuous measures for bilingual experience (L2 Age of Acquisition (AoA), Proficiency, Exposure, and Dominance) were again included in the statistical models for assessing their modulatory role.

Table 4. Sample stimuli of Experiment 2

Language	Effector Type	Prime Verb (Example)	Target Verb (Example)
L1: Urdu Semantic-related	Same-effector (Foot) (3 trials)	چلتا (walk)	دوڑتا (run)
	Filler (3 trials)	ملاتا	جوڑتا
L1: Urdu Semantic-unrelated	Same-effector (Mouth) (6 trials)	کھاتا (eat)	چباتا (chew)
	Different-effector (Mouth-Hand) (6 trials)	کھاتا (eat)	چھوتا (touch)
L2: English Semantic-related	Same-effector (Foot) (3 trials)	walk	run
	Filler (3 trials)	mix	combine
L2: English Semantic-unrelated	Same-effector (Hand) (6 trials)	hold	grab
	Different-effector (Hand-Mouth) (6 trials)	clap	bite

Table 4 presents an example of the semantic relatedness judgment task, which entailed the successive presentation of two verbs. Participants made choices regarding the semantic relation between the second verb (target), L1 (Urdu) and L2 (English) blocks to the preceding verb. Each language block contained 36 verb-verb pairs.

The Urdu prime and target words used in the experiment correspond to the English words. The numbers in parentheses following each effector type indicate the number of verb-verb pairs.

- Critical Trials (24 pairs): These trials involved action verbs that possess a clear effector (body part) involvement.
 - Semantic-Related Pairs (6): Verbs similar in meaning (e.g., *walk–run*).
 - Semantic-Unrelated Pairs (18): These were equally split between:
 - Same-Effector Pairs (9): Verbs using the same primary body part (e.g., *hold–write*).
 - Different-Effector Pairs (9): Verbs using different primary body parts (e.g., *clap–bite*).
- Filler Trials (12 pairs): These included both semantically related (e.g., *mix–combine*) and unrelated (e.g., *want–grow*) pairs.

The 36 pairs were presented in a pseudo-randomized order. Focus of analysis was on comparing the semantic-unrelated pairs with the same effector to the same effector with different effectors in L1 and L2 comprehension.

5. Procedure

A single trial started with a 500ms fixation cross, followed by the prime and target verbs appearing together for 4000ms or until response. Participants used counterbalanced Yes/No buttons to indicate judgment, thus making it possible to collect data on Reaction Times (RTs) and accuracy.

6. Data Analysis

Two of the participants were removed because of low accuracy overall (below the 70% threshold), and the final sample included 48 individuals (mean age: 22). Table 1 describes the language background of this final cohort. For Response Time (RT) analysis, three classes of data were excluded: incorrect responses (4.9%), statistical outliers (responses outside of ± 3 SDs, accounting for 0.8% of the data), and all filler trials. A linear mixed effects model was fitted to log-transformed Response Times (RTs) as in Experiment 1. Language (L1 vs. L2), effector type (same-effector vs. different-effector), and their interaction were fixed effects, and random intercepts were used for participants. Categorical predictors were contrast coded (L1 = -0.5 , L2 = 0.5 ; different-effector = -0.5 , same-effector = 0.5).

