

Abstract

Language experience influences cognition. Here, we provide converging behavioral and neural evidence that bilingual experience can change semantic associations. In Experiment 1, Spanish- and English-speaking bilinguals rated semantically unrelated picture pairs (e.g., *cloud-present*) as significantly more related in meaning than English monolinguals. Experiment 2 demonstrated that bilinguals who were highly proficient in Spanish and English rated both semantically related (e.g., *student-teacher*) and unrelated picture pairs (e.g., *wall-fruit*) as more related than monolinguals and low-proficiency bilinguals. Experiment 3 added ERP measures to provide a more sensitive test of the bilingual effect on semantic ratings, which was assessed with linguistic stimuli (related and unrelated words instead of pictures) and a different bilingual population (Korean-English bilinguals). Bilingualism was associated with a significantly smaller N400 effect (i.e., N400 for unrelated - related), suggesting that bilinguals processed related and unrelated pairs more similarly than monolinguals; this result was coupled with a non-significant behavioral trend of bilinguals judging unrelated words as more related than monolinguals did. Across the three experiments, results show that bilingual experience can influence perceived semantic associations. We propose that bilinguals' denser and more interconnected phonological, orthographic and lexical systems may change the links between semantic concepts.

Introduction

How does bilingualism affect concept associations?

- Connectionist models of language (e.g., McClelland & Rumelhart, 1981; Shook & Marian, 2013) posit that conceptual processing can be influenced by lexical and phonological information.
- Based on Hebbian learning theory (Hebb, 1949), frequent coactivations of words and concepts should lead to closer associations between them (e.g., *popcorn-movie*).
- In bilinguals, each concept is linked to two sets of lexical and phonological representations with different similarity patterns (e.g., phonological similarities in English: *cat-hat*; Spanish: *gato(cat)-pato(duck)*).

Hypothesis: Bilinguals' greater number of connections at the phonological and lexical levels may cause their conceptual nodes to be more closely linked than those of monolinguals.

- Three behavioral and ERP experiments were conducted to test this hypothesis.

