Journal of Experimental Psychology: Learning, Memory, and Cognition

The Influence of Complete and Partial Shared Translation in the First Language on Semantic Processing in the Second Language

Tal Norman, Zohar Eviatar, and Tamar Degani

Online First Publication, September 19, 2024. https://dx.doi.org/10.1037/xlm0001376

AMERICAN PSYCHOLOGICAL ASSOCIATION

Journal of Experimental Psychology: Learning, Memory, and Cognition

ISSN: 0278-7393

https://doi.org/10.1037/xlm0001376

The Influence of Complete and Partial Shared Translation in the First Language on Semantic Processing in the Second Language

Tal Norman[1], Zohar Eviatar[2], and Tamar Degani[1]

[1] Department of Communication Sciences and Disorders, University of Haifa

[2] Department of Psychology, University of Haifa

This study investigated (a) whether L2 semantic processing is modulated by automatic activation of L1 translations, (b) whether L1 translation activation involves both phonological and orthographic representations, and (c) whether these phonological and orthographic representations of L1 translations are accessed along a similar time course. To this end, 48 Hebrew–English bilinguals and 48 native English speakers with no Hebrew knowledge performed a semantic relatedness judgment task in English. Critical prime–target pairs ($n = 96$) were semantically unrelated, but their translations in Hebrew could include form overlap. Specifically, complete translation-overlap pairs shared both a phonological and an orthographic lexical form (e.g., “beak” and “source” = מקור /makor/), whereas partial translation-overlap pairs shared either a phonological form (e.g., “skin” and “light” = /or/) or an orthographic form (e.g., “book” and “barber” = ספר) in Hebrew. Stimulus onset asynchrony (SOA) of the prime–target L2-English words was further manipulated to reveal the time course of phonological and orthographic translation activation. Results showed that complete overlap in the translation lead Hebrew–English bilinguals, but not native English speakers, to judge semantically unrelated pairs as related in meaning and to do so more quickly irrespective of SOA. For partial translation overlap in phonology, the percentage of “yes” responses was affected only in the short SOA (300 ms), and under partial translation overlap in orthography, only in the long SOA (750 ms). These findings suggest that L1 translation activation during L2 word processing spreads to both phonological and orthographic representations but at different time points along processing.

Keywords: translation activation, cross-language influences, shared-translation effect

One of the core characteristics of multilingual language processing is the potential for cross-language influences (cf. Degani et al., 2022) caused by automatic activation of linguistic representations from the language not currently in use. Evidence for such activation serves as a hallmark for the view that multilingual language access is fundamentally nonselective (T. Dijkstra & Van Heuven, 2002; T. O. N. Dijkstra et al., 2019; Kroll et al., 2006). Notably, this prominent view is mostly supported by evidence demonstrating a form-mediated effect, in which similarity across languages in phonological and/or orthographic form leads to activation of nontarget language representations. For instance, cognate and false-cognate words that share phonological and/or orthographic form across languages are processed differently than noncognate items, suggesting that form overlap leads to activation of the other language during comprehension tasks (for review, see e.g., Degani & Tokowicz, 2010; T. Dijkstra, 2005; Lauro & Schwartz, 2017). However, the degree to which nontarget language representations are activated in the *absence* of form overlap, and specifically whether target language words lead to automatic activation of their nontarget language *translations*, has received less work (but see evidence from translation priming studies, e.g., Altarriba & Basnight-Brown, 2007; Schoonbaert et al., 2009). The goal of the present study is to contribute to this literature and specifically examine three interrelated goals. One, does automatic activation of nontarget language translations affect target language processing? Hence, does the fact that two unrelated words in English (“beak” and “source”) share a translation in another language (both words in Hebrew translate to /makor/) affect the processing of these words by multilinguals who know English and Hebrew? Second, to the extent that the translations are indeed activated, is partial form overlap in the translations sufficient to exert an influence on target language lexical

Keith A. Hutchison served as action editor.

Tamar Degani https://orcid.org/0000-0003-2604-8523

The authors thank Natasha Tokowicz and her lab for their generous assistance in collecting data from native English speakers who served as control in the present study. Tal Norman was partially supported by a postdoctoral fellowship from the University of Haifa during the writing of this article.

All data have been made publicly available through the Open Science Framework and can be accessed at https://osf.io/s2mxf/?view_only=aa7913d9b85a4d249671ef14410717e6 (Norman et al., 2024). This study was not preregistered.

Tal Norman played a lead role in formal analysis, visualization, and writing–original draft. Zohar Eviatar played a supporting role in conceptualization, methodology, resources, software, supervision, and writing–review and editing. Tamar Degani played a lead role in conceptualization, investigation, methodology, project administration, and writing–review and editing and an equal role in resources, software, and supervision.

Correspondence concerning this article should be addressed to Tamar Degani, Department of Communication Sciences and Disorders, University of Haifa, 809 Eshkol Tower, 199 Aba Khoushy Avenue, P.O. Box 3338, Haifa 3103301, Israel. Email: tdegani@research.haifa.ac.il

processing, and are these effects driven by phonological overlap or orthographic overlap of the activated translations? Third, what is the time course of these translation activation effects?

The Shared-Translation Effect

Critical evidence for the activation of translation equivalents comes from studies in which single language items are presented to participants (e.g., words solely in English), but the status of their translations in another language is manipulated. For example, Degani et al. (2011) presented Hebrew–English and English–Hebrew bilinguals as well as English monolinguals with pairs of English words, which could share a Hebrew translation (e.g., the English words "dish" and "tool" are both translated to Hebrew as /kli/) or not. Participants were asked to rate these English word pairs on their semantic similarity. Results showed that shared-translation word pairs, either in the L1 or the L2, were more likely to be rated by bilinguals, and not by monolinguals, as closer in meaning, relative to similarly related different-translation pairs (see also Jiang, 2002, 2004; Jouravlev & Jared, 2020). The study suggested that when the translation equivalents of the presented words in the target language shared both phonological and orthographic information, increased connection of the two words was observed.

Notably, in this and other related studies (see Summary Table 1), participants are not instructed to access their other language, and there is no presentation of stimuli from the nontarget language, as is the case in translation recognition studies (e.g., Ma & Ai, 2018; Sunderman & Kroll, 2006; Talamas et al., 1999) or masked translation priming studies (e.g., Grainger, 1998; Wen & van Heuven, 2017). Furthermore, given that in the included stimuli there is also no form overlap across target and nontarget language representations (as is the case in cognate processing), there are no bottom-up cues to nontarget language activation. Hence, evidence for nontarget language activation under these circumstances can serve as strong evidence in favor of automatic implicit activation of nontarget language representations.

In the study of Degani et al. (2011), there were no cross-language shared orthographic or phonological features, especially given that the target (English) and nontarget languages (Hebrew) differ in their orthographic system. However, as the study utilized an offline semantic relatedness judgment task, participants' strategy and awareness may have been, at least partially, involved (for discussion, see also Meade et al., 2017).

Some support for the fact that shared-translation effects are not dependent on participants' awareness comes from studies that utilize a timed task. Specifically, Jouravlev and Jared (2020) reported faster responses and reduced N400 event-related potential (ERP) waveform on a primed lexical decision task, when Russian–English bilinguals responded to L1 targets that were presented after L1 primes that had the same L2 translation, rather than after L1 primes with different L2 translations. Thus, activation of a shared translation in the nontarget language facilitated processing of lexical representations in the target language. Presumably, activation of converging lexical features in the nontarget language makes shared-translation words be perceived as more similar in meaning.

A different approach used to tap this increased semantic relatedness is one in which confusability of words is examined. Specifically, a study by Elston-Güttler and Williams (2008), found that bilinguals, relative to monolinguals, made more errors and displayed longer reaction time (RTs), in an anomaly sentence-judgment task, when the nonsensical final word of the L2 sentence (e.g., His shoes were uncomfortable due to a *bubble*) shared an L1 translation with another L2 word that was compatible with the sentence meaning (e.g., *blister*). This finding again suggests that the L1 translations were activated and led to increased confusability in this paradigm due to their shared form. Together, these studies provide evidence for the activation of nontarget language translation, which due to its overlapping features with another translation, lead to increased connectivity of target language words.

Of note, increased connectivity of translation words may lead to facilitation under some task demands (e.g., priming Jouravlev & Jared, 2020; similarity ratings, Degani et al., 2011) but to response competition under other task requirements. Specifically, if the target-language appropriate response in the task is one of no relation, the presence of a connection via the translations may lead to increased confusability and response competition (e.g., anomaly judgment task, Elston-Güttler & Williams, 2008; semantic relatedness, Thierry & Wu, 2004). Thus, both facilitation and response competition may stem from increased connectivity of the translations depending on the particular instantiation of the task (but see Elston-Güttler et al., 2005, for suggestions of inhibitory connections among the shared translations).

Regardless of the direction observed in a particular task, these findings indicate that bilinguals automatically activate the lexical representations of nontarget language translation equivalents during target language word reading, which in turn, modulate the lexico-semantic processing of these shared-translation target words. However, the extent to which this lexico-semantic modulation during L2 word processing, caused by L1 translation activation, is mediated by phonological and/or orthographic lexical activations and the time course of these lexical effects is not yet clear and is the focus of the present study.

Partial Translation Overlap

The reviewed literature suggests that *complete* overlap in the activated translations affects processing. In such cases, the translation of one word of each pair (e.g., "tool") is identical to that of the other word (e.g., "dish", both translating into Hebrew as /kli/ כלי); thus, the exact same phonological and orthographic features are activated. However, these studies do not dissociate the contribution of a shared phonology versus a shared orthography, such that it is unclear to what extent *partial* overlap in the translation is sufficient to affect processing.

Some evidence for the possibility that partial overlap in the translations can affect target language processing comes from a study of T. Zhang et al. (2011). In that study, Chinese–English bilinguals performed a masked priming lexical decision task in English. Results showed that English word pairs whose Chinese translations shared the first morpheme were processed more quickly than English word pairs with no shared Chinese morpheme. Because presentation of the first of the two English words was brief (59 ms), the authors concluded that fast and automatic activation of the translation occurred together with its morphological decomposition. Interestingly, in a series of studies, Wen and van Heuven (2018) failed to replicate this effect. By manipulating the duration of the prime, as well as whether it was presented in the target or nontarget

Table 1
Summary Table of Studies Testing for the Shared-Translation Effect (Implicit Automatic Translation) Using Single-Language Paradigms

Study	Shared translation	Target population	Measure	Task	Timing (SOA)	Presented stimuli	Result	Comment
Unimodal bilinguals								
Jiang (2002)	Complete	Chinese–English bilinguals	Behavioral	Semantic relatedness ratings, semantic relatedness judgment	Simultaneous presentation for 1,670 ms	Semantically related English pairs	Higher ratings and shorter RTs for shared-translation pairs	
Jiang (2004)	Complete	Korean–English bilinguals	Behavioral	Semantic relatedness judgment	Simultaneous presentation until response	Semantically related English pairs	Shorter RTs and fewer errors on shared-translation pairs	
Degani et al. (2011)	Complete	Hebrew–English and English–Hebrew bilinguals	Behavioral	Semantic relatedness ratings	No constraint	Related and unrelated English pairs	Increased semantic relatedness for shared-translation pairs	Bidirectional, L1 on L2 and L2 on L1
Degani and Tokowicz (2013)	Complete	English–Spanish bilinguals	Behavioral	Timed semantic decision	Simultaneous presentation until response	Pair of English phrases representing different meanings of ambiguous English words (e.g., dinner date–expiration date), with a shared/different Spanish translation	Interference when meanings shared a translation in both English and Spanish	
Elston-Güttler and Williams (2008)	Complete	German–English bilinguals	Behavioral	Anomaly sentence judgment task	SOA 250 ms (from end of prime)	Final anomalous English word shared a translation with a plausible English completion	Increased confusability for shared-translation words	Noun/verb manipulation
Elston-Güttler et al. (2005)	Complete	German–English bilinguals	ERP and behavioral	Priming (ERP)	SOA 200 ms (from end of prime)	English word pairs with a shared German translation	N200 ERP reversed priming; RT interference	Proficiency modulation; sentence context modulations
Jouravlev and Jared (2020)	Complete	Russian–English bilinguals	Behavioral	Primed lexical decision task	SOA 250 ms	Prime–target Russian words; manipulation of conceptual relatedness of the meanings	RT effects for conceptual identical shared translation; ERP for all shared translations	
Wu et al. (2013)	Partial	Chinese–English bilinguals	Eye tracking	Visual shape search task (along with distractor English words)	Simultaneous presentation of shapes and distractor English words, until response	English words with sound repetition of the words circle and square	Bilinguals looked more at competitors sharing phonology with circle/ square; no behavioral effects	
Mishra and Singh (2016)	Partial	Hindi–English	Eye tracking	Visual world paradigm	Visual array 1000 ms prior to auditory target	Auditory targets' translation overlapped phonologically with distractor pictures' translation	Bilinguals looked more at competitors with shared phonology in the translations	Proficiency modulation; bidirectional, L1 on L2 and L2 on L1
Shook and Marian (2019)	Partial	English/Spanish	Eye Tracking	Visual world paradigm	Visual array 500 ms prior to auditory target	Auditory targets' translation overlapped phonologically with distractor pictures' translation	Bilinguals looked more at competitors with shared phonology in the translations	Bidirectional, L1 on L2 and L2 on L1
T. Zhang et al. (2011)	Partial	Chinese–English	Behavioral	Masked priming lexical decision	SOA 82 ms (prime 59 ms, mask 23 ms)	English prime–target pairs whose Chinese translations shared the first or second morpheme	RT priming for pairs with shared first (but not second) morpheme	
Wen and van Heuven (2018)	Partial	Chinese–English	Behavioral and computation	Masked priming lexical decision	SOA 83/114 ms (prime 59 ms/118 ms, mask 24 ms)	English prime–target pairs whose Chinese translations shared the first morpheme	No effects	Effects of translation activation observed in a translation recognition task
Thierry and Wu (2004)	Partial	Chinese–English bilinguals	ERP and behavioral	Semantic relatedness judgment	SOA 1000 ms–1200 ms	Semantically related and unrelated English word pairs whose translations shared a character	ERP N400, RT and error rate, *interference* effects	Concreteness and location of character repetition not controlled