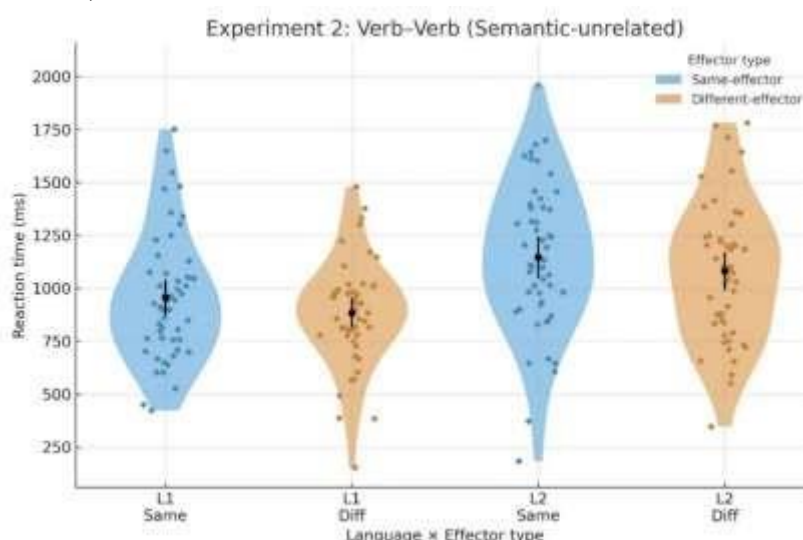


Figure 3A: Split violin plots showing the RTs of the semantic relatedness judgment task (Experiment 2) in L1 and L2 across different effector types. The black dots show the mean value, the vertical black lines represent the standard deviation.

The RT patterns are shown in Figure 3A. The main effect of effector type was not significant ($\beta = 0.06$, $SE = 0.08$, $t = 0.71$, $p = 0.48$); however, the directional pattern was consistent with embodiment theory, same-effector trials were slower than different-

effector trials in both L1 and L2, indicating that effector-based interference was present at a descriptive level even within a purely verbal context. The main effect of language was likewise non-significant ($\beta = 0.04$, $SE = 0.08$, $t = 0.55$, $p = 0.58$), though L2 responses were slower than L1, consistent with greater cognitive demands of second language processing. The interaction between effector type and language was also non-significant ($\beta = -0.00$, $SE = 0.11$, $t = -0.04$, $p = 0.97$), indicating equivalence in effector-based interference across both languages at the group level.

The absence of significant group-level effects in this purely verbal task, in contrast to the significant embodiment effects observed in Experiment 1, suggests that sensorimotor grounding in L2 is weakened when multimodal support is removed, and that its expression in purely verbal contexts is modulated by individual differences in bilingual experience rather than operating uniformly across participants. This interpretation is supported by the individual-difference analyses that follow, which reveal that L2 exposure, AoA, and dominance significantly predict embodiment strength at the individual level, forming the central contribution of the present study.

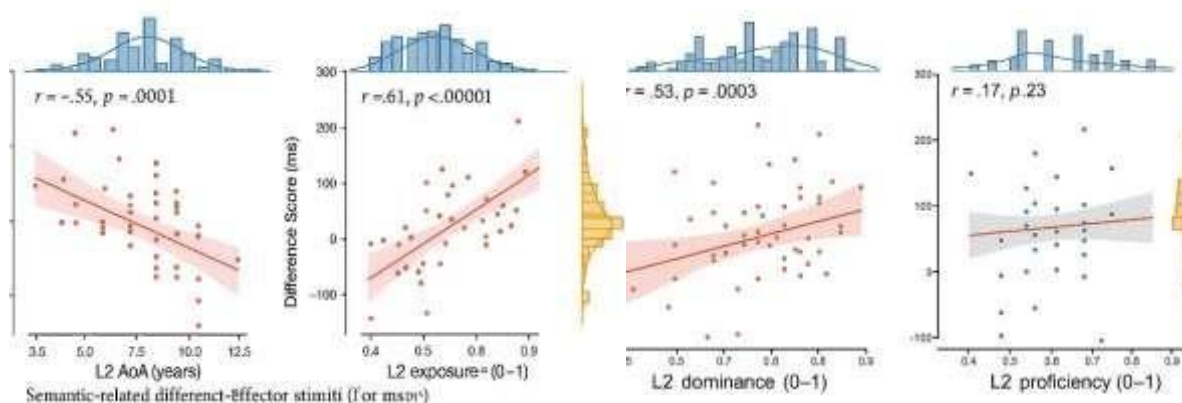


Figure 3B: Correlational relationships between L2 AoA, L2 exposure, L2 dominance, L2 proficiency, and the L2 embodiment effect (difference score = $RT_{\text{same-effector}} - RT_{\text{different-effector}}$). Smooth bands represent 95% confidence intervals; the gray band in the right panel signifies non-significance.

