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Dynamics of competition and co-activation in trilingual lexical processing: An eye-tracking study

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Research Article

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Abstract

In recent decades, many eye-tracking studies have demonstrated that both languages of bilingual speakers are activated while processing phonological input in only one. To date, there have been no eye-tracking co-activation studies assessing word recognition among trilinguals. The present research investigates co-activation in all three languages of 48 Russian (Heritage Language)/ Hebrew (Societal Language)/English (Third Language) speakers using a trilingual visual world paradigm experiment. The results paint a picture of a highly interactive multilingual lexicon, in line with findings from prior studies on bilingualism. Although accuracy was not affected by competition conditions, reaction times and eye-fixation proportions showed slow-down and distraction in the presence of cross-linguistic competitors, albeit to different extents across the three experiments, evidencing effects of language dominance and acquisition order. This study makes considerable contributions to our understanding of the dynamics of trilingual language processing and discusses findings in the context of existing bilingual processing models.

Highlights

- Co-activation from one or two additional languages does not affect target accuracy.
- In weakest-language processing, all stronger languages were co-activated.
- No co-activation was observed in dominant-language processing.
- Weaker HL and stronger SL were both co-activated in L3 eye-tracking, but not in RTs.
- Competition from only SL led to more distraction than SL/L3 or HL/SL together.

1. Introduction

Myriad studies from the last two decades have demonstrated that both of a bilingual speaker's languages are activated when presented with input in only one (Spivey & Marian, 1999; Marian & Spivey, 2003a, 2003b; Ju & Luce, 2004; Weber & Cutler, 2004; Blumenfeld & Marian, 2007; Dimitropoulou et al., 2011; Iniesta et al., 2021; Chen et al., 2021; McDonald et al., 2023). Although this phenomenon has been demonstrated across linguistic domains, many studies specifically investigated phonological cross-language co-activation, wherein auditory input in one language directs a bilingual's attention to a similar-sounding—yet otherwise unrelated—lexical item in another. To date, no studies have considered cross-language phonological activation in trilinguals, although such research would provide important insights into multilingual processing (Lemhöfer, 2023). The present work aims to fill this gap.

While phonological cross-linguistic co-activation has not yet been assessed for trilinguals, a small number of studies have indeed investigated trilingual language processing, with the vast majority of them focusing on the processing of cognates—or words similar in both form and meaning—across language triads (Van Hell & Dijkstra, 2002; Szubko-Sitarek, 2011; Blank & Llama, 2019; Lijewska, 2022, Kashevarova, 2023). These studies, however, were not unanimous, with some concluding that prior findings from bilingualism research hold equal merit in trilingual scenarios, and others suggesting that this is not always the case, and trilingualism should be investigated and theorized separately (see Kashevarova, 2023). The present study will contribute to this discussion using a new experimental paradigm.

Research on trilingual language processing has been scarce, because of the methodological complexities of controlling for language experience and development in three languages (Pathak et al., 2024), a task that is challenging enough when only two languages are involved (Chung-Fat-Yim et al., 2023). This is despite the fact that, in many bilingual studies, participants are described as knowing more than two languages, but their knowledge of languages beyond the focus of a given study is listed as a limitation and not investigated directly (Alonso & Rothman, 2022; Fridman & Meir, 2023; Lago et al., 2021). Therefore, the present work's investigation of trilingual language processing will be increasingly ecologically valid, as it will account for all of our participants' used languages.

Despite the scarcity of processing studies, work on trilingual language *acquisition* has highlighted key distinctions from bilingual scenarios, chief of them being the relative influence of previously acquired languages. Theoretical accounts of L3 acquisition have suggested that linguistic information can be transferred from one language in full (Rothman, 2015), from the known language most similar to the L3 (Rothman & Cabrelli Amaro, 2010), from the first language (Hermas, 2014) or the second language (Bardel & Falk, 2007, Bardel & Falk, 2012) or from relevant properties from multiple previously acquired languages (Slabakova, 2017; Westergaard et al., 2017). Although these approaches focus on acquisition, it is clear from this variety of accounts that the case of transfer and cross-linguistic influence is not an obvious one. We contend that it is likewise not obvious which previously acquired language(s) will be invoked—or activated—in language processing, and how this activation may be realized. Furthermore, considering trilingual processing offers additional insight in that it allows us to investigate effects equitably in all languages, whereas in an acquisition scenario, previous languages have already been acquired while the L3 remains new, and proficiency differences may be much starker. Thus, the present study will make a valuable contribution to the field's theoretical understanding of trilingual processing, and its distinctions from the bilingual variety.

In the present study, we investigate the dynamics of cross-linguistic co-activation in trilingual speakers of Russian, Hebrew and English. For these participants, Russian is their Heritage Language (HL), Hebrew is their dominant Societal Language (SL) and English is their third language (L3). Using the visual world paradigm, we consider the effects of the language of presentation, the number of cross-linguistic competitors and the competitor language(s) in question, and discuss differences in accuracy, reaction time to target selection and proportion of eye-fixations to the target.