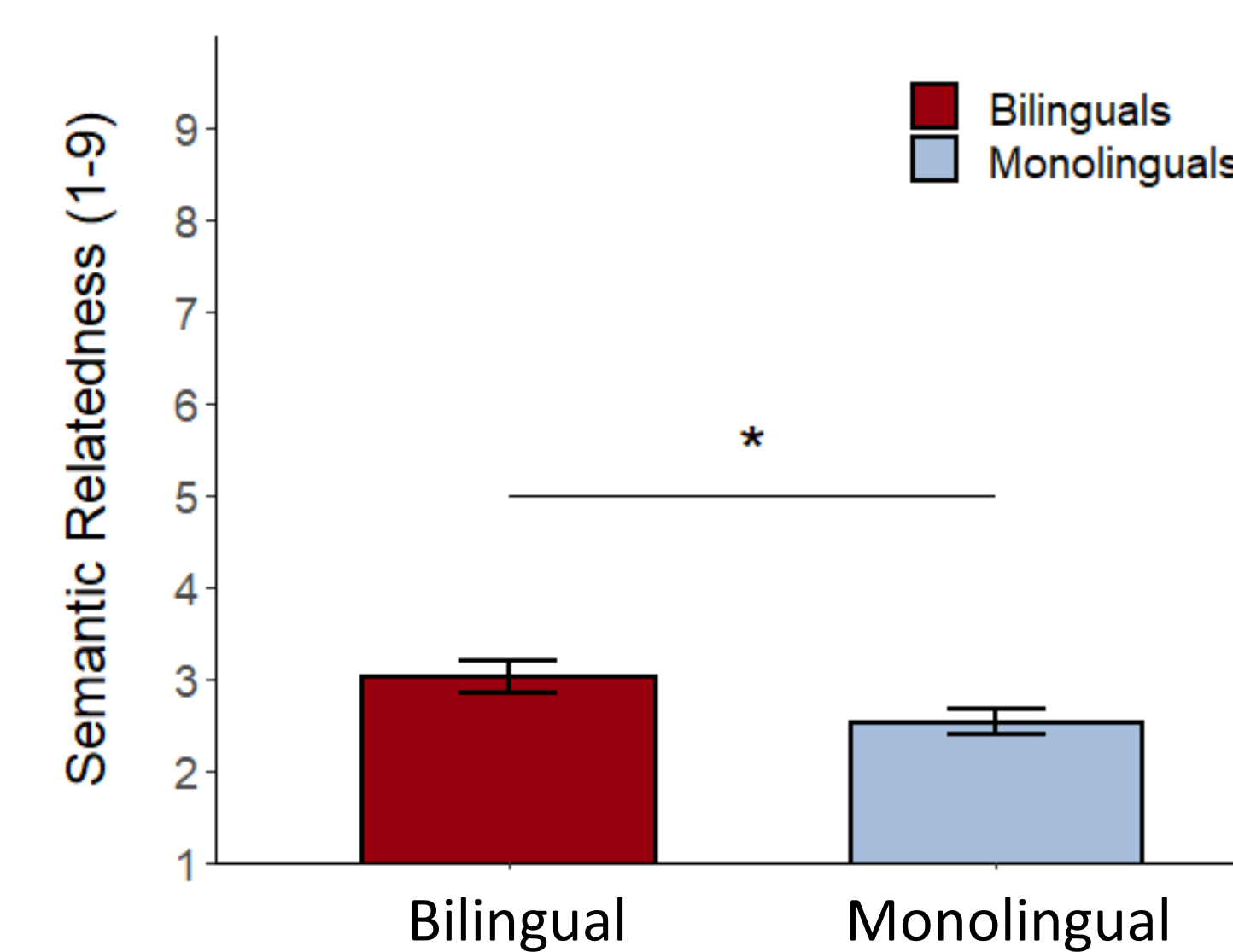
Experiment 1: Bilinguals vs. Monolinguals

Aim: Compare bilinguals (BL) and monolinguals (ML) in rating the semantic relatedness of concept pairs.

Methods: 27 English ML and 19 Spanish-English BL (L2 AOA = 3.5 yrs; proficiency = 9.5/10) viewed 15 picture pairs (e.g., *cloud-present*) and rated how related in meaning they were from 1-9.

Results: Significant effect of group; BL ($M = 3.02$) rated the semantic relatedness of picture pairs higher than ML ($M = 2.54$), $p = .026$.

Discussion: Bilinguals perceived concepts as more related than monolinguals. What are some factors that may influence this bilingualism effect?



Experiment 2. Effects of Relatedness and Proficiency

Aim 1: Compare bilinguals' and monolinguals' relatedness judgments of inherently related and unrelated concept pairs.

Aim 2: Examine whether bilinguals' semantic associations are influenced by proficiency in their non-dominant language.