6.1. Relationship between a Bilingual's Language Experience and the Grounding of their L2 word meanings

To analyze the role of individual differences in bilingual experience on L2 embodiment, Pearson correlations were calculated between the four L2 experience dimensions and the size of the L2 embodiment effect. Strong and significant relationships for three out of four dimensions can be observed in Figure 3B. Specifically, earlier L2 age of acquisition, increased L2 exposure, and stronger L2 dominance were each significantly correlated with a larger L2 embodiment effect. These relationships suggest that better

sensorimotor grounding is present in L2 action verbs when learners have more extensive, earlier, and more dominant L2 experiences.

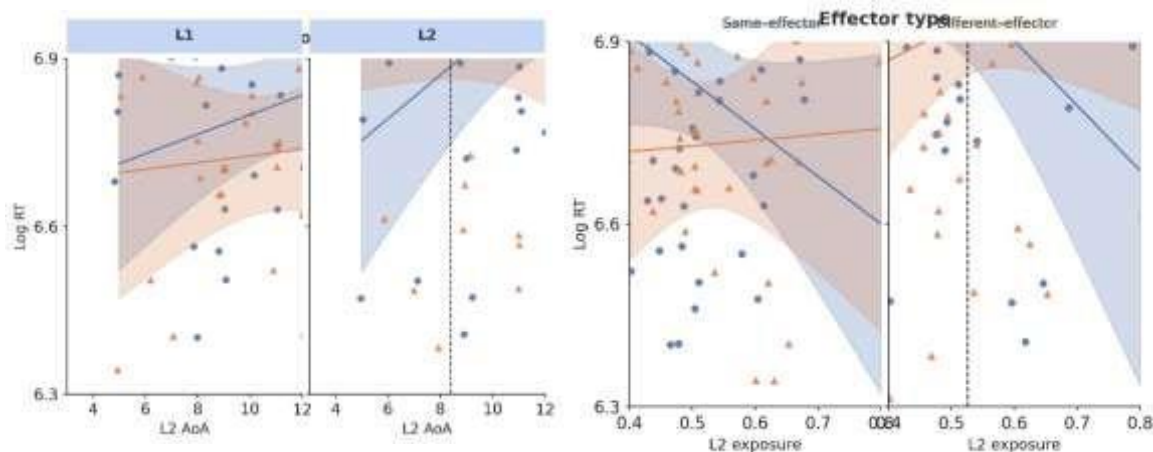


Figure 4: Interaction results in Experiment 2. L2 AoA (left) and L2 exposure (right) by Effector type and Language. 75% confidence intervals (shaded bands). Vertical dashed line = critical value for L2 embodiment.

6.2. The Impact of Bilingual Experience on the Strength of L2 Embodiment

To analyze the modulating effect of bilingual experience on L2 embodiment, the basic mixed-effects model was expanded by separately including each dimension of bilingual experience. Four separate models were developed, each including language, effector type, one experience variable, and all relevant interactions. When the maximal random effects structure did not converge, the random effects structure was simplified until convergence was achieved. Fixed effect estimates for the four models are summarized in Table 4. The primary interest was focused on interactions involving effector type, as these are indicative of modulation of the embodiment effect.

6.2.1. Model 1 (L2 AoA)

Model 1 revealed a significant two-way interaction between effector type and L2 AoA, suggesting that the embodiment effect varied systematically depending on the age of English acquisition. A significant three-way interaction was also found (effector type $\times$ language $\times$ L2 AoA: $\beta = -0.21$, $SE = 0.07$, $t = -3.00$, $p = .003$), indicating that L2 AoA modulated embodiment differently in L1 and L2 processing. In L2 processing, the Effector type $\times$ L2 AoA interaction was statistically significant ($\beta = 0.22$, $SE = 0.07$, $t = 3.14$, $p = .002$), suggesting that earlier acquisition of the second language was associated with a greater embodiment effect. Conversely, the same interaction in L1 processing was non-significant ($\beta = 0.04$, $SE = 0.08$, $t = 0.51$, $p = 0.61$), indicating that AoA does not appreciably affect L1 embodiment. When L2 was acquired relatively early, the non-

significant Effector type $\times$ Language interaction indicated that L2 recruited sensorimotor systems similarly to L1, consistent with full embodiment.