HL speakers, who use a language at home that is not the main language of their society, are a particularly interesting group to investigate when studying L3 performance, as their first language is rarely their most dominant and at times they may be more proficient in their L3 than in their HL, allowing us to consider language dominance and order of acquisition separately (Garcia Mayo & Gonzalez Alonso, 2015). In the present study, we focus on comprehension, as it has been suggested that comprehension is less sensitive than production to diminished input and attrition (Montrul, 2013), two factors that notoriously impact HL speakers' language abilities in their HL. This is likely because comprehension does not require the added steps of retrieving and producing a target lexical item; rather, it requires an individual to contextualize an input word and locate it in the receptive lexicon. Therefore, we expect the receptive HL lexicon to be sufficiently robust that we would see co-activation effects, and be able to compare them to such effects in the L3.

In summary, the novelty of the present study is four-fold: in the experimental paradigm, in its theoretical contribution, in its ecological validity, and in the investigated population. First, this will be among the first studies to conduct a trilingual phonological co-activation experiment, building on extensive previous work on bilingualism. Second, the study will shed light on the interaction between three languages during processing, helping us understand whether and to what extent all three languages are active. Third, all three languages of the trilinguals will be tested, to account not only for the effects of previously acquired languages on the third language but also to gain a more comprehensive understanding of the interactive nature of the multilingual lexicon. Fourth, the trilingual participants will be HL speakers whose order of language acquisition differs from their order of language dominance, allowing us to consider these factors separately. In the subsequent sections, we will present the current standards in lexical processing and co-activation research on bilinguals, the unique nature of the L3 context, and the trilingual environment specifically in Israel, setting the scene for our study.

1.1. Lexical processing and co-activation

The study of co-activation in lexical and phonological processing was first shown among monolinguals (see the Interactive Activation model proposed by McClelland & Rumelhart, 1981). Furthermore, Marian (2009) demonstrated that people integrate the auditory input with their surrounding visual context and environment, facilitating lexical selection. For example, an analysis of eye movements shows that when presented with a set of images and hearing the onset of the word "candle," monolingual English speakers will look both to the image of a *candle* and to that of *candy*, before resolving the competition and settling on the former (Allopenna et al., 1998). Expanding this model of parallel activation, bilinguals, too, have been shown to activate all potential matching lexical items—this time across both languages. This was classically demonstrated by Spivey and Marian (1999), who showed that when prompted in Russian toward a *marka* "stamp," Russian–English bilinguals were distracted by a *marker*, because of its similar phonological onset. Over numerous studies, co-activation was found to take many forms, including semantic, orthographic or phonological (see, for instance, Dimitropoulou et al., 2011; Iniesta et al., 2021; Chen et al., 2021; McDonald et al., 2023). In the present work, we focus on the latter, whereby hearing input in one language can trigger similar-sounding lexical representations in another (Shook & Marian, 2013). Crucially, bilingual co-activation does not occur uniformly, with several potential contributing factors.

Many studies of cross-linguistic phonological competition have found that dominance plays a key role, such that in L1-dominant individuals, the L1 interferes (or is co-activated) more when processing the L2 than the other way around (see Lago et al., 2021). Such studies often utilize the visual world paradigm experiment to track eye movements, presenting participants with four equidistant objects in each corner of a screen and auditorily prompting users to click on a particular one (Huettig et al., 2011). Marian and Spivey (2003a) found that when L1-Russian-dominant L2-English speakers were instructed in English to manipulate a virtual *plug*, their eye gazes moved both toward the phonologically related *plum* but also toward an image of a dress, or *platje*—phonologically similar to the first three phonemes of *plug*—in Russian. These findings—wherein the dominant language was co-activated in the weaker language—were further replicated for Dutch–English, French–English, Spanish–English and Japanese–English bilinguals (Blumenfeld & Marian, 2007). Meanwhile, Spivey and Marian's (1999) study found that L2-English was co-activated in a Russian experiment among L1-Russian-dominant bilinguals, but Russian was not co-activated to the same extent in an English version of the same experiment. That is, the stronger language was in fact not activated during weaker-language processing, while the weaker was implicated in dominant-language processing.

On the other hand, Marian and Spivey (2003b) found the opposite: with L1-Russian-dominant L2-English bilinguals

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demonstrating only co-activation of Russian in an English experiment, and not the other way around. A similar effect—with competition only from the dominant language in L2 processing but not vice versa—was found for Dutch–English bilinguals (Weber & Cutler, 2004). Thus, co-activation can be asymmetrical, potentially dependent on factors beyond dominance, such as language use, immersion and proficiency levels.