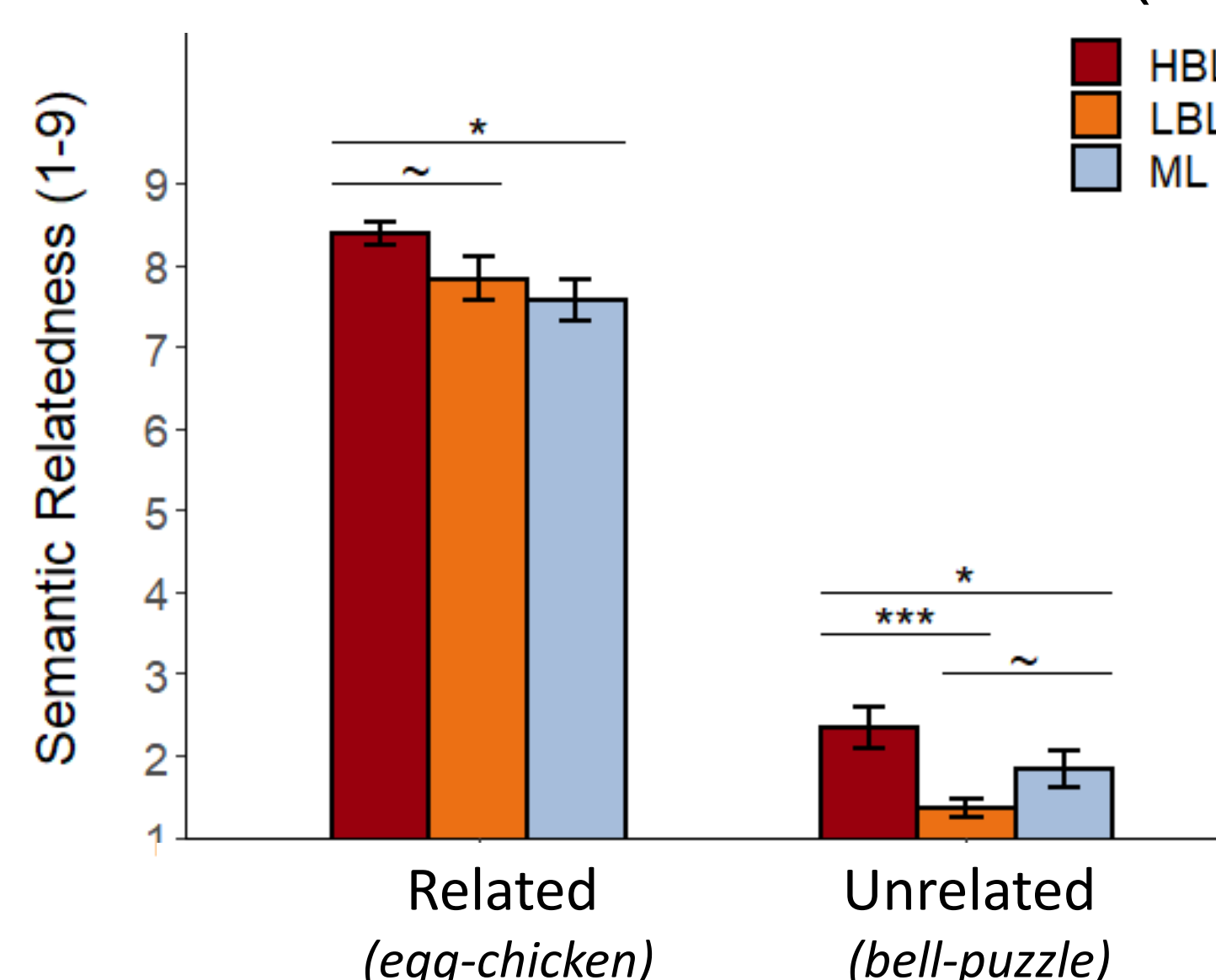
Methods: 18 English ML, 11 high-proficiency BL (HBL; L2 AOA = 5.1 yrs, proficiency = 8.1/10) and 7 low-proficiency BL (LBL; L2 AOA = 12 yrs, proficiency = 5.9/10) of English and Spanish rated the semantic relatedness of 120 related (e.g., *egg-chicken*) and unrelated (e.g., *bell-puzzle*) picture pairs from 1-9.

Results:

- Significant main effect of group; HBL gave higher ratings than LBL & ML, $p < .001$.
- Significant main effect of relatedness, $p < .001$. Significant group (ML vs. LBL) * relatedness interaction, $p < .001$.
- HBL ($M = 2.33$) gave higher ratings for unrelated pairs than both LBL ($M = 1.35$; $p < .001$) and ML ($M = 1.83$; $p = .045$). HBL ($M = 8.39$) also gave higher ratings for related pairs than ML ($M = 7.57$; $p = .014$).