(*table continues*)

Table 1 (*continued*)

Study	Shared translation	Target population	Measure	Task	Timing (SOA)	Presented stimuli	Result	Comment
Thierry and Wu (2007)	Partial	Chinse–English bilinguals	ERP and behavioral	Auditory and visual semantic relatedness judgment	SOA 1000 ms–1200 ms	Semantically related and unrelated English word pairs whose translations shared a character	ERP but no behavioral effects, *facilitation* for unrelated words	
Wu and Thierry (2010)	Partial	Chinese–English bilinguals	ERP and behavioral	Auditory and visual semantic relatedness judgment	SOA 1000 ms–1200 ms	Semantically unrelated English pairs with translation phonological/orthographic overlap	ERP effects for sound repetition but not orthography repetition; no behavioral effects	
Wu and Thierry (2011)	Partial	Chinese–English bilinguals	ERP and behavioral	Rhyme judgment on names of pictures (requires covert naming)	SOA 1000 ms–1200 ms	Pictures whose nontarget language translations shared phonology	N400 ERP, RT and error rate effects suggesting L1 translation activation during L2, but not of L2 during L1	No bidirectional effect
Wu and Thierry (2012a)	Partial	Chinese–English bilinguals	ERP and behavioral	Semantic relatedness judgment	SOA 800 ms–1000 ms	English word pairs; manipulated emotional valence and shared phonology in the translation	ERP effects for sound repetition only for positive and neutral words (not for negative words); no behavioral effects	
Wu and Thierry (2012b)	Partial	Chinese–English	ERP and behavioral	Go/no go visual form judgment on shapes, while ignoring English distractors	500 ms presentation	English words with sound repetition of the words circle and square	N200 ERP effects for sound repetition; no behavioral evidence	
Unimodal and bimodal bilinguals								
Villameriel et al. (2022)	Partial	Bimodal bilinguals Spanish/LSE and Spanish/Basque bilinguals	Eye tracking	Visual world paradigm, in both sign and spoken languages	500 ms display + 2500 ms with sign	Sign and spoken versions	More looks to distractors with shared onset translation (but not rhyme) in the bimodal version; evidence for both in the unimodal version; not all phonological features of the shared sign are activated	Distinguishing overlap in sublexical phonological features (onset vs. rhyme in the spoken language)
Bimodal bilinguals								
Shook and Marian (2012)	Partial	Bimodal English/ASL	Eye tracking	Visual world paradigm	Visual array synchronized with carrier phrase	English auditory targets' translations in ASL overlapped phonologically with distractor pictures' ASL translation	Bilinguals looked more at competitors with shared phonology in the translations	
Kubus et al. (2015)	Partial	Bimodal German/DGS	Behavioral	Semantic relatedness judgment	SOA 1000 ms	German word pairs whose DGS translations shared phonological features	Slower RTs to unrelated German words whose DGS shared phonological features	
Morford et al. (2011)	Partial	Bimodal bilingual English/ASL	Behavioral	Semantic relatedness judgment	SOA 1000 ms	Semantically related and unrelated English word pairs whose ASL translations shared phonological features	RT effects—with partial shared translation—longer RTs for semantically related pairs and shorter RTs for semantically unrelated pairs	Discussion of time course
Morford et al. (2017)	Partial	Bimodal bilingual English/ASL	Behavioral	Semantic relatedness judgment	SOA 300 ms, 750 ms	Semantically related and unrelated English word pairs whose ASL translations shared phonological features	RT effects—with partial shared translation—longer RTs for semantically related pairs and shorter RTs for semantically unrelated pairs, irrespective of SOA	Proficiency modulation

(*table continues*)

Table 1 *(continued)*

Study	Shared translation	Target population	Measure	Task	Timing (SOA)	Presented stimuli	Result	Comment
Morford et al. (2019)	Partial	Bimodal bilingual English/ASL	Behavioral	Semantic relatedness judgment	SOA 750 ms	Semantically related and unrelated English word pairs whose ASL translations shared phonological features	RT effects only for related pairs	Focus on partial overlap—sublexical aspects of ASL
Meade et al. (2017)	Partial	Bimodal bilingual English/ASL	ERP and Behavioral	Semantic relatedness judgment	SOA 1000 ms	Semantically unrelated English word pairs whose ASL translations shared phonological features	ERP and RT evidence	Reading comprehension modulation; focus on participants' awareness
Hosemann et al. (2020)	Partial	German/DGS	ERP	DGS prime–target pairs embedded in sentences (presented as videos)	SOA over 1000 ms	DGS pairs sharing German orthography and phonology	N400 ERP priming	
Ormel et al. (2012)	Partial	Bimodal bilingual Dutch/NGT *Children*	Behavioral	Picture verification task	Simultaneous until response	Semantically unrelated Dutch word and picture, whose NGT translation shared phonological features	Slower RT and more errors when (unrelated) word picture pairs shared phonology in NGT translations	

Note. SOA = stimulus onset asynchrony; RT = reaction time; ERP = event-related potential; LSE = Spanish Sign Language; ASL = American Sign Language; DGS = German Sign Language; NGT = Sign Language of the Netherlands.

language, the findings (and model simulations) suggested that the effect of translation activation of the masked prime is weak. However, translation activation of the target word (which is presented in an unmasked manner for lexical decision) does seem to take place. These findings suggested that for behavioral evidence to surface, participants needed to have full access to the word in the target language. Critically, however, these studies focused on partial shared translation in the form of a shared Chinese morpheme, but it is difficult to extract from these results whether phonological overlap and/or orthographic overlap of the translations could independently affect processing.

Other paradigms that have been used to tap the automatic activation of translations and the effect of partial overlapping features include the visual world paradigm (Misrha & Singh, 2016; Shook & Marian, 2012, 2019; Villameriel et al., 2022). In these studies, participants are auditorily presented with a target word (e.g., the word "duck" in English) and are asked to select the appropriate referent of a visually presented display. Of relevance, eye movements in such paradigms are measured to examine looks to distractor referents (e.g., a picture of a shovel) whose nontarget language translation (e.g., /pala/ in Spanish = shovel) shares a feature with the translation of the presented target (e.g., /pato/ = "duck" in Spanish). Notably, however, as these studies include auditory presentation of the target word, the cascaded flow of processing of the target language may be different from that of visually presented words (especially with respect to time course). Furthermore, such studies cannot determine the extent to which this translation activation effect was driven by phonological and/or orthographic translation activation, since phonologically related distractors are also orthographically related in most cases (e.g., pato vs. pala).

Moreover, many of the studies that utilized the visual world paradigm tested bimodal bilinguals (Shook & Marian, 2012; Villameriel et al., 2022), examining the effect of shared features of a sign language (e.g., handshape/location) on processing of the spoken language (or vice versa). Such studies do not allow for clear dissociation between phonological and orthographic effects, as targeted in the present study (for additional work on translation activation in bimodal bilinguals using other paradigms, see also Hosemann et al., 2020; Kubus et al., 2015; Morford et al., 2011, 2017, 2019; Meade et al., 2017; Ormel et al., 2012).

The most relevant evidence for the contribution of phonological and orthographic features to the shared-translation effect comes from a series of six ERP studies of Wu and Thierry in which they examined whether brain responses to L2 word pairs were affected by whether or not their L1 translations share an initial character or sound during word reading and listening (Thierry & Wu, 2004, 2007; Wu & Thierry, 2010, 2011, 2012a, 2012b). Thierry and Wu (2007) asked Chinese–English bilinguals to decide whether semantically related and unrelated prime–target L2 English words were related in meaning or not. They found a significant ERP priming effect (i.e., a reduced amplitude in the N400 time window), but no speed or accuracy effects, when the L1-Chinese translations of the L2-English prime–target words shared an initial character and sound (e.g., post, 郵政, /you-zheng/—mail, 郵件, /you-jian/, train, 火車, /huo-che/—ham, 火腿, /huo-tui/) relative to L2 pairs with form-unrelated L1 translations.

To specifically separate the contribution of phonology and orthography to this translation activation effect, Wu and Thierry (2010) employed the same semantic relatedness task, with semantically unrelated L2-English word pairs that their L1-Chinese translations shared either an initial character but not sound (i.e., orthographic overlap; e.g., accountant, 會計, /kuai-ji/—conference, 會議, /hui-yi/) or an initial sound but not character (i.e., phonological overlap; e.g., experience, 經驗, /jing-yan/—surprise, 驚喜, /jing-ya/). In both an auditory and a visual version of the task, they found that sound sharing across the two L1-Chinese translations significantly modulated participants' ERP brain responses, but not their speed and accuracy performance, during the semantic judgments of L2-English word pairs, whereas character sharing had no effect. The authors interpreted their findings to suggest that advanced bilinguals activate the phonology (see also Wu & Thierry, 2012a), but not the orthography, of L1 translations when processing L2 words.

Additional evidence for the activation of shared-translation phonology was indexed by nonverbal tasks of searching for circles and squares, where the translation of target words shared phonology with the words for these shapes (Wu & Thierry, 2012b; Wu et al., 2013; for evidence for the role of phonology and not orthography, see E. H. Zhang et al., 2022, using a masked translation priming paradigm).

These findings are based, however, on a single bilingual population—Chinese–English bilinguals—and it is not clear whether the contribution of phonology and orthography of the activated translation would be the same in a different population of bilinguals with other orthographic systems. Furthermore, the partial shared-translation effect was only evident in brain- (Thierry & Wu, 2007; Wu & Thierry, 2010, 2012a) and eye-tracking indices (Wu et al., 2013) but not in behavioral outcomes (but see Thierry & Wu, 2004, for an exception). Given the behavioral evidence above with full overlap in the translation (e.g., Degani et al., 2011), it is important to examine whether multilinguals' overt responses may be affected by shared phonological and orthographic features of the translation. Moreover, although these studies utilized ERPs, which provide rich characterization of the time course of processing, the studies focused on brain indices locked to the presentation of the target, revealing little evidence regarding the duration of processing of the prime. Finally, although some studies aimed to compare the contribution of different features of the translation (e.g., Villameriel et al., 2022), as evident in Table 1, there are currently no studies that include both complete and partial overlap. Thus, a unique feature of the present study is the inclusion of both complete overlap, phonological overlap, and orthographic overlap in the translation, within the same study.

Time Course of the Effect

The third goal of the present study was to provide evidence regarding the potential time course of activation of phonological and orthographic features of the translation. There is currently very little evidence regarding the time course of translation activation. The series of studies by Wu and Thierry discussed above did manipulate the lag between the prime and the target words, but the results of this manipulation were not reported. Moreover, as noted by Morford et al. (2017), previous work typically utilized long stimulus onset asynchronies (SOAs) of 1 s or more. In their study, Morford et al. (2017) manipulated SOA to include short (300 ms) and long (750 ms) SOAs. Across both durations, they observed that deaf American Sign Language (ASL)–English bilinguals activated ASL phonological features during a semantic judgment task on pairs of English words. However, as these findings focus on cross-modal effects, they do not substantially inform the time course of activation of phonological and orthographic features during unimodal bilingual processing.