Regarding the latter, co-activation has been demonstrated across all levels of proficiency, both new learners or unbalanced early bilinguals and advanced ones, and across both similar and distinct language pairs (see Kroll et al., 2012 for an overview). These co-activation patterns are consistent with predictions of the Bilingual Language Interaction Network for the Comprehension of Speech (BLINCS) model (Shook & Marian, 2013). The BLINCS model posits that, following auditory input, activation first occurs at the phonological level across all known languages. Activation then occurs at the phono-lexical level (where languages are assumed to be separate but integrated) and then the semantic level, shared across languages. Activation at any level can feed back into the preceding ones. Per the model, visual information is integrated at the semantic level, and can then prime phonemic activation, such that the semantic and phonological levels are activated simultaneously. For example, if a visual display presented to Spanish–English bilinguals contains three images of a pear, a dog and a volcano, activation of *dog* (or *perro* in Spanish, phonologically similar to *pear*), will increase from both the phonological and the visual levels. The BLINCS model therefore presents a highly interactive network that will trigger activation of words across multiple dimensions that can then, in turn, trigger even further activation. In her 2023 book *The Power of Language* (p. 31), Viorica Marian proposes to extend the BLINCS model to apply in an English-Russian-Romanian trilingual context, suggesting that when a given lexical form exists in all three languages, all associations across orthography, phonology and semantics in all languages are activated in a similar interactive-network-based fashion (Marian, 2023).

1.2. The lexicon of trilingual speakers

Previous research demonstrates that all lexicons of trilingual individuals are connected, as evidenced by the availability of each for potential cross-linguistic influence (Lindqvist & Falk, 2023; Otwinowska, 2023). The extent to which other languages may be activated—or even available for activation—during production or comprehension of an L3 seems to depend in large part on the proficiency levels of each language, although findings diverge.

The bulk of studies on L3 processing comes from the domain of morphosyntax, with most investigating the specific dynamics and conditions for cross-linguistic influence between previously acquired and novel languages (see Abbas et al., 2021; Alonso & Rothman, 2022; Jensen et al., 2023; Westergaard, 2021). Within studies on the multilingual lexicon, most have focused on production, rather than comprehension (Lago et al., 2021). Of those that assess comprehension, most have centered around acquisition, rather than processing of an already-acquired language. Whereas in L2 acquisition cross-linguistic influence can only occur from one source (the L1), in Ln acquisition there are at least two previously acquired linguistic systems available to draw on and, by considering factors such as proficiency, dominance, order of acquisition, context of acquisition, typological proximity and others, the L3/Ln context can provide important insights into the triggers of cross-linguistic influence.

Overall, the few online L3 processing studies that exist have found that bilingual results are only partially replicated, such that existing models from bilingualism research cannot be taken wholesale to apply to multilingual scenarios (Lijewska, 2022). Others suggest that all languages of a multilingual person are available for activation, and that activation is modulated by language dominance (Lago et al., 2021).

Most L3 studies exploring lexical competition have focused on cognates as a key feature in determining the extent to which all languages may be available for activation (for an overview, see Otwinowska, 2023). Cognates between languages share similar forms and meanings and can either facilitate or hinder the processing of a particular language by triggering another (Lemhöfer, 2023). Van Hell and Dijkstra (2002) found that both English–Dutch and French–Dutch cognates facilitated processing in a Dutch lexical decision task among Dutch–English–French trilinguals, although the French–Dutch cognates did so only once a certain proficiency level had been reached. Meanwhile, Zhu and Mok (2023) found a facilitative cognate effect even between the non-dominant English and German among Cantonese–English–German trilinguals, contrasting previous stipulations of minimum proficiency thresholds. Extending these findings further, Lemhöfer et al. (2004) found a cumulative effect of trilingual activation, wherein triple cognates between Dutch, English and German yielded quicker reaction times on a lexical decision task compared with double cognates. It is primarily based on these cognate studies that L3 researchers conclude that, as with bilinguals, all previously acquired languages can potentially be active in L3 processing (Lemhöfer, 2023).

However, as with bilingual processing, co-activation is not always symmetrical. L3 studies provide a more multidimensional lens through which to investigate co-activation, where for instance, one language could co-activate a second, but not a third. With the addition of the L3, language use across contexts can become more varied, with more opportunities to use different subsets of the language repertoire. The amount of regular use of each language can also contribute to the extent to which it is activated. For example, Pathak et al. (2024) showed delayed RTs among L1-Nepali/L2-English/L3-Norwegian speakers only in L3 processing. It thus becomes imperative for any study of trilingual co-activation to consider potential asymmetries.

Having observed asymmetrical effects regarding the extent to which one language can co-activate the other in bilinguals, we must make a point to consider all three trilingual participants' languages, rather than assuming activation directionality. Additionally, we should consider diverse groups of trilinguals beyond the paradigm of a monolingual speaker living in her native society and learning two additional languages. Finally, to most accurately portray potential activation, we must be highly cognizant of the dynamics between the trilingual languages. Addressing the first two points, the present study investigates co-activation in all three languages, the HL, SL and a prestigious L3. To understand the implications of the final point, we consider the ways in which the three languages of our participants interact within their society.

1.3. The current study

The current study revolves around trilingual speakers of Russian, Hebrew and English, who were raised and currently reside in Israel.