Discussion:

- Replicating Exp1 findings, bilinguals gave higher semantic relatedness ratings than monolinguals, with comparable increases for semantically related and unrelated pictures.
- HBL gave higher ratings than LBL and ML, suggesting that the strengthening of concept associations takes time and repeated co-activations.



Experiment 3A: Effect of Stimulus Type (Word vs. Picture)

Aim: Investigate effects of using word vs. picture stimuli by conceptually replicating Experiment 2 with written words.

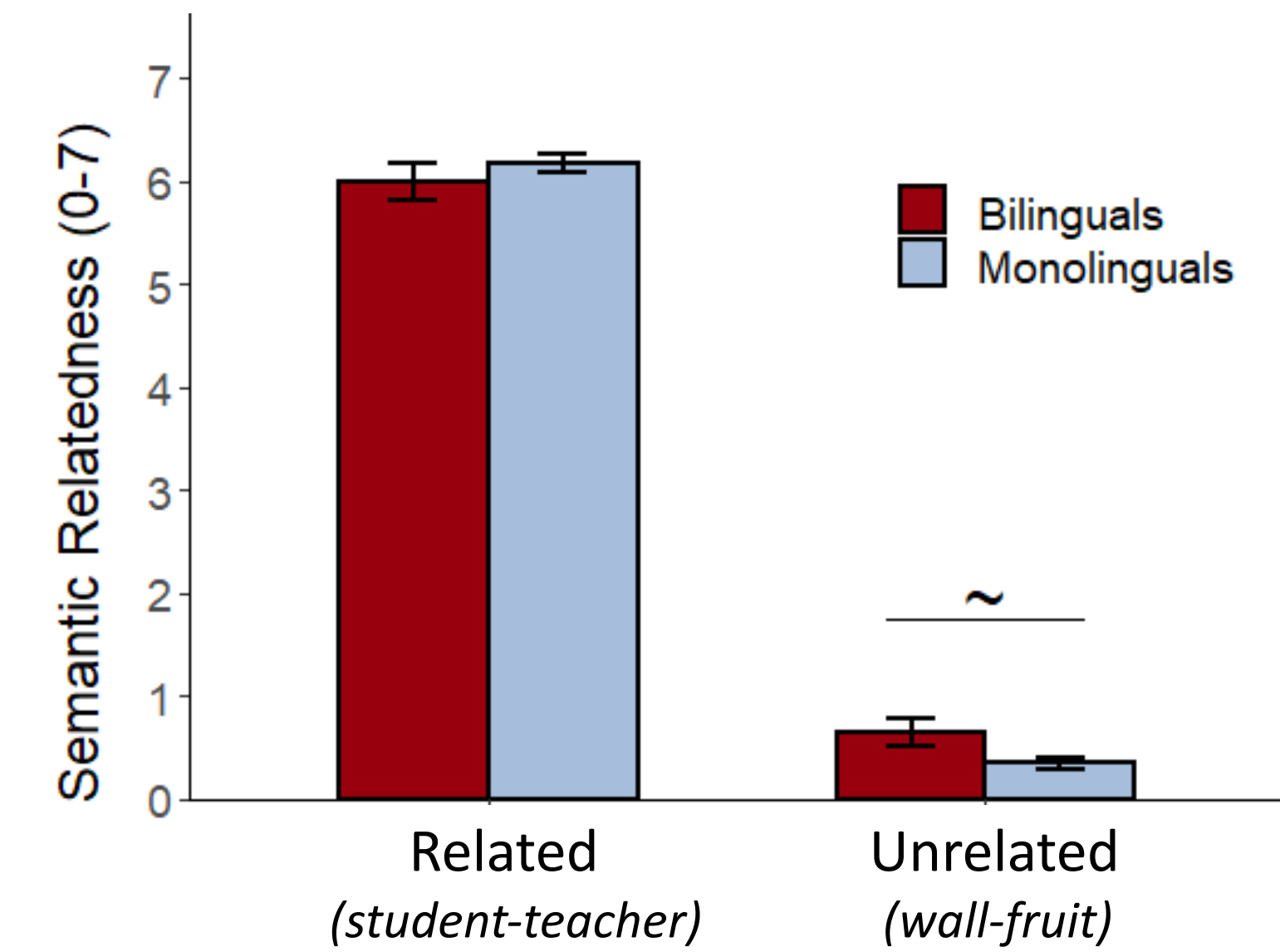
Methods: 23 English ML and 22 Korean-English BL (L2 AOA = 5.48 yrs, proficiency = 8.7/10) rated the semantic relatedness of 392 semantically related (e.g., *student-teacher*) and unrelated (e.g., *wall-fruit*) word pairs from 0-7.