The Present Study

To further investigate these issues, the present study employed a semantic relatedness judgment task, in which Hebrew–English bilinguals were asked to decide whether prime–target L2-English word pairs, presented one after the other, were semantically related or not. To examine the separate and joint influence of phonological and orthographic translation activation on the semantic processing of L2 words, we presented L2-English word pairs consisting of L1-Hebrew translations that either shared both a phonological and an orthographic form (e.g., "beak" and "source" = מקור /makor/), a phonological form (e.g., "skin" and "light" = /or/) but not an orthographic form ("עור" vs. "אור"), or an orthographic form (e.g., "book" and "barber" = ספר) but not a phonological form (/sefer/ vs. /sapar/). Finally, to reveal the time course of L1 phonological and orthographic translation activations during visual L2 word processing, we manipulated the time between the presentation of the prime and the target, such that in the short condition, targets were presented 50 ms after the offset of the prime (SOA = 300 ms), whereas in the long condition, they were presented 500 ms after the offset of the prime (SOA = 750 ms).

Our predictions were as follow. If Hebrew–English bilinguals automatically activate L1-Hebrew translations during L2-English word reading, then unrelated English word pairs with translation overlap in Hebrew will be judged as related in meaning, faster and more often relative to nontranslation-overlap pairs. Moreover, if both the phonological and orthographic forms are activated, a stronger semantic effect will be exhibited under complete, relative to partial translation overlap. Finally, if Hebrew–English bilinguals activate the phonological and orthographic forms of L1-Hebrew translations to different extents, then distinct semantic effects will be exhibited under phonological and orthographic translation overlap. Relatedly, if these are activated at different time courses, then differential effects should be exhibited as a function of SOA.

Method

Participants

A total of 96 students participated in the study. Of these, 48 were Hebrew–English bilinguals, and 48 were native English speakers with no knowledge in Hebrew. See Table 2 for participants' characteristics. Bilingual participants were tested at a large university in Israel and were compensated for their participation with class credit or payment. They were native Hebrew speakers who had learned English after the age of 6. Native English control participants were tested at a large mideastern university in the United States and received class credit for their participation. Participants in both groups were not exposed to languages other than their

Table 2
Participants' Characteristics

Measure compared	Hebrew–English bilingual	Native English speaker
Number of participants	48	48
Males/females	13/35	23/25
Age*	24.77 (3.45)	19.27 (4.85)
Education (in years)	13.38 (2.23)	13.13 (1.71)
English age of acquisition*	8.50 (1.24)	0 (0.00)
English subjective proficiency (0–10)*	7.54 (1.27)	9.75 (0.57)
English current use (0–10)*	6.63 (1.42)	9.94 (0.32)
English objective proficiency	0.63 (0.02)	N/A
Hebrew objective proficiency	0.88 (0.07)	N/A

Note. English subjective proficiency is the mean score of the self-rated proficiency in speaking, writing, reading, and spoken language comprehension, on a scale of 0 (*the lowest level of ability*) to 10 (*the highest level of ability*). English current use is the mean score of the self-rated level of current English use in speaking, writing, reading, internet, listening to music/radio, and watching TV/movies, on a scale of 0 (*the lowest level of use*) to 10 (*the highest level of use*). English/Hebrew objective proficiency is the mean accuracy rate in the Mint test (Gollan et al., 2012; see the Procedure section). N/A = not applicable.
* Significant difference between the two groups at the .05 level based on an independent *t* test.

L1 during childhood. Additionally, the native English speakers were not highly proficient in any additional languages. Data from 16 additional participants were excluded because they were exposed to other languages during childhood (seven Hebrew–English bilinguals; nine native English speakers), and two other native English speakers were excluded because of technical problems during administration. All participants were right-handed based on the Edinburgh Handedness Inventory (Oldfield, 1971), free of cognitive deficits, and with normal or corrected to normal vision. Notably, participants in these two groups were not matched in terms of their age. Therefore, this measure was included as a control variable in the statistical analyses.

Design

We employed a 2 × 2 × 4 mixed design with Group (native English speakers/Hebrew–English bilinguals) and SOA (short/long) as between-participant factors, and Translation Overlap (phonological and orthographic/phonological/orthographic/none) as a within-participant factor.

Stimuli

Stimuli consisted of 192 English word pairs. Half (96) were expected to yield a yes response (semantically related pairs) and half were expected to result in a no response (semantically unrelated pairs) based on semantic relatedness norms (described below). The 96 semantically unrelated English word pairs served as critical items in the four translation-overlap conditions. In the phonological and orthographic overlap condition, the two words in each pair corresponded to a Hebrew homonym (i.e., a phonological and orthographic lexical form corresponding to two meanings). In the phonological overlap condition, the two words in each pair corresponded to a Hebrew homophone (i.e., a phonological lexical form with two meanings, each corresponding to a different orthographic form). In the orthographic overlap condition, the two words in each pair corresponded to a Hebrew homograph (i.e., an orthographic lexical form with two meanings, each corresponding to a different phonological form). In the none-overlap condition, the two words in each pair corresponded to two phonologically and orthographically distinct Hebrew words. See Table 3 for examples of stimuli.

Word pairs across these four conditions were matched on the average length (number of letters), frequency (log SubtLex frequency), and orthographic neighborhood density (taken from English Lexicon Project; https://elexicon.wustl.edu/index.html, Balota et al., 2007), of both words. Furthermore, pairs across these four conditions did not differ statistically in semantic and form similarity ratings (see detailed norms below), as well as in the average concreteness rating of both words (Brysbaert et al., 2014; taken from English Lexicon Project).

The remaining 96 semantically related word pairs served as filler items to yield a 50% yes/no ratio and were matched to the critical pairs on all relevant dimensions, other than in semantic similarity rating. See Table 3 for stimuli characteristics.

Selection of Word Pairs With Shared Hebrew Translation

An initial large set of ambiguous Hebrew words (homonyms, homophones, and homographs) were identified based on previous studies that tested within-language ambiguity in Hebrew (Peleg et al., 2012, 2016). First, the two dominant meanings of each ambiguous Hebrew word were translated into English by two proficient Hebrew–English bilinguals. Then, stimuli selection was informed by two sets of norms, collected from separate groups of participants who did not participate in the main experiment, as detailed below. In some cases, there was more than one potential English translation for each meaning of the ambiguous Hebrew word, so both options were normed.

Translation-Overlap Norms

These were collected to verify that both words in each English word-pair indeed elicit the shared Hebrew ambiguous word translation. To this end, English word-pairs were separated, word duplicates were removed, and the remaining words were divided into three lists. Care was taken to ensure that two English translations of the same Hebrew ambiguous word were not presented within the same list, to prevent them from priming each other. Then, each word list was translated to Hebrew by eight Hebrew–English bilinguals. English word-pairs were excluded if one of the words was known by less than five participants, or if one of the words did not elicit the intended shared (or partially shared) Hebrew translation by more than two participants.

Semantic and Form Relatedness Norms

To ensure that the selected critical English word-pairs were indeed unrelated, irrespective of their translation-overlap condition, semantic and form similarity ratings on a scale of 1–7 (with 1 indicating *low similarity* and 7 indicating *high similarity*) were collected from 36 monolingual English speakers with no knowledge

Table 3
Example of Stimuli and Stimuli Characteristics

Translation overlap status	Phonological and orthographic	Orthographic	Phonological	None	Filler
English word pair	Beak–source	Barber–book	Skin–light	Plant–roof	Wife–husband
Hebrew translation	מקור-מקור/makor/-/makor/	ספר-ספר/sapar/-/sefer/	עור-אור/or/-/or/	צמח-גג/tsemax/-/gag/	אישה-בעל/isha/-/baal/
Number of items	16	16	16	48	96
Type of Hebrew words	Homonym	Homograph	Homophone	Two distinct word pairs	Two distinct word pairs
Semantic relation	Unrelated	Unrelated	Unrelated	Unrelated	Related
Average length (number of letters)	6.53_a	5.65_a	7.37_a	6.78_a	7.19_a
Average frequency (log SubtLex)	2.76_a	3.01_a	2.69_a	2.80_a	2.94_a
Average orthographic neighbors	4.37_a	3.06_a	3.17_a	3.01_a	2.33_a
Semantic similarity rating (on a 1–7 scale)	2.28_a	1.87_a	2.09_a	2.13_a	4.00_b
Form similarity rating (on a 1–7 scale)	2.29_a	2.06_a	2.30_a	2.36_a	2.46_a
Average concreteness rating*	3.90_a	4.26_a	3.36_a	3.56_a	3.59_a

Note. Asterisk indicates averege concreteness rating of words was taken from the English Lexicon Project (Balota et al., 2007). Means in the same row that do not share subscripts differ at the .05 level based on a one-way ANOVA with the Bonferroni adjustments for multiple comparisons on the post hoc tests. The average frequency and average orthographic neighbors of one word pair as well as the average concreteness rating of four word pairs could not be obtained. These missing values were replaced with the means of each measure. ANOVA = analysis of variance.

of Hebrew, who were not exposed to languages other than English before Age 10. Using two lists, each word-pair was rated by a minimum of 14 participants. Following these norms, critical English word-pairs were excluded if their form and semantic similarity average exceeded 3.

Selection of Word-Pairs With Separate Hebrew Translation

Semantically unrelated word-pairs for the none-overlap condition and semantically related word-pairs that served as filler items were selected from previous semantic relatedness norms collected from monolingual English speakers in previous studies (Degani et al., 2011; Smith et al., 2014, unpublished). The semantic similarity average rating for the unrelated pairs did not exceed 3 and was above 3.5 for the related pairs (on a scale of 1–7). Furthermore, it was verified that none of these pairs shared a translation in Hebrew, as established in previous English to Hebrew translation norms (Degani et al., 2011) and that no English word was repeated in the experiment.

Procedure

Each trial began with a fixation cross (+) presented for 2 s that was followed by a prime word. To draw participants' attention, the fixation cross blinked once, 100 ms prior to the presentation of the prime, which was displayed for 250 ms in the same location. A blank screen was then presented for 50 ms in the short SOA condition or for 500 ms in the long SOA condition (thus, short SOA = 300 ms; long SOA = 750 ms). Then, the target word was presented at a visual angle of 1.5° below the location of the prime until participants made a response, by pressing yes/no with their right index finger (to avoid decisions being made by both dominant and nondominant hand, see e.g., Peleg & Eviatar, 2008). A fixation cross signaling the beginning of the next trial immediately followed the response. Because relatedness judgments are subjective by nature, no feedback was presented throughout the study. Primes and targets were presented in lowercase font Courier New size 18.

Two versions with pseudorandomized order of word-pairs were created, such that no more than two critical pairs were presented consecutively, and these were never of the same translation-overlap condition. In addition, no more than three pairs, which were expected to yield the same response (yes/no), were presented consecutively. Each of these two versions was presented in a short (300 ms) and long (750 ms) SOA, resulting in a total of four versions of the experiment. Notably, each participant saw only one of the four experimental versions; thus, each version was presented to a quarter of the participants in each group. Ten practice pairs (five expected to yield a yes response and five expected to yield a no response) preceded the experimental trials.

To objectively measure bilinguals' level of proficiency in both languages, following the relatedness judgment task, the Hebrew–English bilingual participants completed a computerized version of the Mint picture-naming task (Gollan et al., 2012) in both English and Hebrew. In this task, they were asked to name out loud as quickly and accurately as possible 33 pictures in one language (see also Prior & Gollan, 2013). Following a short break, in which they filled out a handedness questionnaire (Oldfield, 1971), they were asked to name a different set of 33 pictures in the other language. In both language tasks, pictures were ordered according to their estimated difficulty, and the order of the two language tasks was counterbraced across participants.

Following the picture-naming tasks, the Hebrew–English bilingual participants also completed a vocabulary posttest, in which they were presented with the critical English–Hebrew translation pairs and asked to mark unknown items or translations. Before debriefing, participants completed a detailed language history questionnaire designed to measure their proficiency and use of L1 and L2 (following Degani, 2011).

Materials, data, and analysis script are available through the Open Science Framework platform at https://osf.io/s2mxf/?view_only=aa7913d9b85a4d249671ef14410717e6.

Results

Data Cleaning

Filler trials (i.e., semantically related word-pairs; $n = 9{,}216$) were removed, and analyses included critical trials only (i.e., semantically unrelated word-pairs; $n = 9{,}216$). Critical trials with unavailable RT ($n = 1$) or with English words that were marked as unknown in the vocabulary posttest ($n = 287$) were excluded (3.1%), resulting in 8,928 critical trials for analysis.

Analysis Approach

Results were analyzed using linear mixed-effects models, as implemented in the "lme4" (Baayen et al., 2008) in R (Version 4.0.3; R Core Team, 2020). These models allow to simultaneously account for the variance due to the random selection of participants and items and, thus, to generalize the findings over these two random factors. Two main analyses were performed. First, we analyzed the yes response (1/0) measure to determine under which conditions participants tend to reach a "yes" response, even though a "no" response was expected in all critical trials. In the second analysis, we explored the RT measure as a function of response type (yes/no).