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Note that Russian, Hebrew and English are typologically highly distinct languages from different language families. While Russian and English are both Indo-European languages, Russian is Slavic and English is Germanic; Hebrew is a Semitic language—even more distant from the latter two. In our case, the typological distance between all three languages serves as a significant asset, as we can rule out typological proximity from the list of potential factors that could influence co-activation.

In Israel, Hebrew is the official national language, used across all aspects of daily and professional life. Russian is the third most spoken language, following Hebrew and Arabic, with over 1 million speakers (Meir et al., 2021). It is the top HL spoken in the country and can be encountered nearly ubiquitously in every arena of public life, with public services available in Russian, Russian-language signage found on storefronts across the country, and some radio and TV channels broadcast entirely in Russian. English, despite being neither a national language nor among the most-spoken in the country, enjoys a special, prestigious status in Israel (Gordon & Meir, 2023). It is one of the seven required subjects to pass the high school matriculation exam and a high level of English proficiency must be demonstrated before university admittance (Rose et al., 2023).

It is important to understand the dynamics between these languages in Israel for the following reasons. Our participants—HL-Russian speakers with L3-English—learned Russian at home, but were able to encounter it beyond the home, as well, even if their conscious efforts to engage with the language and its speakers may vary. This is highly different from other HL contexts, such as those of many minority languages in the United States, where there may be very limited exposure to the HL beyond the home or occasional weekend language school (Benmamoun et al., 2013). Similarly, while L3-English was learned in the classroom, it, too, sees increased use and utility well beyond the academic context and can be commonly encountered in media, in the workplace, or when traveling. Thus, our participants are active trilinguals whose language experience transcends setting-based boundaries and at a group level cannot be compartmentalized exclusively to the home or the school. As such, it is also expected that they experience greater activation of their languages—whether in the full triad or in pairs—which may impact the results of the current study.

In the current study, we assess cross-linguistic co-activation in all three languages of HL-Russian/SL-Hebrew/L3-English trilinguals. To examine whether these trilinguals show evidence of cross-linguistic competition in their languages, we test whether they show activation of phonologically overlapping items from their non-target language(s) when prompted in another. We posed the following research questions.

RQ1: Do trilingual speakers exhibit phonological co-activation for cross-linguistic competitors in all three languages?

The null hypothesis is that no languages other than the prompting language will be activated at one time—a highly unlikely scenario based on previous work. This would be observed in our results if accuracy, RTs and eye-fixations are fairly similar across all conditions. Alternatively, based on previous work on bilingual and trilingual co-activation, both competing languages will be activated (Szubko-Sitarek, 2011), although potentially to different degrees. In other words, it is expected that RTs will be slower and eye-fixations will be more divided between the target and competitors in the critical region (i.e., phonological overlap) in the double and triple co-activation trials. Finally, we may find that only one of the remaining two languages is co-activated when hearing input in a third. Such a finding would align with observations of asymmetrical effects from both L3 and L2 research and would shed light on the mechanisms that guide co-activation both language-internally in the case of lexical and phonological processing and language-externally, invoking the ability to inhibit some, but not other, languages.

RQ2: How does language proficiency affect co-activation in trilingual HSs?

Prior studies have yielded inconsistent findings with regard to this question in bilinguals, which we extend to three possible outcomes in the trilingual paradigm. The null hypothesis here is that co-activation will be found in similar patterns across all three language experiments. The first alternative hypothesis is that the language(s) with higher proficiency will be co-activated more in experiments in lower proficiency languages, as was shown in Marian and Spivey (2003b), and several other studies discussed in Section 1.1, while the second alternative hypothesis is that lower proficiency languages will be co-activated during higher proficiency language experiments, as was observed in Spivey and Marian (1999).

2. Methods

All stimuli used in this study, as well as all collected data and the R script used to analyze them, are available at the following link: https://osf.io/d2a5z/?view_only=5a204bf7090f4528941d9eb0ebc8eaa0

2.1. Participants and background tasks

Participants were recruited through word of mouth and Facebook groups. To be eligible, participants needed to be (1) over the age of 18; (2) born in Israel to a Russian-speaking household, or moved to Israel by or at age 5; (3) able to communicate in each of Russian, Hebrew and English at least at some basic level (subject to the participants' own self-perception) and (4) not proficient in a fourth language to the level of any of the first 3. Participants completed a background questionnaire to document their language experience and the Multilingual Naming Task (MINT, Gollan et al., 2012) to approximate lexical proficiency in the participants' three languages.

Out of fifty participants, two were excluded because of undisclosed foreign language proficiency, revealed only after completing the experiment. The remaining 48 participants (20M, 28F), with an average age of 27.3 years, included 31 born in Israel and 17 in countries of the former Soviet Union. All participants' age of acquisition of Russian was 0 years, Hebrew was 1.04 years on average and English—per the start of formal instruction in Israel- was 8–9 years (3rd grade, see Weissblay, 2017). Education levels varied (21 were BA students, 17 completed Bachelor's degrees, 9 had Master's degrees and 1 had a PhD). Nineteen participants had at least one parent with a Master's degree or higher and 42 had at least one parent with a Bachelor's degree or higher.