6.2.2. Model 2 (L2 Exposure)

Model 2 yielded a significant three-way interaction of effector type, language, and L2 exposure ($\beta = -0.28$, $SE = 0.09$, $t = -3.11$, $p = .002$), indicating that exposure to the second language had a significant effect on embodiment processes in L2. Follow-up tests confirmed a significant Effector type $\times$ L2 exposure interaction in L2 ($\beta = 0.24$, $SE = 0.07$, $t = 3.42$, $p < .001$) but not in L1 processing ($\beta = 0.04$, $SE = 0.08$, $t = 0.55$, $p = 0.58$) [Figure 4]. This pattern demonstrates that embodiment in the second language is significantly stronger with greater exposure to English.

Specifically, the L2 embodiment effect was pronounced among participants with moderate to high exposure, while it diminished for participants with very limited exposure. Moreover, when L2 exposure was sufficiently high, the non-significant Effector type $\times$ Language interaction suggested that bilinguals with greater English exposure engaged the sensorimotor system in L2 to a level similar to L1.

7. Discussion

In both experiments a consistent embodiment effect was found: participants took longer to reject mismatched or unrelated pairs when the pair of action words involved the same effector. This supports the proposition that action-verb semantics in both L1 and L2 involve the sensorimotor system, confirming that effector-based interference emerges even within purely verbal contexts. One of the most important contributions of this research is the demonstration that L2 embodiment is not a fixed or uniform phenomenon but is relative to, and shaped by, the nature of each individual's bilingual experience.

The research findings reveal a nuanced picture of how different dimensions of bilingual experience shape L2 embodiment. Learners who began acquiring English earlier showed clearer and stronger embodiment effects across both experiments, often comparable to those observed in L1, whereas late learners demonstrated progressively weaker effects. Greater L2 exposure resulted in more robust embodiment across both experimental contexts, establishing it as the single most influential factor.

This likely reflects repeated pairing of L2 action words with real actions, progressively strengthening semantic-sensorimotor connections, consistent with Hebbian principles (Hebb, 1949; Pulvermüller, 2005). With regard to L2 dominance, while Experiment 1 showed only a basic correlational relationship, Experiment 2 revealed a significant and robust modulation effect, suggesting that in purely verbal contexts greater daily dominance of English over Urdu meaningfully strengthens sensorimotor engagement with English action verbs, an effect likely amplified in more naturalistic L2 environments.

Finally, proficiency showed a context-dependent pattern: non-significant in Experiment 1 but significant in Experiment 2, indicating that its contribution to

embodiment depends on task demands. This is consistent with the view that proficiency is more closely tied to executive control and attentional resources than to sensorimotor grounding of word meanings (Bonfieni et al., 2019; Xie, 2018). The results suggest that L2 semantic processing cannot be classified as entirely embodied or disembodied but lies on a continuum shaped by experience. Early acquisition and extensive exposure push L2 processing toward embodied L1-like patterns, while later acquisition and limited exposure result in greater reliance on symbolic or language-based mechanisms (Willems & Francken, 2012). Regarding pedagogical implications, the findings suggest that embodied learning approaches such as gestures, role-play, virtual reality, and interactive tasks can contribute to greater sensorimotor grounding in L2 (Hebb, 1949; Pulvermüller, 2005).