In each analysis, a maximal linear mixed-effects model was submitted to the *buildmer* function in the "buildmer" package (v. 2.2, Voeten, 2019), which uses the *lmer* function (for Gaussian distribution—the RT measure) or the *glmer* function (for binomial distribution—the yes response measure) from the "lme4" package (v. 1.1.−21, Bates et al., 2015). In this maximal model, in addition to random intercepts, random slopes justified by the design were included, to account for the possible variability of participants and/or items in their sensitivity to the experimental manipulations (Barr et al., 2013) Starting from the maximal model, and using backward-fitting model selection procedure, the *buildmer* function systematically simplifies the random slopes until convergence, in addition to using likelihood ratio tests, to examine the contribution of random slopes to the fit of the model (Matuschek et al., 2017, p. 308). The contribution of each fixed effect to the model fit is evaluated via a chi-square test on the residual sum of squares of each model. In both analyses, the fixed variables of interest were set to be included in the selected model (using the *include* subcommand) to allow evaluation of their contribution.

The selected model in each analysis was refitted using the *glmer/lmer* function, and p values for main effects were determined using the *anova* function from the "stats" package, which calculates a Type III analysis of variance (ANOVA) table with Satterthwaite's method. Additionally, within the two selected models, interactions and pairwise comparisons were further tested using the *testInteraction* function from the "phia" package (v.0.2-1, Martinez, 2015), which computes chi-square test with Bonferroni adjustments for multiple comparisons.

For the yes response analysis, the maximal model included (a) the (dummy coded) fixed effects of Group (Hebrew–English bilinguals/native English speakers, with "native English speakers" as the reference level), Translation Overlap (phonological and orthographic/orthographic/phonological/none, with "none" as the reference level), SOA (short = −0.5/long = 0.5, with 0 as the reference), and the interactions among them; (b) the fixed effect of the control variable Age (normalized; to control for the significant difference between the Hebrew–English bilinguals and the native English speakers in age); and (c) the random effects of Participants and Items, with by-participant and by-item intercepts, by-participant slope for Translation Overlap, and by-item slopes for Group and SOA.

RT data were log-transformed (Nicklin & Plonsky, 2020), since examination of the RT distribution revealed substantial deviation from normality.[1] Indeed, log transformation improved the QQ plot, skew, and kurtosis of the RT distribution (skew: raw RT = 2.07, log RT = −0.39; kurtosis: raw RT = 6.69, log RT = 5.46). Log RTs were then submitted to the *buildmer* function with the same maximal model of fixed and random effects, as in the yes response analysis, except that here Response Type (yes/no; dummy coded; with "yes" as the reference level) was added to the fixed and random effects.

Finally, our analyses were guided by the hypothesis that performance in the three critical translation-overlap conditions (i.e., the "phonological and orthographic", "phonological", and "orthographic") would significantly differ from the control "none" overlap condition, but only in the Hebrew–English bilingual group. Thus, in both measures planned contrasts were performed, testing none versus phonological and orthographic, none versus phonological, and none versus orthographic, separately for each group.

Analyses

Model 1: Yes Response

Table 4 presents the ANOVA table for the selected model in the yes response analysis (see Table A9 in the Appendix for model summary). As shown in the table, the main effect of Group was significant, such that the percentage of yes responses was higher in the group of Hebrew–English bilinguals than in the group of native English speakers, irrespective of the other variables. The main effect of Translation Overlap was significant but was critically modified by Group and SOA, as the two-way interaction between Translation Overlap and Group, as well as the three-way interaction among Translation Overlap, Group, and SOA, were also significant.

To examine the critical interaction between Group and Translation Overlap, we examined the three planned contrasts, separately for each Group. As seen in Table 5 and Figure 1, there was a significant effect only in the phonological and orthographic versus none contrast and only for Hebrew–English bilinguals.

To better understand the effect of SOA on the interaction between Group and Translation Overlap, two additional models—one for each SOA condition—were fitted to the critical data set using the *buildmer* approach (see the Analysis Approach section above).

Within the selected *short SOA model,* the main effect of Group was significant, $\chi^2(1) = 19.45$, $p < .001$, as was the main effect of Translation Overlap, $\chi^2(3) = 10.14$, $p < .001$, and the interaction between them, $\chi^2(3) = 8.06$, $p < .001$. Model summary showed that the interaction between Translation Overlap and Group was driven by a significant modulation of the contrast between the phonological and orthographic versus the none overlap conditions ($b = 1.75$, $SE = 0.36$, $z = 4.89$, $p < .001$) and the phonological versus the none

[1] We additionally fitted a general linear model predicting raw RTs, using a gamma distribution with an identity link (after removing RTs smaller than 300ms and greater than 5000ms). This model yielded the same pattern of results as the model predicting log RTs. See Lo and Andrews (2015) and Lupker and Spinelli (2023) for further discussion on model fitting of skewed RT data.

Table 4
Model 1: ANOVA Table of the Fixed Effects and Interactions Within the Selected Model

Fixed effect/interaction	*df*	*F* value	*p* value
Group	1	30.257	**<.001**
SOA	1	0.107	.744
Translation overlap	3	6.070	**<.001**
Group: SOA	1	0.415	.520
Group: translation overlap	3	6.731	**<.001**
SOA: translation overlap	3	2.509	.057
Group: translation overlap: SOA	3	3.605	**.013**

Note. Bolded *p* values are significant. ANOVA = analysis of variance; SOA = stimulus onset asynchrony.

overlap contrast ($b = 0.69$, $SE = 0.34$, $z = 2.05$, $p < .05$; see Table A10 for full model summary). Specifically, planned comparisons within each group revealed that Hebrew–English bilinguals exhibited significantly higher percentage of yes responses in the phonological and orthographic (*estimated* $M = 30\%$, $SE = 7\%$), compared to the none overlap condition, estimated $M = 15\%$, $SE = 3\%$; $\chi^2(1) = 8.55$, $p = 0.041$. However, for native English speakers, the percentage of yes responses in the phonological and orthographic (estimated $M = 4\%$, $SE = 2\%$) and none (estimated $M = 8\%$, $SE = 2\%$) overlap conditions did not differ significantly, $\chi^2(1) = 2.47$, $p = 1.00$.

The difference between the phonological and none overlap conditions did not reach significance in any of the groups when examined separately but critically was in opposite directions. Specifically, Hebrew–English bilinguals exhibited *higher* percentage of yes responses in the phonological (estimated $M = 22\%$, $SE = 5\%$) compared to the none overlap condition, estimated $M = 15\%$, $SE = 3\%$; $\chi^2(1) = 2.47$, $p = 1.00$; whereas native English speakers demonstrated lower percentage of yes responses in the phonological (estimated $M = 6\%$, $SE = 5\%$) compared to the none overlap condition, estimated $M = 8\%$, $SE = 2\%$, $\chi^2(1) = 0.15$, $p = 1.00$; see Figure 2.

Within the selected *long SOA model*, the main effect of Group was significant, $\chi^2(1) = 15.41$, $p < .001$, as was the main effect of Translation Overlap, $\chi^2(3) = 3.45$, $p < .05$, and the interaction between them, $\chi^2(3) = 4.06$, $p < .01$. Interestingly, in contrast to the short SOA model, here, the interaction between Translation Overlap and Group was driven by significant modulations of the phonological and orthographic versus the none contrast ($b = 1.06$, $SE = 0.36$, $z = 3.00$, $p < .01$) and the orthographic versus the none overlap contrast ($b = 0.82$, $SE = 0.39$, $z = 2.11$, $p < .05$; see Table A11 for full model summary). Follow-up comparisons within each group revealed that Hebrew–English bilinguals exhibited significantly higher percentage of yes responses in the phonological and orthographic (estimated $M = 36\%$, $SE = 8\%$) compared to the none overlap condition, estimated $M = 15\%$, $SE = 3\%$; $\chi^2(1) = 11.67$, $p < .01$, but no such difference existed for native English speakers, phonological and orthographic estimated $M = 8\%$, $SE = 3\%$ versus none estimated $M = 8\%$, $SE = 2\%$; $\chi^2(1) = 0.05$, $p = 1.00$.

Furthermore, the difference between the orthographic and none overlap conditions did not reach significance in any of the groups when examined separately, but the pattern differed. Thus, whereas for Hebrew–English bilinguals the percentage of yes responses in the orthographic (estimated $M = 15\%$, $SE = 4\%$) and the none overlap conditions hardly differed, $\chi^2(1) = 0.02$, $p = 1.00$, native English speakers exhibited lower percentage of yes responses in the orthographic (estimated $M = 3\%$, $SE = 1\%$), compared to the none overlap condition, estimated $M = 8\%$, $SE = 2\%$, $\chi^2(1) = 3.79$, $p = .619$; see Figure 3. Thus, the lower percentage observed for the orthographic overlap condition in native English control participants, was absent in the Hebrew–English bilingual group.

In sum, we found that SOA modulated the effect of Translation Overlap within the group of Hebrew–English bilinguals when the two Hebrew translations of the prime–target English words shared phonology or orthography only. Specifically, in both the "short" and "long" SOAs, Hebrew–English bilinguals tended to respond "yes" more often when the two Hebrew translations shared both a phonological and an orthographic form, compared to a no translation-overlap condition. However, while in the short SOA they tended to do so also when the two Hebrew translations shared only a phonological form, in the long SOA, they tended to do so when the two Hebrew translations shared only an orthographic form. Thus, it seems that phonological overlap between the two L1-Hebrew translations increased the tendency of Hebrew–English bilinguals to judge semantically unrelated English word-pairs as related in meaning, relative to native English speakers, earlier in processing (only in the short SOA). Conversely, orthographic overlap caused this pattern of performance later on, only in the long SOA.

Proficiency Modulations of Yes Response

Next, we wanted to examine whether among Hebrew–English bilinguals the effect of Translation Overlap was modulated by L2 proficiency level. To this end, we fitted an additional model—proficiency modulation model—to the yes response data of the bilingual participants, in which bilinguals' English Mint Accuracy score was used as a measure of L2 proficiency. As before (see the

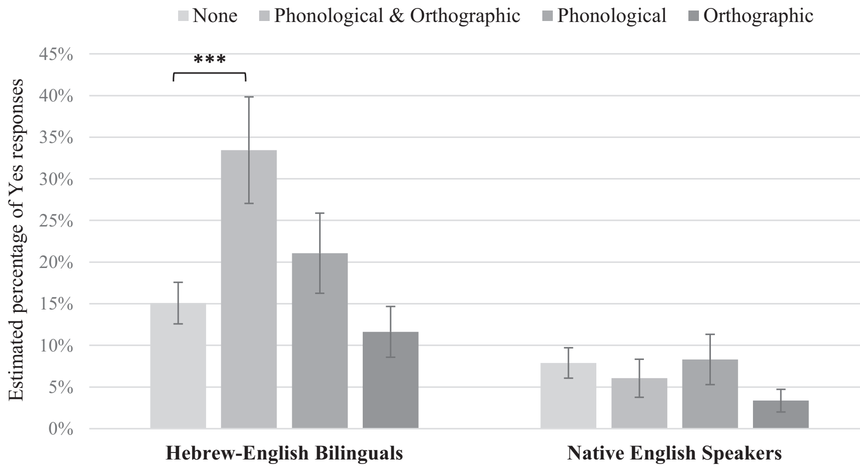
Table 5
Model 1: Planned Contrasts Between the Four Translation-Overlap Conditions in Each Group

Group	Translation-overlap contrast	*df*	χ^2	*p* value
Hebrew–English bilinguals	Phonological and orthographic versus none	1	11.64	**.039**
	Orthographic versus none	1	0.94	1.000
	Phonological versus none	1	1.76	1.000
Native English speakers	Phonological and orthographic versus none	1	0.42	1.000
	Orthographic versus none	1	3.94	.283
	Phonological versus none	1	0.02	1.000

Note. Chi-square tests with Bonferroni correction for multiple comparisons. Bolded *p* values are significant.