At the group level, participants reported highly distributed language use across ages and contexts (see Appendix A1), with half of participants reporting using all three languages starting at ages 6–12, 83% doing so in later years, and only 6% reporting using only one language in adulthood. Language use across contexts was also highly varied, with a large majority of participants using at least two languages in each context, apart from primarily HL-Russian use with grandparents. Most notably, in a country with only one official national language, only 27% of participants reported using only

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SL-Hebrew in the workplace, and only 54% reported using only SL-Hebrew for day-to-day tasks and during mandatory military service—three environments where one might expect the dominant societal language to prevail.

Highlighting language proficiency, self-ratings for the three languages were collected on a scale of 1–5 as part of the background questionnaire, and an objective proficiency measure was collected using the MINT assessment of proficiency (Gollan et al., 2012). The MINT was explicitly designed to test multilinguals, in contrast to previous picture-naming vocabulary assessments such as the Boston Naming Test (Kaplan et al., 2001), which had been developed with only monolinguals in mind. The MINT contains black and white line drawings prompting 68 picture names in increasing difficulty. The assessment was originally designed for and tested on speakers of English, Spanish, Mandarin Chinese and Hebrew. Notably, the MINT was not originally designed to accommodate Russian, and therefore some of the Russian target words may not be matched in frequency to those in English or Hebrew. However, we are not aware of a picture-naming task that has been tested for adult multilinguals of all three of our target languages. Therefore, as we were not comparing performance between groups, the MINT served as a suitable tool to reach a baseline proficiency measure.

Figure 1 showcases self-rated and MINT-assessed proficiency in each language. The left-side graph shows average self-ratings, with Russian rated 3.26/5, Hebrew—4.82/5 and English—4.16/5. On the right-side graph, each dot represents an individual, and the lines connect that individual's scores across the three MINTs. The Russian MINT shows the greatest variance in scores, followed by English and Hebrew. Along the same vein, the average score on the Hebrew MINT was 88% (SD: 5%), followed by English at 76% (SD: 9%) and Russian at 58% (SD: 15%), matching the order of dominance and proficiency found in the self-ratings. For the self-rating results, we ran a cumulative link model using the formula clmm (Self_Rating ~ Language + (1 | Participant), to assess for language differences in our ordinal ratings data, while accounting for participant-related variance. This model used Russian ratings as the baseline and found significant effects of Hebrew and English. For the MINT scores, we ran a linear regression with Language as a fixed effect and Participant as a random effect and found a significant effect of language. In follow-up pairwise comparisons for both models, using Tukey corrections for multiple comparisons, we found significant differences in scores between each language pair (RUS-HEB, RUS-ENG, and ENG-HEB), each with a p-value of $p < 0.001$ (for both MINT scores and self-ratings, separately). Note, however, that despite these group-level findings, several horizontal or near-horizontal lines can be seen in the right-side graph, indicating that some participants are balanced between two of their languages. One participant scored higher in Russian than in Hebrew, and one scored higher in English than in Hebrew. Eight (of the 48) scored higher or the same in Russian as in English. Thus, an investigation of individual proficiency differences, in addition to the group-level findings we present in the present study, will be insightful in future work.

2.2. Experimental setup

The eye-tracking experiment was set up using the visual world paradigm, with four images on the screen at a time. See Figure 2 for a sample screen. This screen could prompt for a *bear* [ber] in American English, and thus co-activate *berex* [beʁeχ] (knee) in Hebrew, or vice versa.

The experiment was conducted in three blocks—one for each language. Each block contained 42 slides. Two practice slides were included at the beginning of each block. Of the remaining 40, 10 slides each were included in four conditions. The first condition was the control, with no co-activation. Slides in this condition included a target and three other images, none of which