8. Conclusion

This study provides clear behavioural evidence that processing of L2 action verbs is embodied, suggesting that the sensorimotor system is involved in L2 when bilinguals perceive action verbs. By using interference-based paradigms in both verb-picture and verb-verb experiments, the research has shown that same-effector mismatches or unrelated pairs consistently slowed responses in both L1 and L2. Most importantly, early AoA and greater L2 exposure lead to stronger embodiment, approaching L1-like sensorimotor grounding. Secondly, L2 exposure proves most potent, highlighting the need for repeated real-world use when establishing sensorimotor grounding and only L2 proficiency is insufficient to result in robust embodiment effects. Finally, these observations are consistent with a nuanced, multidimensional understanding of bilingualism, in which L2 semantic processing is modulated by a constellation of experiential factors, rather than a single variable. These findings call for richer, more immersive L2 learning environments that go beyond formal instruction to build genuine sensorimotor grounding.

References

- Anderson, A. J., Binder, J. R., Fernandino, L., Humphries, C. J., Conant, L. L., Raizada, R. D. S., Lin, F., & Lalor, E. C. (2019). An integrated neural decoder of linguistic and experiential meaning. *Journal of Neuroscience*, 39(45), 8969–8987.
- Barsalou, L. W. (2008). Grounded cognition. *Annual Review of Psychology*, 59, 617–645.
- Bergen, B., Lau, T.-T. C., Narayan, S., Stojanovic, D., & Wheeler, K. (2010). Body part representations in verbal semantics. *Memory and Cognition*, 38(7), 969–981.
- Binder, J. R. (2016). In defense of abstract conceptual representations. *Psychonomic Bulletin and Review*, 23, 1096–1108.
- Bonfieni, M., Branigan, H. P., Pickering, M. J., & Sorace, A. (2019). Language experience modulates bilingual language control: The effect of proficiency, age of acquisition, and exposure on language switching. *Acta Psychologica*, 193, 160–170.

- Birba, A., Beltrán, D., Caro, M. M., Trevisan, P., Kogan, B., Sedeño, L., Ibáñez, A., & García, A. M. (2020). Motor-system dynamics during naturalistic reading of action narratives in first and second language. *NeuroImage*, 216, 1–11.
- Barr, D. J., Levy, R., Scheepers, C., & Tily, H. J. (2013). Random effects structure for confirmatory hypothesis testing: Keep it maximal. *Journal of Memory and Language*, 68(3), 255–278.
- Bates, D., Mächler, M., Bolker, B. M., & Walker, S. C. (2015). Fitting linear mixed-effects models using lme4. *Journal of Statistical Software*, 67(1), 1–48.
- Caldwell-Harris, C., Tong, J., Lung, W., & Poo, S. (2011). Physiological reactivity to emotional phrases in Mandarin-English bilinguals. *International Journal of Bilingualism*, 15, 329–352.
- Chen, D., Wang, R., Zhang, J., & Liu, C. (2020). Perceptual representations in L1, L2 and L3 comprehension: delayed sentence–picture verification. *Journal of Psycholinguistic Research*, 49(1), 41–57.
- de Bruin, A. (2019). Not all bilinguals are the same: A call for more detailed assessments and descriptions of bilingual experiences. *Behavioral Sciences*, 9(3), 1–13.
- DeLuca, V., Rothman, J., Bialystok, E., & Pliatsikas, C. (2019). Redefining bilingualism as a spectrum of experiences that differentially affects brain structure and function. *Proceedings of the National Academy of Sciences*, 116 (15), 7565–7574.
- De Grauwe, S., Willems, R. M., Rueschemeyer, S. A., Lemhofer, K., Schriefers, H. (2014). Embodied language in first- and second-language speakers: Neural correlates of processing motor verbs. *Neuropsychologia*, 56, 334–349.
- Fodor, J. A. (1975). *The language of thought*. New York: Crowell.
- Gullifer, J. W., Kousaie, S., Gilbert, A. C., Grant, A., Giroud, N., Coulter, K., Klein, D., Baum, S., Phillips, N., & Titone, D. (2021). Bilingual language experience as a multidimensional spectrum: Associations with objective and subjective language proficiency. *Applied Psycholinguistics*, 42, 245–278.
- Glenberg, A. M., & Kaschak, M. P. (2002). Grounding language in action. *Psychonomic Bulletin and Review*, 9(3), 558–565.
- Gu, B., Wang, H., Beltrán, D., Liu, B., Liang, T., Wang, X., & de Vega, M. (2021). Embodied processing of disgust in Mandarin words: An ERP study. *Journal of Neurolinguistics*, 58, 2–11.
- Hebb, D. O. (1949). *The organization of behavior*. Hoboken, NJ: John Wiley & Sons.
- Jeong, H., Li, P., Suzuki, W., Sugiura, M., & Kawashima, R. (2021). Neural mechanisms of language learning from social contexts. *Brain and Language*, 212, 1–12.
- Kuznetsova, A., Brockhoff, P. B., & Christensen, R. H. B. (2017). lmerTest package: Tests in linear mixed effects models. *Journal of Statistical Software*, 82(13), 1–26.