Figure 1

Model 1: Estimated Percentage of Yes Responses by Translation Overlap and Group



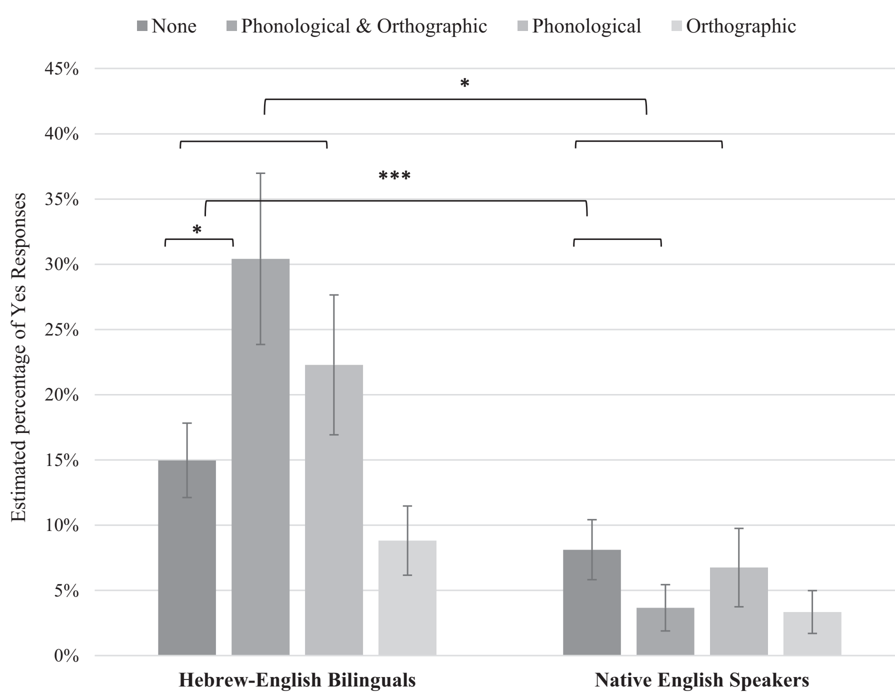
Note. Error bars mark standard error.
*** $p < .001$.

Analysis Approach section), a maximal model including the fixed effects of Translation Overlap (phonological and orthographic/orthographic/phonological/none, with none as the reference level), English Mint Accuracy (normalized), SOA (short = −0.5/long = 0.5, with 0 as the reference), and the interactions among them, as well as the random effect of Participants and Items, with by-participant and by-item intercepts, by-participant slope for Translation Overlap and by-item slopes for English Mint Accuracy and SOA, was entered to the *buildmer* function. Table 6 presents the ANOVA table for the selected *proficiency modulation model* (see Table A12 for model summary).

As seen in Table 6, the two-way interaction between Translation Overlap and English Mint Accuracy was significant. To unpack this effect, we performed planned pairwise comparisons with Bonferroni

Figure 2

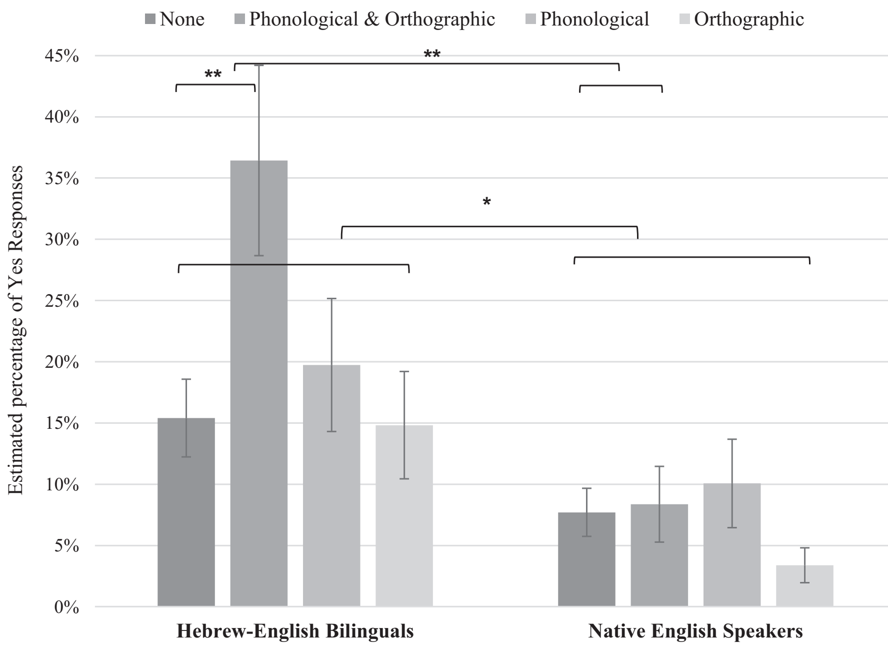
Short SOA Model: Estimated Percentage of Yes Responses by Translation Overlap and Group in the "Short" SOA Condition



Note. Error bars mark standard error. SOA = stimulus onset asynchrony.
* $p < .05$. *** $p < .001$.

Figure 3

Long SOA Model: Estimated Percentage of Yes Responses by Translation Overlap and Group for the "Long" SOA Condition



Note. Error bars mark standard error. SOA = stimulus onset asynchrony.
* $p < .05$. ** $p < .01$.

adjustment for multiple comparisons, between the none and the other three translation-overlap conditions, separately for bilinguals with high (1 *SD* above the mean) and low (1 *SD* below the mean) English Mint Accuracy scores. At higher proficiency scores, a significantly higher percentage of yes responses was observed in the phonological and orthographic (estimated $M = 35\%$, $SE = 7\%$), compared to the none overlap condition (estimated $M = 13\%$, $SE = 3\%$; $b = -1.318$, $SE = 0.328$, $z = -4.017$, $p < .001$). Conversely, at lower proficiency scores, the effect of Translation Overlap was not significant. Thus, although the direction of the effect of phonological and orthographic (estimated $M = 30\%$, $SE = 7\%$) relative to none overlap condition (estimated $M = 18\%$, $SE = 3\%$) remained consistent with that observed at higher proficiency scores, the lack of statistical significance ($b = -0.670$, $SE = 0.335$, $z = -2.002$, $p = .2719$) suggests a diminished influence of Translation Overlap among bilinguals with lower English Mint Accuracy scores (see Figure 4). Note that SOA did not significantly modulate these effects.

Table 6

Proficiency Modulation Model: ANOVA Table of the Fixed Effects and Interactions Within the Selected Model Predicting Yes Responses With English Mint Accuracy

Fixed effect/interaction	*df*	*F* value	*p* value
Translation overlap	3	5.01	**.002**
English mint accuracy	1	2.74	.098
SOA	1	0.80	.371
Translation overlap: English mint accuracy	3	2.94	**.032**
Translation overlap: SOA	3	2.05	.104
English mint accuracy: SOA	1	0.03	.857
Translation overlap: English mint accuracy: SOA	3	1.37	.249

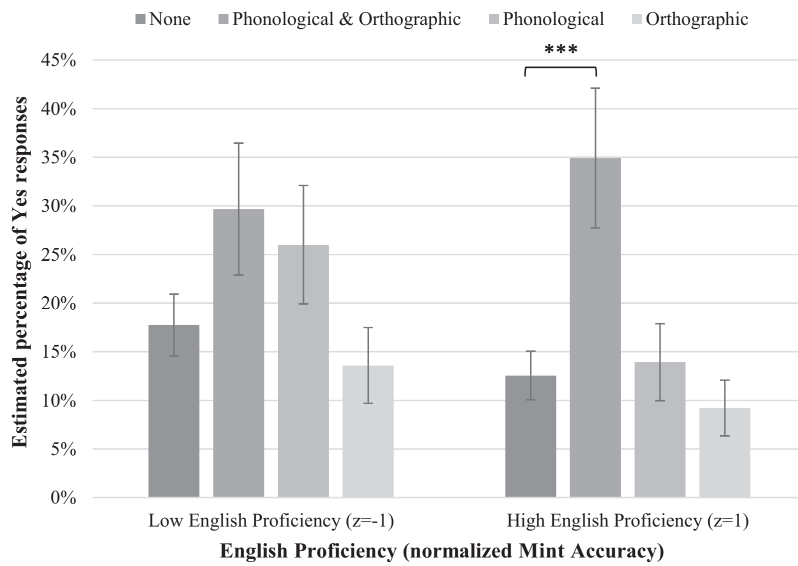
Note. Bolded *p* values are significant. ANOVA = analysis of variance; SOA = stimulus onset asynchrony.

Model 2: Response Time

Table 7 presents the ANOVA table for the selected model in the response time analysis (see Table A13 for model summary). As shown in this table, the main effect of Group was significant. Overall, Hebrew–English bilinguals responded slower (estimated $M = 1394.54$, $SE = 62.01$) than native English speakers (estimated $M = 907.03$, $SE = 40.54$), irrespective of the other variables. Additionally, we observed significant interactions between Group and Response Type, as well as among Group, Translation Overlap, and Response Type, indicating that Response Type modulated the other factors.

To better understand the effect of Responses Type, we examined the two-way interaction among Group and the three critical Translation Overlap contrasts, separately for yes and no responses, revealing a significant interaction only for yes responses and only in the phonological and orthographic versus none contrast (see Table 8). Note that this interaction was significant in spite of the substantially smaller number of yes responses ($n = 1{,}629$), relative to no responses ($n = 7{,}299$) in the sample. Thus, as seen in Figure 5, on yes trials, while Hebrew–English bilinguals were faster in the phonological and orthographic (estimated $M = 1341.21$, $SE = 79.21$) than in the none (estimated $M = 1433.16$, $SE = 74.16$) overlap condition, native English speakers exhibited the opposite

Figure 4
Proficiency Modulation Model: Estimated Percentage of Yes Responses by Translation Overlap in Each English Mint Accuracy Level (±1 SD From the Mean) for Hebrew–English Bilinguals



Note. Error bars mark standard error.
*** $p < .001$.

pattern (phonological and orthographic estimated $M = 1023.04$, $SE = 68.28$; none estimated $M = 926.51$, $SE = 48.80$). Performance of the native English speakers serves as the control on these items, and the differential pattern exhibited by the Hebrew–English bilinguals indicates sensitivity to the experimental manipulation (i.e., shared translation) which did not affect the control participants.

As seen in Table 7, the effect of SOA was not significant and did not interact with any of the effects of interest (Group, Translation Overlap, and Response Type).

Table 7
Model 2: ANOVA Table of the Fixed Effects and Interactions Within the Selected Model

Fixed effect/interaction	*df*	*F* value	*p* value
Group	1	48.784	**<.001**
SOA	1	0.047	.829
Translation overlap	3	2.671	**.050**
Response type	1	1.611	.206
Group: SOA	1	0.007	.934
Group: translation overlap	3	1.010	.390
Group: response type	1	4.335	**.039**
SOA: translation overlap	3	0.632	.595
SOA: response type	1	0.011	.916
Translation overlap: response type	3	0.920	.430
Group: translation overlap: SOA	3	1.512	.209
Group: translation overlap: response type	3	4.479	**.004**
Group: SOA: response type	1	0.173	.679
Translation overlap: SOA: response type	3	0.767	.512
Group: translation overlap: SOA: response type	3	0.991	.396

Note. Bolded *p* values are significant. ANOVA = analysis of variance; SOA = stimulus onset asynchrony.

Discussion

The present study set out to examine the degree to which nontarget language representations are activated in the absence of form overlap across languages. Specifically, we tested whether translations are activated when different-script Hebrew–English bilinguals perform a semantic judgment task in their L2. Furthermore, the study tested whether the phonological and orthographic subcomponents of the translation are activated, and what is the time course of this subcomponent activation. Using behavioral evidence only, we were able to show that bilinguals' nontarget language translations are activated and affect performance in a single language task. In particular, pairs of English words whose translations in Hebrew share both phonological and orthographic representations were faster and more likely to be judged as semantically related compared to pairs with no translation overlap. This effect was evident for Hebrew–English bilinguals but not for native English controls. Moreover, this pattern of increased semantic relatedness was observed irrespective of SOA. Furthermore, when the translations of the English word pairs shared phonology but not orthography in Hebrew, increased relatedness was observed early in processing, in the short SOA, but when the translations shared orthography, the effect was observed only in the longer SOA, suggesting differential patterns of activation of phonological and orthographic representations.

Complete Overlap in the Translation

The results of the present study show a shared-translation effect in both proportion of yes responses and RT measures in a semantic relatedness judgment task. Thus, the findings extend previous work in which an effect was observed in an offline semantic relatedness rating task (Degani et al., 2011). Critically, the effects here emerged

Table 8

Model 2: Chi-Square Tests With Bonferroni Correction for Multiple Comparisons Examining the Two-Way Interaction Between Translation Overlap and Group for Each of the Three Planned Contrast in Each Response Type

Response type	Planned contrast	*df*	χ^2	*p* value
Yes	Phonological and orthographic versus none: group	1	7.46	**.038**
	Orthographic versus none: group	1	0.00	1.00
	Phonological versus none: group	1	0.05	.823
No	Phonological and orthographic versus none	1	2.80	.564
	Orthographic versus none	1	3.35	.404
	Phonological versus none	1	0.75	.388

Note. Bolded *p* value are significant.

in a timed task, reducing the likelihood that strategic processing and participants' awareness underlie the observed pattern. This conclusion is further supported by the fact that increased relatedness was observed here even when targets were presented shortly after the prime (SOA of 300 ms), deeming it unlikely that participants had sufficient time to overtly translate the prime before processing the target word.