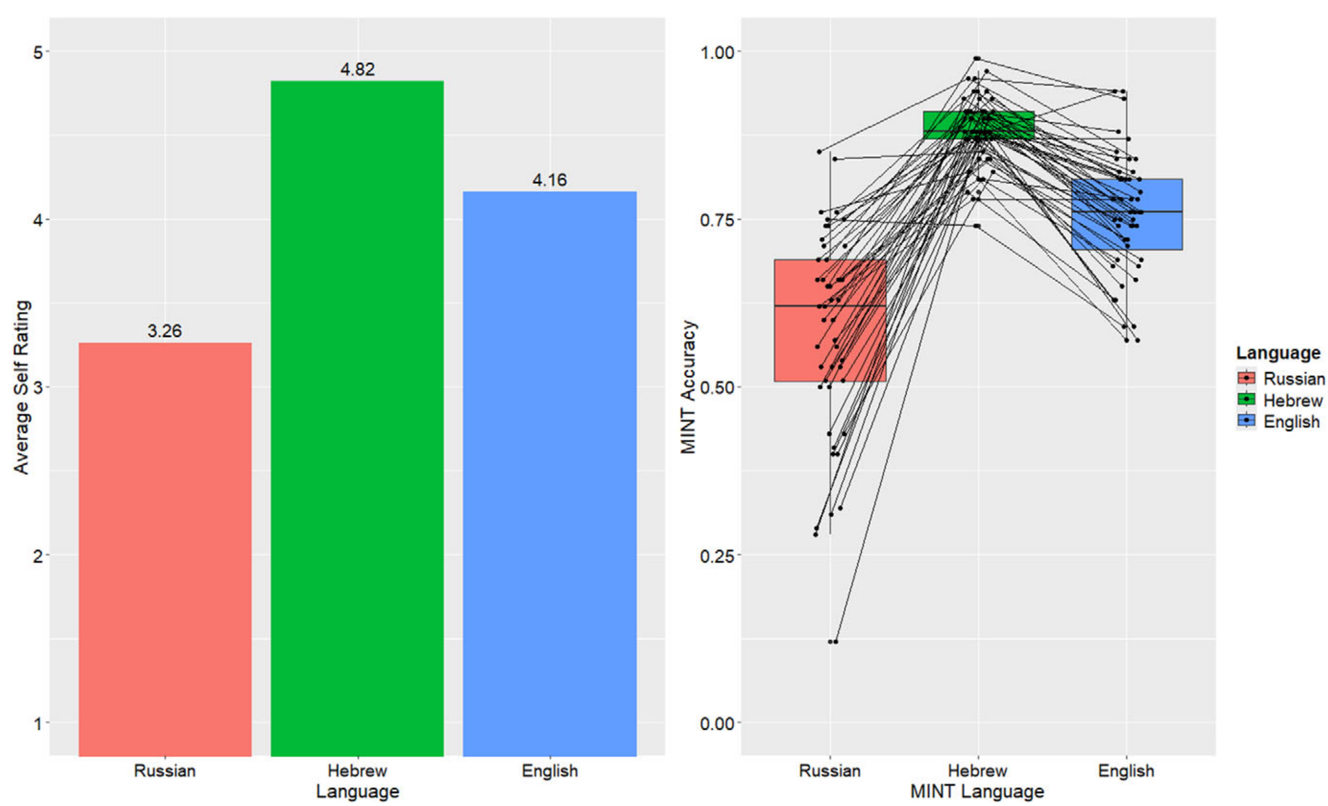

Figure 1. Self-Rated (left, with average scores on a 1–5 scale) and MINT-assessed (right, with each individual score as a dot) proficiency in HL-Russian, SL-Hebrew and L3-English.

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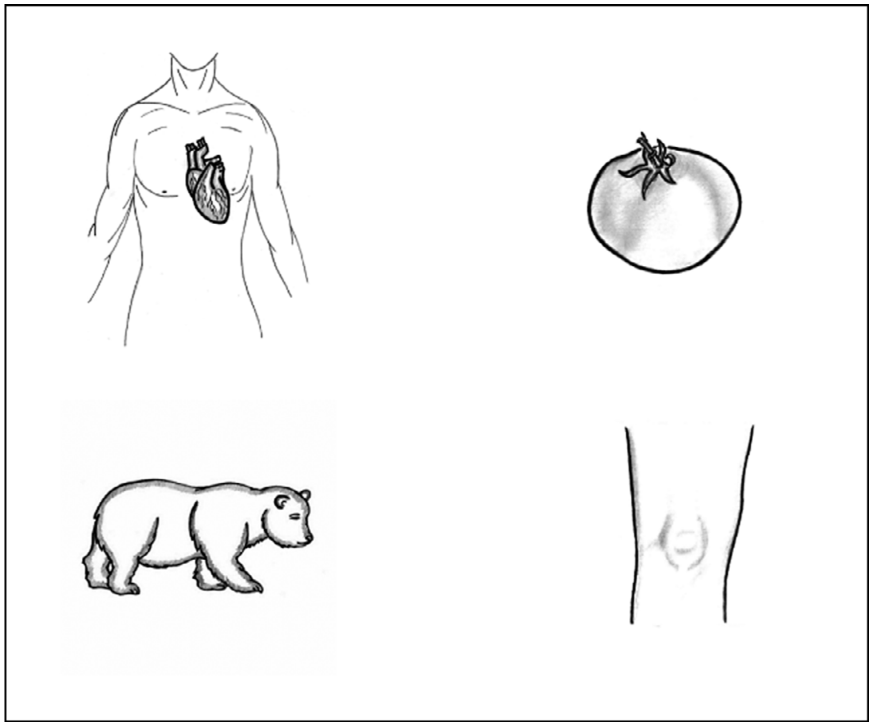

Figure 2. Sample screen.

were cross-linguistic phonological competitors. The second and third conditions included the target, one competitor and two additional images. In the fourth condition, there was a target, two competitors in the two remaining languages and one additional image. Examples of each condition can be found in Table 1. The 40 slides were presented in a randomized order, and the examples in Table 1 do not represent the order in which the stimuli were presented.