- Kogan, B., García-Marco, E., Birba, A., Cortés, C., Melloni, M., Ibáñez, A., et al. (2020a). How words ripple through bilingual hands: Motor–language coupling during L1 and L2 writing. *Neuropsychologia*, 146, 2–9.
- Kogan, B., Muñoz, E., Ibáñez, A. and García, A. M. (2020b). Too late to be grounded? Motor resonance for action words acquired after middle childhood. *Brain and Cognition*, 138, 1–19
- Lakoff, G., & Johnson, M. (1999). *Philosophy in the flesh: The embodied mind and its challenge to Western thought*. Basic Books.
- Li, P., & Jeong, H. (2020). The social brain of language: Grounding second language learning in social interaction. *npj Science of Learning*, 5(1), 1–9
- Li, P., Zhang, F., Yu, A., & Zhao, X. (2019). Language history questionnaire (LHQ3): An enhanced tool for assessing multilingual experience. *Bilingualism: Language and Cognition*, 1–7.
- Li, J., Zheng, Y., & Yang, J. (2018). The influence of second language proficiency on the automatic activation of Chinese during English lexical access in Chinese-English bilinguals. *Foreign Language Teaching and Research*, 50(1), 101–113.
- Monaco, E., Jost, L. B., Gygax, P. M., & Annoni, J.-M. (2019). Embodied Semantics in a Second Language: Critical Review and Clinical Implications. *Frontiers in Human Neuroscience*, 13, 1–21.
- Matuschek, H., Kliegl, R., Vasishth, S., Baayen, H., & Bates, D. (2017). Balancing Type I error and power in linear mixed models. *Journal of Memory and Language*, 94, 305–315
- Monaco, E., Mouthon, M., Britz, J., Sato, S., Stefanos-Yakoub, I., Annoni, J. M., & Jost, L. B. (2023). Embodiment of action-related language in the native and a late foreign language – An fMRI-study. *Brain and Language*, 244, 1–12.
- Norman, T., & Peleg, O. (2022). The reduced embodiment of a second language. *Bilingualism: Language and Cognition*, 25(3), 406–416
- Pylyshyn, Z. W. (1984). *Computation and cognition*. Cambridge, MA: MIT Press.
- Pulvermüller, F. (2005). Brain mechanisms linking language and action. *Nature Reviews Neuroscience*, 6(7), 576–582.
- Pavlenko, A. (2012). Affective processing in bilingual speakers: Disembodied cognition? *International Journal of Psychology*, 47(6), 405–428.
- Tang, D., Fu, Y., Wang, H., Liu, B., Zang, A., & Kärkkäinen, T. (2023). The embodiment of emotion-label words and emotion-laden words: Evidence from late Chinese–English bilinguals. *Frontiers in Psychology*, 14, 1–11.
- Willems, R. M., & Francken, J. C. (2012). Embodied cognition: Taking the next step. *Frontiers in Psychology*, 3, 1–3.

- Xie, Z. (2018). The influence of second language (L2) proficiency on cognitive control among young adult unbalanced Chinese-English bilinguals. *Frontiers in Psychology*, 9, 412–412.
- Zhang, X., Yang, J., Wang, R., & Li, P. (2020). A neuroimaging study of semantic representation in first and second languages. *Language, Cognition and Neuroscience*, 35(10), 1223–1238.