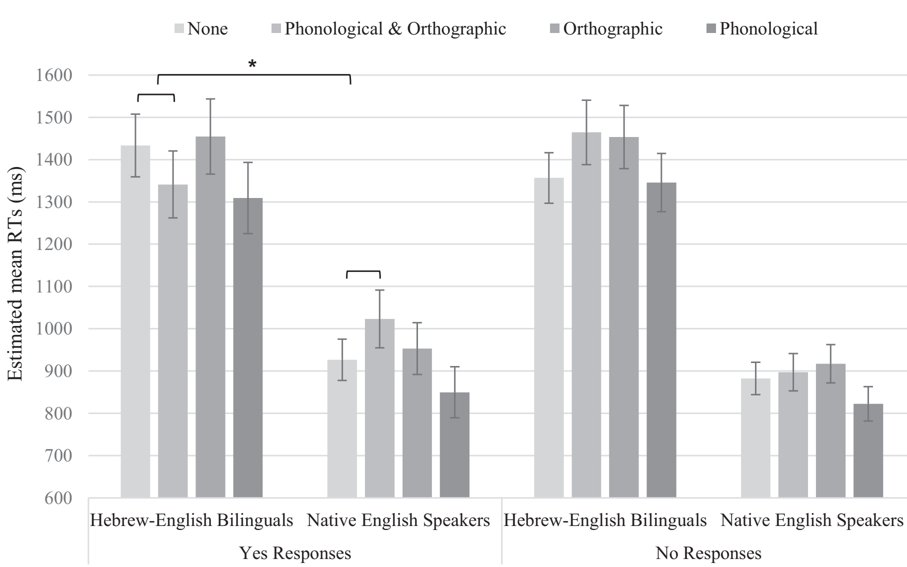
These results are consistent with the recent findings of Jouravlev and Jared (2020), who observed a similar effect with Russian–English bilinguals using a primed lexical decision task with comparable timing parameters (SOA of 250 ms). Together, the emerging pattern is one in which multilingual speakers, including those who use completely different scripts, automatically activate nontarget language translations quickly, to the extent that they affect their target language lexical and semantic processing.

Of note, in the present study, target words were unrelated in meaning, such that a translation overlap leading to a yes response in essence outweighed the lack of semantic (and form) overlap across the prime and target words in the target language. This finding extends previous demonstrations of a shared-translation effect with semantically related word pairs (Jiang, 2002, 2004) or of an effect that is dependent on conceptual identity of the meanings of the shared translation (Jouravlev & Jared, 2020). As such, the results suggest a fully interconnected system in which activation of nontarget-language-form representations (phonology and orthography) affects semantic processing in the other language of multilingual speakers.

The effects of lexical form on processing of meaning observed here converge with studies in which form representations affected processing of the meanings of pictures. Specifically, Peleg et al. (2016) found that semantically unrelated picture pairs, which their corresponding words in one of the speakers' languages shared a phonological and/or an orthographic lexical form, were more difficult to reject in a semantic relatedness judgment task, relative to similarly unrelated picture pairs with unrelated lexical labels (see also Eviatar et al., 2023; Lev-Ari & Keysar, 2014). The current findings suggest that influences of form overlap affect processing of

Figure 5

Model 2: Estimated Mean Reaction Times (ms) by Translation Overlap, Group, and Response Type



Note. Error bars mark standard error.
* $p < .05$.

meaning beyond a language boundary in a fully interconnected multilingual system.

Notably, the effects in the present study were most striking in the proportion of yes responses. Thus, the effects were sufficient to influence the decision outcome, leading bilinguals to treat unrelated English word pairs as related in meaning. Furthermore, rather than excluding yes responses as errors in the RT analysis, given that the intended response was "no" for these semantically unrelated English pairs, we included response type in the RT analysis. This allowed us to tap response competition and observe effects of translation overlap in the latency data. The effect reached significance for yes responses, in that bilinguals reached a yes response more quickly in the case of shared phonology and orthography in the translations. Although the effect was not significant in the time to reach a no decision, the pattern of means suggests a similar process. In particular, as seen in Figure 5, bilinguals took longer to judge as unrelated pairs of English words whose translations shared phonology and orthography, relative to those with no shared features in their translations. The overall pattern is consistent with the idea of response competition evident in previous work (e.g., anomaly judgment task, Elston-Güttler & Williams, 2008; semantic relatedness, Thierry & Wu, 2004; semantic decision with form overlap, Degani et al., 2018), where relatedness of translations overruled unrelatedness in the target language. Together, the findings suggest internal automatic activation of translations when these are not required for task performance.

Partial Overlap in the Translation

A unique feature of the current design is that it allowed us to test the contribution not only of complete overlap in the translation but also of partial overlap of either phonological or orthographic translation representations. Our results show that overlap in phonology was sufficient to affect the proportion of yes responses of Hebrew–English bilinguals early on, when the SOA was only 300 ms. This rapid activation of translation phonology is consistent with other studies that tested only the effect of partial overlap in translation (see summary, Table 1). The current findings extend the literature to a different unimodal bilingual population than that typically targeted in previous work (Chinese–English, see e.g., Thierry & Wu, 2007). Moreover, the effects were observed here in behavioral indices, rather than only using ERPs, a finding which resembles what has been observed with bimodal bilinguals (e.g., Meade et al., 2017).

Critically, our findings further suggest that with more processing time between the prime and the target (long SOA), activation spreads to orthographic representation of the nontarget language translation. Such orthographic effects were rarely observed before (Hosemann et al., 2020, with bimodal bilinguals but not in Wu & Thierry, 2010) but are consistent with the idea that activation spreads to all linked representations (e.g., the multilink, T. O. N. Dijkstra et al., 2019). Of note, the fact that phonological effects emerged prior to orthographic effects may suggest that the flow of translation activation is from phonology to orthography. Thus, phonological features of the shared translation are activated prior to its orthographic features, but both are sufficiently internally activated to affect semantic decisions in the target language (for effects of orthographic overlap on nonverbal stimuli, see Peleg et al., 2016; Eviatar et al., 2023).

Time Course of Translation Activation

The behavioral findings observed here were present using relatively short presentation parameters. Even the long SOA (750 ms) was substantially shorter than that used in previous studies (typically over 1 s, e.g., Thierry & Wu, 2004, 2007; Morford et al., 2011). In their discussion of bimodal bilinguals, Morford et al. (2017) outlined two general alternatives by which L2 written representations may activate nontarget language translations in the L1. Under serial models, the L2 would first activate L2 phonology or shared semantic representations, and these will subsequently activate the L1 phonology. In contrast, parallel perspectives would posit that L2 orthography would directly activate L1 phonology, along with spreading activation to L2 phonology and semantics (see also Ormel et al., 2012). Based on their SOA manipulation, Morford et al. (2017) concluded that, given that their participants were influenced by translation activation even at the short SOA, their findings suggest that L2 orthographic representations directly activated L1 phonology. Presumably, there was insufficient time in their short SOA (which was 300 ms) to allow serial activation of L2 phonology prior to L1 phonology. Following a similar rationale, the fact that the present study revealed translation activation at the short and long SOA suggests that the results are more consistent with parallel and integrated bilingual language models, where activation spreads to all linked representations in parallel, and are not constrained to target language representations being activated before nontarget language representations receive activation. Moreover, whereas the discussion with respect to bimodal bilinguals (Morford et al., 2017) naturally excludes the possibility that activation spreads to L1 (sign) orthographic representations of the translation, such spreading activation is suitable to explain the orthographic effects observed here with unimodal bilinguals.

Proficiency Modulations

The current results also allowed an exploratory examination of how participants' proficiency in the target language (L2) modulate the shared-translation effect. Relying on a picture-naming task as an objective proficiency measure (Gollan et al., 2012), our findings showed that Hebrew–English bilinguals who were more proficient in the L2 were more strongly affected by the activation of L1 translation. These findings presumably suggest stronger translation activation effects as L2 proficiency increases. However, strong conclusions are premature for several reasons. First, although the difference between English word pairs that shared a translation versus those that do not was not significant for individuals with lower English proficiency, the numerical pattern was the same. Thus, increased variability in these individuals may underlie the weaker effect in this group. Second, as the sampled participants constituted a relatively humongous group, more work is needed in sampling individuals across a wider range of proficiencies. Moreover, other dimensions on which bilinguals differ beyond proficiency, such as contexts of acquisition and use (e.g., Marian & Hayakawa, 2021; Titone & Tiv, 2023), need to be examined for a fuller understanding of how multilingual diversity modulates translation activation. Nonetheless, at the minimum, these analyses reveal that automatic activation of L1 translations during semantic processing of visually presented L2 words is not limited to beginning learners or those with lower L2 proficiency (consistent with the bidirectional findings of Degani et al., 2011 regarding L2 on L1 influences).

Limitations and Future Directions

The current findings suggest that both phonological and orthographic representations of the nontarget language translation are automatically activated during an L2 semantic decision task. To allow these conclusions regarding the effects of partial shared translation, the present study utilized Hebrew translations that are homographic heterophones (e.g., אור/עור both being pronounced as/or/) to tap the influence of phonology, or heterophonic homographs (e.g., ספר pronounced as/sapar/or/sefer/) to index the influence of orthography. Of note, as these examples show, there is still some overlap in the other features (phonology for orthographic overlap and orthography for phonological overlap). Therefore, the observed effects by which orthographic translation overlap influenced performance in the long SOA may be partly explained by the fact that the two Hebrew heterophonic homographs did share some phonological features (e.g., the phonemes/s/and/r/in the/sefer// sapar/examples). Given that evidence for orthographic translation activation is currently scarce (Hosemann et al., 2020; but not Wu & Thierry, 2010), additional research is needed to substantiate the observed orthographic findings.

In addition, although they were moderately to highly proficient in their L2, the bilingual participants tested here were relatively late learners of the L2 and were immersed in their L1 at the time of testing. These characteristics may have increased the likelihood of L1 activation during L2 processing. However, as previous work did suggest automatic activation of translations in other bilingual populations, some of which were immersed in their L2 (Wu & Thierry, 2011), automatic activation of translations appears to be a key feature of the multilingual lexicon that is not constrained by the language of the environment. Furthermore, as noted above, the findings observed in the present study appeared to be driven more by individuals with higher L2 proficiency, suggesting that the effects are not limited to the early stages of L2 acquisition. Nonetheless, more research is needed into the effects of language proficiency (e.g., Mishra & Singh, 2016) and patterns of language use (Titone & Tiv, 2023).

Relatedly, previous work showed that, for bilinguals of Hebrew and English, semantic relatedness ratings were influenced not only by shared translations in the L1 but also by shared translations in the L2 (Degani et al., 2011). These bidirectional influences were documented, however, in an offline rating task, which may have been at least partially influenced by participants' awareness. Therefore, it remains to be seen whether bidirectional effects of automatic translation activation can be observed in a timed task with short presentation parameters of the type utilized here.

Conclusion

The present study provided evidence of the automatic activation of translations in the L1, which was sufficient to affect behavioral performance of different-script bilinguals as they completed a semantic decision solely in their L2. These effects emerged more strongly in the case of complete shared translation but were also present for partial shared translations. Specifically, phonological representations of the translation appear to be activated prior to orthographic representations, but both receive spreading activation and affect performance in the L2. The findings contribute to the view that all languages of multilingual speakers are nonselectively activated and that both phonology and orthography in the nontarget language may exert an influence on target language performance. Therefore, language processing of multilingual speakers must always be considered in the context of their broader linguistic knowledge.

References

Altarriba, J., & Basnight-Brown, D. M. (2007). Methodological considerations in performing semantic- and translation-priming experiments across languages. *Behavior Research Methods*, *39*(1), 1–18. https://doi.org/10.3758/BF03192839

Baayen, R. H., Davidson, D. J., & Bates, D. M. (2008). Mixed-effects modeling with crossed random effects for subjects and items. *Journal of Memory and Language*, *59*(4), 390–412. https://doi.org/10.1016/j.jml.2007.12.005

Balota, D. A., Yap, M. J., Cortese, M. J., Hutchison, K. A., Kessler, B., Loftis, B., Neely, J. H., Nelson, D. L., Simpson, G. B., & Treiman, R. (2007). The English lexicon project. *Behavior Research Methods*, *39*(3), 445–459. https://doi.org/10.3758/BF03193014

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. https://doi.org/10.1016/j.jml.2012.11.001

Bates, D., Mächler, M., Bolker, B., Walker, S., Christensen, R. H., Singmann, H., & Dai, B. (2015). *lme4: Linear mixed-effects models using Eigen and S4*. R package Version 1.1–7. 2014.

Brysbaert, M., Warriner, A. B., & Kuperman, V. (2014). Concreteness ratings for 40 thousand generally known English word lemmas. *Behavior Research Methods*, *46*(3), 904–911. https://doi.org/10.3758/s13428-013-0403-5

Degani, T. (2011). *Bidirectional transfer: Consequences of translation ambiguity for bilingual word meaning*. [Unpublished dissertation], University of Pittsburgh.