Results: Significant group * relatedness interaction, $p < .05$.

- Unrelated: Nonsignificant trend of BL giving higher ratings than ML, $p = 0.086$.
- Related: No significant group difference was found, $p = .52$.

Discussion:

- With word instead of picture stimuli, the BL-ML difference in semantic relatedness ratings is reduced to a non-significant trend in the unrelated condition.
- Bilinguals' lower exposure to English words compared to monolinguals may have reduced the semantic associations they perceive between English words and corresponding concepts. This may be especially true for related words, which are coactivated more frequently, particularly for monolinguals.



Experiment 3B: Neural Measures of Relatedness

Aim: Examine the neural processing of inherently related and unrelated words in bilinguals and monolinguals.

Methods: Participants from Exp3A gave Yes/No judgments on whether 224 auditory word pairs were semantically related or not by button press while their EEG signals were collected.

Results (Behavioral): Nonsignificant trend of BL categorizing more unrelated pairs as related than monolinguals, $p = 0.079$.

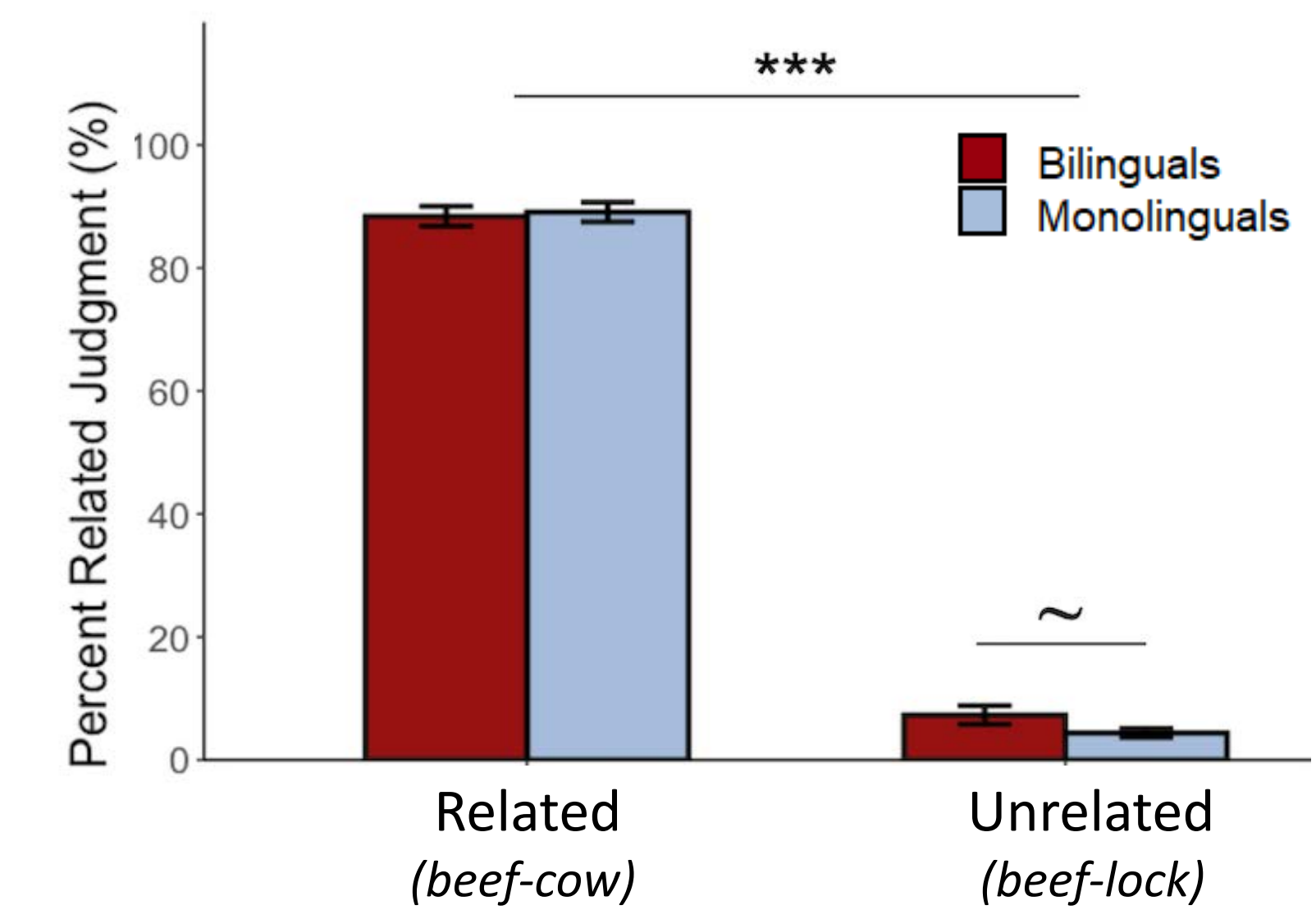
Results (ERP):