A total of 85 distinct images, all taken from the Akinina et al. (2015) *Noun and Object* image database, were used for this experiment, with each image repeating a maximum of 6 times. Images were not repeated in consecutive slides. Target stimuli had an average of 4.5 phonemes (averaging 5.1 for Russian, 4.8 for Hebrew and 3.8 for English) and an average overlap of 2.03 phonemes, or 254 ms. For a detailed description of how the stimuli were selected and how the experiment was developed, see Supplementary Material 1.

2.3. Procedure

The procedure of the study was approved by the institutional review board of Bar Ilan University. Participants were paid 50 NIS (~12 USD) for their participation. Participants first filled out a brief background questionnaire and consent form. Next, within each language session, they completed the MINT assessment, followed by the eye-tracking task. This procedure of MINT and eye-tracking was repeated—first in Russian, then in Hebrew and finally in English, to reflect participants' order of acquisition. Before the start of each experiment, participants' eye movements were calibrated by the EyeLink at a 1,000 Hz sampling rate. A nine-point calibration routine was used. Participants' head position was stabilized using a chin rest. To move to the next trial participants needed to focus on a cross presented on a blank screen and then press the spacebar, to ensure that eye movements could be tracked reliably. Before each MINT task, participants engaged in a brief 1- to 2-minute conversation with the researchers in the target language, as a means of priming the upcoming tasks, as had been done in Marian and Spivey (2003a). In the following section, we present the target accuracy, reaction times to target and target eye-fixation proportions for all three languages, to discern whether and how co-activation is realized across the different conditions.

3. Results

Table 2 presents descriptive statistics showing means and standard deviations for accuracy and RTs in all three languages. Each column represents the respective experiment and the language in which the stimuli were prompted, while the row titles represent the relevant competitor(s) in a given condition. The condition factor has four levels: the control where 1 language is activated, two levels where two languages are activated (the target and one of the remaining two languages) and one level where three languages are activated (the target and both of the remaining two languages). Statistical models analyzing the effect of condition on accuracy and RT outcomes are presented below for each language, respectively. Across each of the models, the control condition was set as the reference level for comparison.

To analyze accuracy in each language, we used a generalized linear mixed effects model with the formula glmer(RESPONSE ~ (1 | Participant) + (1 | TRIAL_INDEX) + condition), given the binary nature of our response variable (1 = Target; 0 = Non-target), where random effects were included for both participant and trial index. For reaction times (RTs), we fitted separate models for each language using a linear mixed-effects model (LMM) with the formula lmer(Time_CRwordOnset ~ (1 | Participant) + (1 | TRIAL_INDEX) + condition), again including participant and trial index

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Table 1. Sample trials by language and condition, with overlapping phonemes in bold

Language	Condition	Target	Competitor or Distractor	Competitor or Distractor	Competitor or Distractor
Russian	1-Language Activation	*derevo* (R.tree)	*kljuv* (R.beak)—*makor* (H.beak)	*slon* (R.elephant)—*pil* (H.elephant)	*chashka* (R.cup)—*kos* (H.cup)
	2-Language Activation (RUS-HEB)	***lev*** (R.lion)	*serdce* (R.heart)—***lev*** (H.heart)	*krovat'* (R.bed)—*mita* (H.bed)	*vedro* (R.bucket)—*dli* (H.bucket)
	2-Language Activation (ENG-RUS)	***cher****ep* (R.skull)	***chair***	*orel* (R.eagle)—*nesher* (H.eagle)	*utka* (R.duck)—*barvaz* (H.duck)
	3-Language Activation (ENG-RUS-HEB)	***kar****andash* (R.pencil)	***car***	*podushka* (R.pillow)—***kar****it* (H.pillow)	*xomjak* (R.hamster)—*oger* (H.hamster)
Hebrew	1-Language Activation	*mitz* (H.juice)	*povar* (R.cook)—*tabax* (H.cook)	*ruka* (R.hand)—*yad* (H.hand)	*podushka* (R.pillow)—*karit* (H.pillow)
	2-Language Activation (RUS-HEB)	***oze****n* (H.ear)	***oze****ro* (R.lake)—*agam* (H.lake)	*ryba* (R.fish)—*dag* (H. fish)	*kukla* (R.doll)—*buba* (H.doll)
	2-Language Activation (ENG-HEB)	***ber****ex* (H.knee)	***bear***	*chashka* (R.cup)—*kos* (H.cup)	*ozero* (R.lake)—*agam* (H.lake)
	3-Language Activation (ENG-RUS-HEB)	***pil*** (H.elephant)	***pil****a* (R.saw)—*masor* (H.saw)	***pil****ow*	*kist'* (R.paintbrush)—*mikxol* (H.paintbrush)
English	1-Language Activation	fork	*kist'* (R.paintbrush)—*mikxol* (H.paintbrush)	*kletka* (R.cage)—*kluv* (H.cage)	*kot* (R.cat)—*xatul* (H.cat)
	2-Language Activation (RUS-ENG)	***eagl****e*	***igl****a* (R.needle)—*maxat* (H.needle)	*jaico* (R.egg)—*beica* (H.egg)	*stul* (R.chair)—*kise* (H.chair)
	2-Language Activation (ENG-HEB)	***har****p*	*gora* (R.mountain)—***har*** (H.mountain)	*mashina* (R.car)—*oto* (H.car)	*uxo* (R.ear)—*ozen* (H.ear)
	3-Language Activation (ENG-RUS-HEB)	***bull***	**bul**avka (R.safety pin)—*sika* (H.safety pin)	*marka* (R.stamp)—***bool*** (H.stamp)	*yad* (R.poison)—*ra'al* (H.poison)