Degani, T., Prior, A., & Hajajra, W. (2018). Cross-language semantic influences in different script bilinguals. *Bilingualism: Language and Cognition*, *21*(4), 782–804. https://doi.org/10.1017/S1366728917000311

Degani, T., Prior, A., & Tokowicz, N. (2011). Bidirectional transfer: The effect of sharing a translation. *Journal of Cognitive Psychology*, *23*(1), 18–28. https://doi.org/10.1080/20445911.2011.445986

Degani, T., Prior, A., & Wodniecka, Z. (2022). Modulators of cross-language influences in learning and processing. *Frontiers in Psychology*, *13*, Article 898793. https://doi.org/10.3389/fpsyg.2022.898793

Degani, T., & Tokowicz, N. (2010). Semantic ambiguity within and across languages: An integrative review. *Quarterly Journal of Experimental Psychology: Human Experimental Psychology*, *63*(7), 1266–1303. https://doi.org/10.1080/17470210903377372

Degani, T., & Tokowicz, N. (2013). Cross-language influences: Translation status affects intraword sense relatedness. *Memory & Cognition*, *41*, 1046–1064. https://doi.org/10.3758/s13421-013-0322-9

Dijkstra, T. (2005). Bilingual visual word recognition and lexical access. In J. F. Kroll, & A. De Groot (Eds.), *Handbook of bilingualism: Psycholinguistic approaches* (pp. 179–201). Oxford University Press.

Dijkstra, T., & Van Heuven, W. J. (2002). The architecture of the bilingual word recognition system: From identification to decision. *Bilingualism: Language and Cognition*, *5*(3), 175–197. https://doi.org/10.1017/S1366728902003012

Dijkstra, T. O. N., Wahl, A., Buytenhuijs, F., Van Halem, N., Al-Jibouri, Z., De Korte, M., & Rekké, S. (2019). Multilink: A computational model for bilingual word recognition and word translation. *Bilingualism: Language and Cognition*, *22*(4), 657–679. https://doi.org/10.1017/S1366728918000287

Elston-Güttler, K. E., Paulmann, S., & Kotz, S. A. (2005). Who's in control? Proficiency and L1 influence on L2 processing. *Journal of Cognitive Neuroscience*, *17*(10), 1593–1610. https://doi.org/10.1162/089892905774597245

Elston-Güttler, K. E., & Williams, J. N. (2008). First language polysemy affects second language meaning interpretation: Evidence for activation of first language concepts during second language reading. *Second Language Research*, *24*(2), 167–187. https://doi.org/10.1177/0267658307086300

Eviatar, Z., Binur, N., & Peleg, O. (2023). Interactions of lexical and conceptual representations: Evidence from EEG. *Brain and Language*, *243*, Article 105302. https://doi.org/10.1016/j.bandl.2023.105302

Gollan, T. H., Weissberger, G. H., Runnqvist, E., Montoya, R. I., & Cera, C. M. (2012). Self-ratings of spoken language dominance: A multilingual naming test (MINT) and preliminary norms for young and aging Spanish–English bilinguals. *Bilingualism: Language and Cognition*, *15*(3), 594–615. https://doi.org/10.1017/S1366728911000332

Grainger, J. (1998). Masked priming by translation equivalents in proficient bilinguals. *Language and Cognitive Processes*, *13*(6), 601–623. https://doi.org/10.1080/016909698386393

Hosemann, J., Mani, N., Hermann, A., Steinbach, M., & Altvatar-Mackensen, N., (2020). Signs activate their written word translation in deaf adults: An ERP study on cross-modal co-activation in German Sign Language. *Glossa: A Journal of General Linguistics*, *5*(1), Article 57. https://doi.org/10.5334/gjgl.1014

Jiang, N. (2002). Form-meaning mapping in vocabulary acquisition in a second language. *Studies in Second Language Acquisition*, *24*(4), 617–637. https://doi.org/10.1017/S0272263102004047

Jiang, N. (2004). Semantic transfer and its implications for vocabulary teaching in a second language. *Modern Language Journal*, *88*(3), 416–432. https://doi.org/10.1111/j.0026-7902.2004.00238.x

Jouravlev, O., & Jared, D. (2020). Native language processing is influenced by L2-to-L1 translation ambiguity. *Language, Cognition and Neuroscience*, *35*(3), 310–329. https://doi.org/10.1080/23273798.2019.1652764

Kroll, J. F., Bobb, S. C., & Wodniecka, Z. (2006). Language selectivity is the exception, not the rule: Arguments against a fixed locus of language selection in bilingual speech. *Bilingualism: Language and Cognition*, *9*(2), 119–135. https://doi.org/10.1017/S1366728906002483

Kubus, O., Villwock, A., Morford, J., & Rathmann, C. (2015). Word recognition in deaf readers: Cross-language activation of German Sign Language and German. *Applied Psycholinguistics*, *36*(4), 831–854. https://doi.org/10.1017/S0142716413000520

Lauro, J., & Schwartz, A. I. (2017). Bilingual non-selective lexical access in sentence contexts: A meta-analytic review. *Journal of Memory and Language*, *92*, 217–233. https://doi.org/10.1016/j.jml.2016.06.010

Lev-Ari, S., & Keysar, B. (2014). Executive control influences linguistic representations. *Memory & Cognition*, *42*(2), 247–263. https://doi.org/10.3758/s13421-013-0352-3

Lo, S., & Andrews, S. (2015). To transform or not to transform: Using generalized linear mixed models to analyse reaction time data. *Frontiers in Psychology*, *6*, Article 148545. https://doi.org/10.3389/fpsyg.2015.01171

Lupker, S. J., & Spinelli, G. (2023). An examination of models of reading multi-morphemic and pseudo multi-morphemic words using sandwich priming. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *49*(11), 1861–1880. https://doi.org/10.1037/xlm0001289

Ma, F., & Ai, H. (2018). Chinese learners of English see Chinese words when reading English words. *Journal of Psycholinguistic Research*, *47*(3), 505–521. https://doi.org/10.1007/s10936-017-9533-8

Marian, V., & Hayakawa, S. (2021). Measuring bilingualism: The quest for a "bilingualism quotient." *Applied Psycholinguistics*, *42*(Suppl. 2), 527–548. https://doi.org/10.1017/S0142716420000533

Martinez, H. D. R. (2015). Analysing interactions of fitted models. *CRAN-R Project*.

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. https://doi.org/10.1016/j.jml.2017.01.001

Meade, G., Midgley, K. J., Sevcikova Sehyr, Z., Holcomb, P. J., & Emmorey, K. (2017). Implicit co-activation of American sign language in deaf readers: An ERP study. *Brain and Language*, *170*, 50–61. https://doi.org/10.1016/j.bandl.2017.03.004

Mishra, R. K., & Singh, N. (2016). The influence of second language proficiency on bilingual parallel language activation in Hindi–English bilinguals. *Journal of Cognitive Psychology*, *28*(4), 396–411. https://doi.org/10.1080/20445911.2016.1146725

Morford, J. P., Occhino, C., Zirnstein, M., Kroll, J. F., Wilkinson, E., & Piñar, P. (2019). What is the source of bilingual cross-language activation in deaf bilinguals? *Journal of Deaf Studies and Deaf Education*, *24*(4), 356–365. https://doi.org/10.1093/deafed/enz024

Morford, J. P., Occhino-Kehoe, C., Piñar, P., Wilkinson, E., & Kroll, J. F. (2017). The time course of cross-language activation in deaf ASL-English bilinguals. *Bilingualism: Language and Cognition*, *20*(2), 337–350. https://doi.org/10.1017/S136672891500067X

Morford, J. P., Wilkinson, E., Villwock, A., Piñar, P., & Kroll, J. F. (2011). When deaf signers read English: Do written words activate their sign translations? *Cognition*, *118*(2), 286–292. https://doi.org/10.1016/j.cognition.2010.11.006

Nicklin, C., & Plonsky, L. (2020). Outliers in L2 research in applied linguistics: A synthesis and data re-analysis. *Annual Review of Applied Linguistics*, *40*, 26–55. https://doi.org/10.1017/S0267190520000057

Norman, T., Eviatar, Z., & Degani, T. (2024, April 6). *Partial and shared translation activation*. PsyArXiv. https://osf.io/s2mxf

Oldfield, R. C. (1971). The assessment and analysis of handedness: The Edinburgh inventory. *Neuropsychologia*, *9*(1), 97–113. https://doi.org/10.1016/0028-3932(71)90067-4

Ormel, E., Hermans, D., Knoors, H., & Verhoeven, L. (2012). Cross-language effects in written word recognition: The case of bilingual deaf children. *Bilingualism: Language and Cognition*, *15*(2), 288–303. https://doi.org/10.1017/S1366728911000319

Peleg, O., Edelist, L., Eviatar, Z., & Bergerbest, D. (2016). Lexical factors in conceptual processes: The relationship between semantic representations and their corresponding phonological and orthographic lexical forms. *Memory & Cognition*, *44*(4), 519–537. https://doi.org/10.3758/s13421-015-0576-5

Peleg, O., & Eviatar, Z. (2008). Hemispheric sensitivities to lexical and contextual information: Evidence from lexical ambiguity resolution. *Brain and Language*, *105*(2), 71–82. https://doi.org/10.1016/j.bandl.2007.09.004

Peleg, O., Markus, A., & Eviatar, Z. (2012). Hemispheric asymmetries in meaning selection: Evidence from the disambiguation of homophonic vs. heterophonic homographs. *Brain and Cognition*, *80*(3), 328–337. https://doi.org/10.1016/j.bandc.2012.08.005

Prior, A., & Gollan, T. H. (2013). The elusive link between language control and executive control: A case of limited transfer. *Journal of Cognitive Psychology*, *25*(5), 622–645. https://doi.org/10.1080/20445911.2013.821993

R Core Team. (2020) *R: A language and environment for statistical computing* (Version 4.0.3). R Foundation for Statistical Computing. http://www.R-project.org

Schoonbaert, S., Duyck, W., Brysbaert, M., & Hartsuiker, R. J. (2009). Semantic and translation priming from a first language to a second and back: Making sense of the findings. *Memory & Cognition*, *37*(5), 569–586. https://doi.org/10.3758/MC.37.5.569

Shook, A., & Marian, V. (2012). Bimodal bilinguals co-activate both languages during spoken comprehension. *Cognition*, *124*(3), 314–324. https://doi.org/10.1016/j.cognition.2012.05.014

Shook, A., & Marian, V. (2019). Covert co-activation of bilinguals' non-target language: Phonological competition from translations. *Linguistic Approaches to Bilingualism*, *9*(2), 228–252. https://doi.org/10.1075/lab.17022.sho

Smith, Y., Walters, J., & Prior, A. (2014). *Translation norms for Hebrew and English* (Translation data for a set of 700 words in Hebrew and English). https://langnum.haifa.ac.il/EPriorpublication.php

Sunderman, G., & Kroll, J. F. (2006). First language activation during second language lexical processing: An investigation of lexical form, meaning, and grammatical class. *Studies in Second Language Acquisition*, *28*(3), 387–422. https://doi.org/10.1017/S0272263106060177

Talamas, A., Kroll, J. F., & Dufour, R. (1999). From form to meaning: Stages in the acquisition of second-language vocabulary. *Bilingualism: Language and Cognition*, *2*(1), 45–58. https://doi.org/10.1017/S1366728999000140

Thierry, G., & Wu, Y. J. (2004). Electrophysiological evidence for language interference in late bilinguals. *Neuroreport*, *15*(10), 1555–1558. https://doi.org/10.1097/01.wnr.0000134214.57469.c2

Thierry, G., & Wu, Y. J. (2007). Brain potentials reveal unconscious translation during foreign-language comprehension. *Proceedings of the National Academy of Sciences of the United States of America*, *104*(30), 12530–12535. https://doi.org/10.1073/pnas.0609927104

Titone, D. A., & Tiv, M. (2023). Rethinking multilingual experience through a Systems Framework of Bilingualism. *Bilingualism: Language and Cognition*, *26*(1), 1–16. https://doi.org/10.1017/S1366728921001127

Villameriel, S., Costello, B., Giezen, M., & Carreiras, M. (2022). Cross-modal and cross-language activation in bilinguals reveals lexical competition even when words or signs are unheard or unseen. *Proceedings of the National Academy of Sciences of the United States of America*, *119*(36), Article e2203906119. https://doi.org/10.1073/pnas.2203906119

Voeten, C. (2019) *buildmer: Stepwise elimination and term reordering for mixed–effects regression* (R package Version 1.3). https://CRAN.R-project.org/package=buildmer

Wen, Y., & van Heuven, W. J. (2018). Limitations of translation activation in masked priming: Behavioural evidence from Chinese–English bilinguals and computational modelling. *Journal of Memory and Language*, *101*, 84–96. https://doi.org/10.1016/j.jml.2018.03.004

Wen, Y., & van Heuven, W. J. B. (2017). Non-cognate translation priming in masked priming lexical decision experiments: A meta-analysis. *Psychonomic Bulletin & Review*, *24*(3), 879–886. https://doi.org/10.3758/s13423-016-1151-1