- Significant effect of relatedness: EEG amplitudes during N400 were smaller when presented with related vs. unrelated word pairs, $p < .001$.
- Significant group * relatedness interaction. BL had a smaller N400 effect size (between-condition difference; $M = 2.39mV$) than ML ($M = 3.88mV$), $p = .012$.
- The main effect of group was not significant, $p = .24$.

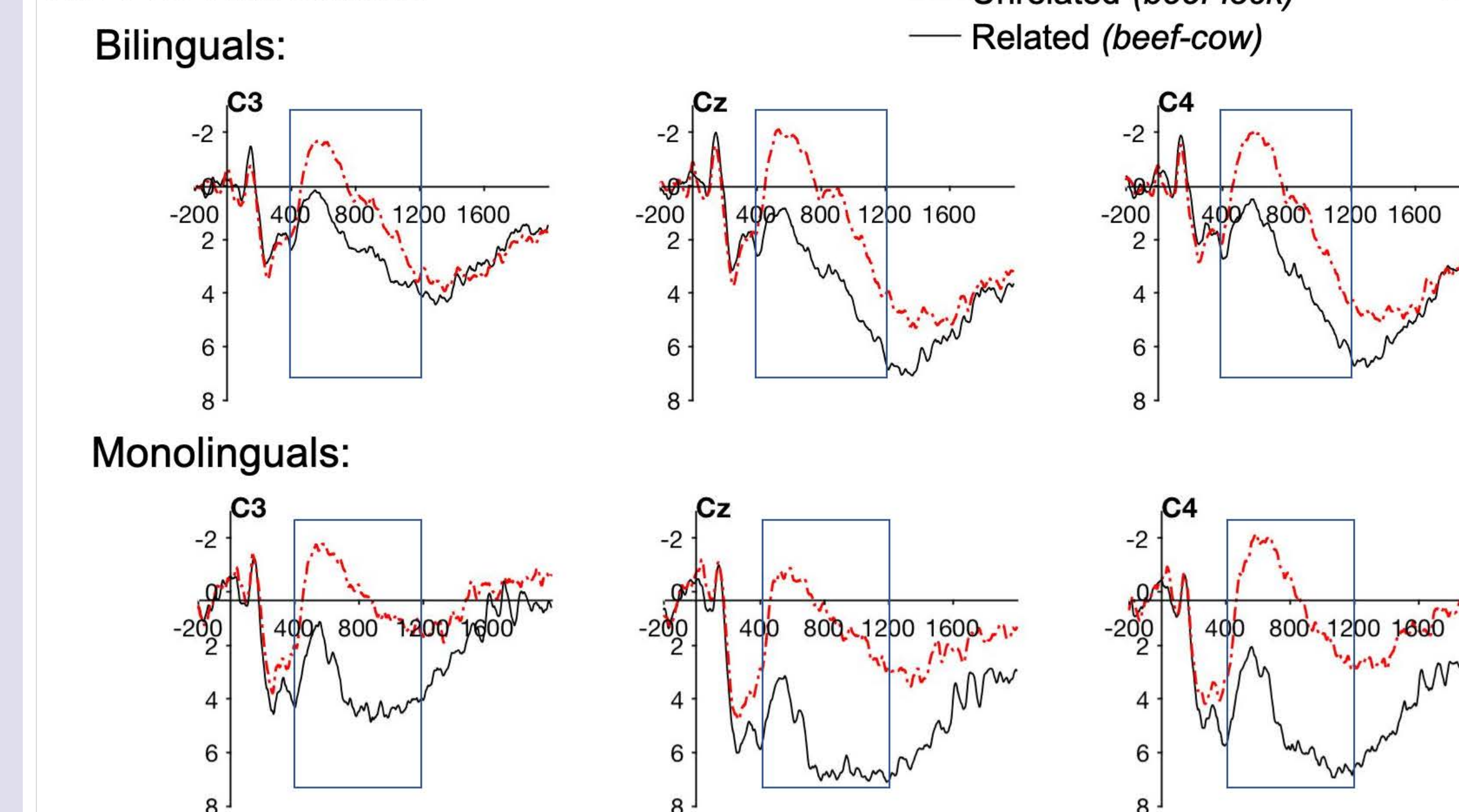
Discussion:

- N400 is reduced by semantic priming. All participants showed smaller N400 amplitudes for related vs. unrelated stimuli, consistent with the literature.
- Bilinguals displayed a smaller N400 effect (i.e., N400 for unrelated - related) than monolinguals, suggesting that bilinguals processed unrelated and related concept pairs in a more similar way than monolinguals. Combined with behavioral data, results indicate that bilinguals may perceive semantically unrelated words as more related than monolinguals do, but this bilingual increase may be negligible for inherently related words. This asymmetrical effect echoes Exp3A findings and may be attributed to using word stimuli.