Wu, Y. J., Cristino, F., Leek, C., & Thierry, G. (2013). Non-selective lexical access in bilinguals is spontaneous and independent of input monitoring: Evidence from eye tracking. *Cognition*, *129*(2), 418–425. https://doi.org/10.1016/j.cognition.2013.08.005

Wu, Y. J., & Thierry, G. (2010). Chinese–English bilinguals reading English hear Chinese. *The Journal of Neuroscience*, *30*(22), 7646–7651. https://doi.org/10.1523/JNEUROSCI.1602-10.2010

Wu, Y. J., & Thierry, G. (2011). Event-related brain potential investigation of preparation for speech production in late bilinguals. *Frontiers in Psychology*, *2*, Article 114. https://doi.org/10.3389/fpsyg.2011.00114

Wu, Y. J., & Thierry, G. (2012a). How reading in a second language protects your heart. *The Journal of Neuroscience*, *32*(19), 6485–6489. https://doi.org/10.1523/JNEUROSCI.6119-11.2012

Wu, Y. J., & Thierry, G. (2012b). Unconscious translation during incidental foreign language processing. *NeuroImage*, *59*(4), 3468–3473. https://doi.org/10.1016/j.neuroimage.2011.11.049

Zhang, E. H., Li, J., Zhang, X. D., Li, D., & Cao, H. W. (2022). Electrophysiological correlates of masked orthographic and phonological priming in Chinese–English bilinguals. *Scientific Reports*, *12*(1), Article 16648. https://doi.org/10.1038/s41598-022-21072-z

Zhang, T., van Heuven, W. J., & Conklin, K. (2011). Fast automatic translation and morphological decomposition in Chinese–English bilinguals. *Psychological Science*, *22*(10), 1237–1242. https://doi.org/10.1177/0956797611421492

(*Appendix follows*)

Appendix

Detailed LME Model Summaries

Table A9

Model 1: A Summary of the LME Model Selected by Buildmer Predicting the Percentage of Yes Responses in a Semantic Relatedness Judgment of English Word Pairs

Fixed effect	*b*	*SE*	*Z* value
(intercept)	−2.458	0.252	−9.763***
Group (HeEn)	0.731	0.227	3.225**
Translation overlap (Ph and Or)	−0.284	0.440	−0.645
Translation overlap (Ph)	0.058	0.436	0.132
Translation overlap (Or)	−0.898	0.453	−1.985*
SOA	−0.309	0.276	−1.122
Group (HeEn): translation overlap (Ph and Or)	1.322	0.295	4.484***
Group (HeEn): translation overlap (Ph)	0.348	0.290	1.200
Group (HeEn): translation overlap (Or)	0.595	0.317	1.878#
SOA: group (HeEn)	0.397	0.382	1.041
SOA: translation over (Ph and Or)	0.786	0.288	2.734**
SOA: translation overlap (Ph)	0.701	0.272	2.580*
SOA: translation overlap (Or)	−0.006	0.320	−0.018
Group (HeEn): translation overlap (Ph and Or): SOA	−0.560	0.360	−1.554
Group (HeEn): translation overlap (Ph): SOA	−0.844	0.353	−2.387*
Group (HeEn): translation overlap (Or): SOA	0.532	0.405	1.313
Random effect	**Variance**	***SD***	
Participant (intercept)	0.669	0.818	
Item (intercept)	1.989	1.410	
Group (HeEn)	0.570	0.755	

Note. Fixed effects reflect simple effects relative to the reference level, when other factors are at their reference level or hold constant at the mean, without correction for multiple comparisons. For instance, the coefficient for Group reflects its effect at the reference level of the other factors, namely the none Translation Overlap, while SOA is held constant at the mean. For main effects, see *F* values in the text. LME = linear mixed effects; *b* = effect size, *SE* = standard errors; HeEn = Hebrew-English bilingual group; Ph = phonological; Or = Orthographic; SOA = stimulus onset asynchrony.
$^{\#}p < .1$. $^{*}p < .05$. $^{**}p < .01$. $^{***}p < .001$.

(*Appendix continues*)

Table A10

Short SOA Model: A Summary of the LME Model Selected by Buildmer Predicting the Percentage of Yes Responses in a Semantic Relatedness Judgment of English Word Pairs, Including Only "Short" SOA Trials

Fixed effect	*b*	*SE*	*Z*
(intercept)	−2.427	0.308	−7.870***
Translation overlap (Ph and Or)	−0.843	0.536	−1.572
Translation overlap (Ph)	−0.200	0.518	−0.385
Translation overlap (Or)	−0.938	0.542	−1.730#
Group (HeEn)	0.689	0.286	2.414*
Group (HeEn): translation overlap (Ph and Or)	1.753	0.359	4.888***
Group (HeEn): translation overlap (Ph)	0.688	0.336	2.050*
Group (HeEn): translation overlap (Or)	0.339	0.371	0.912
Random effect	**Variance**	***SD***	
Participant (intercept)	0.581	0.762	
Item (intercept)	2.634	1.623	
Group (HeEn)	0.525	0.725	

Note. Fixed effects reflect simple effects relative to the reference level, when other factors are at their reference level or hold constant at the mean, without correction for multiple comparisons. Thus, coefficient for Group reflects its effect at the reference level of the other factors, namely the none Translation Overlap. For main effects, see *F* values in the text. SOA = stimulus onset asynchrony; LME = linear mixed effects; *b* = effect size, *SE* = standard errors; Ph = phonological; Or = Orthographic; HeEn = Hebrew-English bilingual group.
# $p < .1$. * $p < .05$. *** $p < .001$.

Table A11

Long SOA Model: A Summary of the LME Model Selected by Buildmer Predicting the Percentage of Yes Responses in a Semantic Relatedness Judgment of English Word Pairs, Including Only "Long" SOA Trials

Fixed effect	*b*	*SE*	*Z* value
(intercept)	−2.483	0.277	−8.956***
Translation overlap (Ph and Or)	0.090	0.418	0.215
Translation overlap (Ph)	0.294	0.416	0.707
Translation overlap (Or)	−0.870	0.447	−1.947#
Group (HeEn)	0.780	0.308	2.533*
Group (HeEn): translation overlap (Ph and Or)	1.056	0.352	3.00**
Group (HeEn): translation overlap (Ph)	0.006	0.354	0.017
Group (HeEn): translation overlap (Or)	0.825	0.390	2.113*
Random effect	**Variance**	***SD***	
Participant (intercept)	0.701	0.837	
Item (intercept)	1.588	1.260	
Group (HeEn)	0.689	0.830	

Note. Fixed effects reflect simple effects relative to the reference level, when other factors are at their reference level or hold constant at the mean, without correction for multiple comparisons. Thus, coefficient for Group reflects its effect at the reference level of the other factors, namely the none Translation Overlap. For main effects see, *F* values in the text. SOA = stimulus onset asynchrony; LME = linear mixed effects; *b* = effect size, *SE* = standard errors; Ph = phonological; Or = Orthographic; HeEn = Hebrew-English bilingual group.
# $p < .1$. * $p < .05$. ** $p < .01$. *** $p < .001$.

(*Appendix continues*)

Table A12

Proficiency Modulation Model: A Summary of the LME Model Selected by Buildmer Predicting the Percentage of Yes Responses in a Semantic Relatedness Judgment of English Word-Pair by Translation Overlap, English Mint Accuracy, and SOA

Fixed effect	*b*	*SE*	*Z* value
(intercept)	−1.737	0.187	−9.256***
Translation overlap (Ph and Or)	0.994	0.307	3.239**
Translation overlap (Ph)	0.302	0.309	0.978
Translation overlap (Or)	−0.332	0.316	−1.051
English mint accuracy	−0.203	0.121	−1.689#
SOA	0.100	0.239	0.419
Translation overlap (Ph and Or): English mint accuracy	0.324	0.125	2.587**
Translation overlap (Ph): English mint accuracy	−0.183	0.123	−1.492
Translation overlap (Or): English mint accuracy	−0.015	0.142	−0.106
Translation overlap (Ph and Or): SOA	0.275	0.222	1.243
Translation overlap (Ph): SOA	0.002	0.234	0.008
Translation overlap (Or): SOA	0.589	0.255	2.312*
English mint accuracy: SOA	−0.020	0.241	−0.082
Translation overlap (Ph and Or): English mint accuracy: SOA	−0.370	0.248	−1.488
Translation overlap (Ph): English mint accuracy: SOA	0.226	0.245	0.921
Translation overlap (Or): English mint accuracy: SOA	0.053	0.283	0.199
Random effect	**Variance**	***SD***	
Participant (intercept)	0.502	0.708	
Item (intercept)	0.964	0.982	

Note. Fixed effects reflect simple effects relative to the reference level, when other factors are at their reference level or hold constant at the mean, without correction for multiple comparisons. For instance, the coefficient for SOA reflects its effect at the reference level of the other factors, namely the none Translation Overlap, while English Mint Accuracy is held constant at the mean. For main effects, see *F* values in the text. LME = linear mixed effects; SOA = stimulus onset asynchrony; *b* = effect size, *SE* = standard errors; Ph = phonological; Or = Orthographic.
# $p < .1$. * $p < .05$. ** $p < .01$. *** $p < .001$.

(*Appendix continues*)

Table A13
Model 2: LME Model Predicting the Reaction Times in the Semantic Relatedness Judgment of English Word Pairs

Fixed effect	*b*	*SE*	*t* value
(intercept)	6.783	0.043	156.311***
Group (HeEn)	0.430	0.059	7.269***
TransOverlap (Ph and Or)	0.016	0.033	0.492
TransOverlap (Ph)	0.039	0.033	1.156
TransOverlap (Or)	−0.071	0.033	−2.127
SOA	0.009	0.082	0.106
RespType (yes)	0.049	0.030	1.605
Group (HeEn): TransOverlap (Ph and Or)	0.060	0.036	1.674
Group (HeEn): TransOverlap (Ph)	0.030	0.035	0.863
Group (HeEn): TransOverlap (Or)	0.063	0.034	1.829#
Group (HeEn): SOA	0.013	0.116	0.110
SOA: TransOver (Ph&Or)	−0.015	0.032	−0.455
SOA: TransOverlap (Ph)	−0.009	0.032	−0.294
SOA: TransOverlap(Or)	−0.001	0.032	−0.024
RespType (yes): Group (HeEn)	0.006	0.041	0.151
RespType (yes): TransOverlap (Ph&Or)	0.083	0.050	1.666#
RespType (yes): TransOverlap (Ph)	−0.010	0.046	−0.226
RespType (yes): TransOverlap (Or)	−0.016	0.055	−0.294
RespType (yes): SOA	0.078	0.057	1.373
Group (HeEn): TransOverlap (Ph and Or): SOA	0.010	0.051	0.191
Group (HeEn): TransOverlap (Ph): SOA	0.036	0.049	0.744
Group (HeEn): TransOverlap (Or): SOA	0.004	0.046	0.089
Group (HeEn): TransOver (Ph and Or): RespType (yes)	−0.225	0.062	−3.653***
Group (HeEn): TransOverlap (Ph): RespType (yes)	−0.043	0.060	−0.724
Group (HeEn): TransOverlap (Or): RespType (yes)	−0.066	0.069	−0.955
Group (HeEn): RespType (yes): SOA	−0.082	0.078	−1.060
RespType (yes): TransOver (Ph and Or): SOA	−0.005	0.093	−0.051
RespType (yes): TransOverlap (Ph): SOA	−0.142	0.086	−1.648#
RespType (yes): TransOverlap (Or): SOA	−0.119	0.102	−1.166
Group (HeEn): TransOver (Ph and Or): RespType (yes): SOA	−0.063	0.118	−0.536
Group (HeEn): TransOverlap (Ph): RespType (yes): SOA	0.118	0.114	1.034
Group (HeEn): TransOverlap (Or): RespType (yes): SOA	0.154	0.132	1.167

Random effect	Variance	*SD*
Participant (intercept)	0.077	0.277
Resptype (yes)	0.016	0.125
Item (intercept)	0.010	0.101
Group (HeEn)	0.007	0.086
Residual	0.128	0.358

Note. Fixed effects reflect simple effects relative to the reference level, when other factors are at their reference level or hold constant at the mean, without correction for multiple comparisons. For instance, the coefficient for Group reflects its effect at the reference level of the other factors, namely the none Translation Overlap, while SOA is held constant at the mean. For main effects, see *F* values in the text.; LME = linear mixed effects; *b* = effect size, *SE* = standard errors; HeEn = Hebrew-English bilingual group; Ph = phonological; Or = Orthographic; TransOverlap = translation overlap; SOA = stimulus onset asynchrony; RespType = response type.

Received October 22, 2023
Revision received April 6, 2024
Accepted April 23, 2024 ■