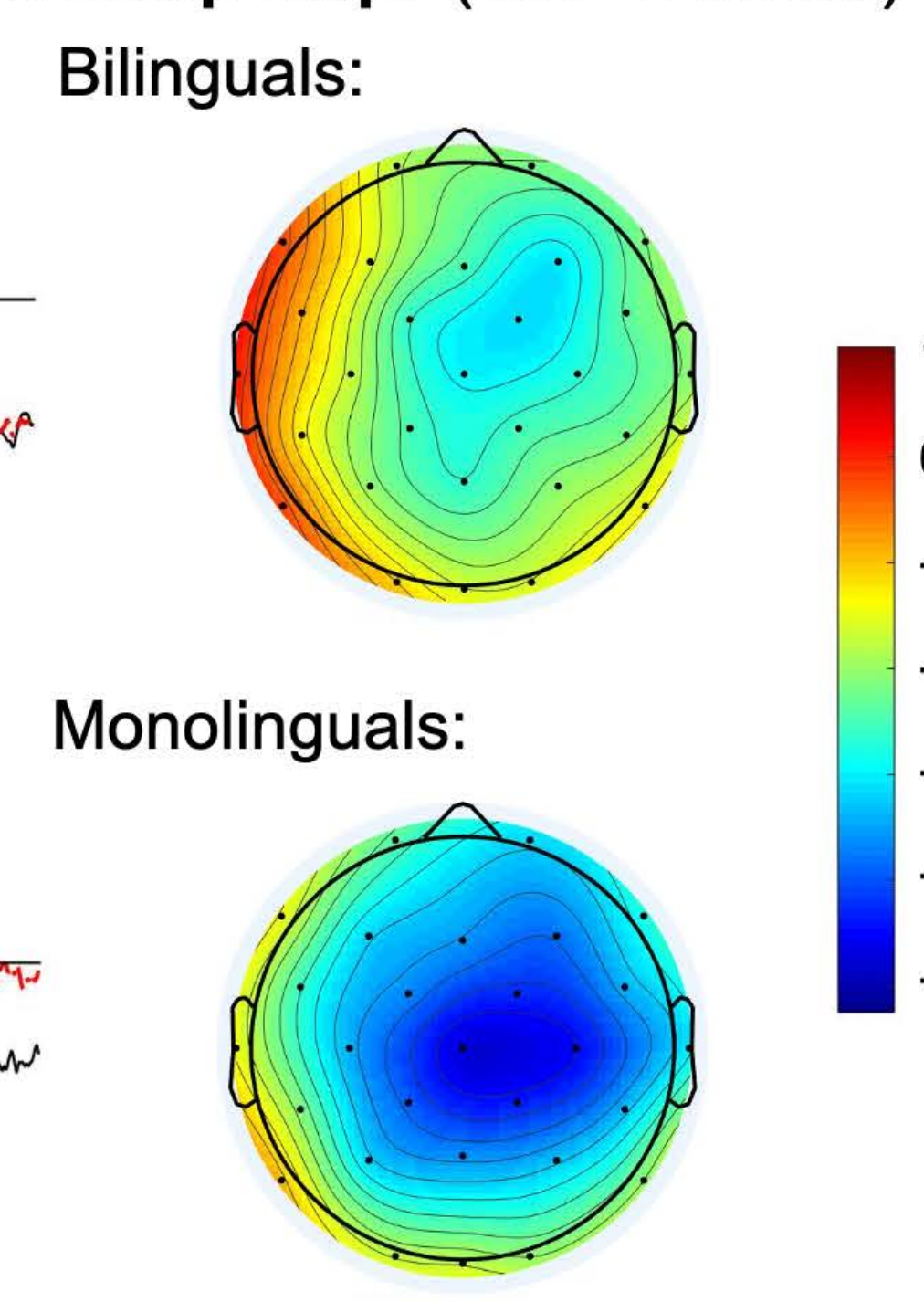
Behavioral Results:



A. EEG Waveforms



B. Scalp maps (400-1200 ms)



ERP Results:

(A) ERP waveforms recorded at centro-parietal sites in bilinguals ($N = 15$) and monolinguals ($N = 16$) in response to related and unrelated auditory word pairs. (B) Voltage scalp topography of bilingual and monolingual N400 difference waves (calculated by subtracting mean related amplitudes from mean unrelated amplitudes) from 400 to 1200ms. The scale extends from $-5 \mu V$ to $1 \mu V$, with bluer shades representing a larger N400 effect.

Discussion

Extensive bilingual experience changes concept associations:

- Bilinguals' denser and more interconnected phonological and lexical systems may cause them to think of concepts as more related than monolinguals do. This effect is modulated by bilinguals' L2 proficiency and is seen across both related and unrelated concepts when tested with pictures but only emerges for unrelated concepts with word stimuli.

Results support connectionist models of language:

- Structures of phono-lexical levels can influence conceptual level associations.

Results may have implications for bilingual creative thinking (e.g., Kharkhurin, 2010; Ricciardelli, 1992), which might be influenced by language structures.