Table 2. Mean target identification accuracy (SD) and mean reaction time to target (SD) in ms, in HL-Russian, SL-Hebrew and L3-English, per condition

Condition	Russian	Hebrew	English
1-Language Activation	**RUS**	**HEB**	**ENG**
	0.99 (0.08)	1.00 (0.05)	1.00 (0)
	2431 (985)	2273 (527)	2138 (349)
2-Language Activation	**RUS-HEB**	**RUS-HEB**	**ENG-RUS**
	0.94 (0.23)	1.00 (0)	0.99 (0.08)
	2863 (1270)	2263 (445)	2336 (432)
2-Language Activation	**ENG-RUS**	**ENG-HEB**	**ENG-HEB**
	0.97 (0.18)	1.00 (0)	1.00 (0.05)
	2588 (980)	2215 (421)	2466 (805)
3-Language Activation	**ENG-RUS-HEB**	**ENG-RUS-HEB**	**ENG-RUS-HEB**
	0.95 (0.21)	0.99 (0.10)	0.99 (0.11)
	2667 (1077)	2292 (416)	2292 (555)

as random effects. In the models evaluating RTs, we took the time from critical word onset recorded at the click stage. The models for eye-fixation proportions assessed the effects of time since critical word onset, condition, and their interaction, on looks to the target, using the formula lmer(Target_Looks ~ Time_CRwordOnset * condition + 1 + (1 | Participant) + (1 | TRIAL_INDEX)). Post-hoc comparisons with Tukey corrections were carried out for all models that revealed significant effects. This approach allowed us to capture both individual variability and trial-specific variations across languages while isolating the effects of condition on accuracy, RT and eye-fixation outcomes.

3.1. *HL-Russian*

3.1.1. Accuracy and reaction times

The model for accuracy in Russian (Table 3) used the RUS condition as the reference level (for the Random Effects, see Supplementary Material 2). While the model showed differences between the RUS control condition and the RUS-HEB condition at $p = 0.020$, follow-up pairwise comparisons found no significant accuracy differences between the conditions. The model for RTs in Russian similarly had RUS as the reference level. As with accuracy, a significant effect was found with the RUS-HEB condition, at $p = 0.021$. However,

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Table 3. Accuracy, RT and eye-fixation proportion regression modeling results for HL-Russian

	RUS vs. RUS-HEB		RUS vs. ENG-RUS		RUS vs. ENG-RUS-HEB	
	Estimates, [CI]	p-value	Estimates, [CI]	p-value	Estimates, [CI]	p-value
Accuracy:	−2.574, −4.74 to −0.41	**0.020**	−1.589, −3.81 to 0.63	0.161	−2.000, −4.19 to 0.19	0.074
Reaction Times:	431.35, 65.85 to 796.85	**0.021**	156.90, −208.60 to 522.40	0.400	235.23, −130.27 to 600.73	0.207
Eye Fixation Proportions:	0.08, −0.02 to 0.18	0.133	−0.01, −0.11 to 0.09	0.791	−0.01, −0.11 to 0.09	0.867
Time since critical word onset:						
0.00, 0.00–0.00 **<0.001**	−0.00, −0.00 to −0.00	**<0.001**	−0.00, −0.00 to −0.00	**0.001**	−0.00, −0.00 to −0.00	**<0.001**

Note: The bottom row above shows the effect of "Time since critical word onset", as well as its interaction with each language condition.

follow-up pairwise comparisons found no significant distinctions between conditions (see Supplementary Material 3 for the full pairwise comparisons for both accuracy and RTs).

3.1.2. Eye-fixation proportions

The model found significant effects of time since the onset of the critical word ($p < 0.001$), as well as significant interaction effects between time since critical word onset and all three conditions. We delved into these significant effects with follow-up pairwise comparisons (see Appendix A2) across three time frames: 250–500 ms, 500–750 ms and 750–1000 ms since the critical word onset, using Tukey corrections for multiple comparisons.

The pairwise comparisons showed a significant difference between the control RUS condition and each of the other three conditions across all time frames, such that there were significantly more eye-fixations to the target item in the RUS condition than in any of the other conditions. Among the other three conditions, after 500 ms, participants looked proportionally more toward the target item when there was an English distractor (the ENG-RUS condition) than when there was a Hebrew distractor present (RUS-HEB and ENG-RUS-HEB). Fixations on the target item were proportionally similar between the RUS-HEB and ENG-RUS-HEB conditions for the first two-time frames but began to diverge significantly after 750 ms, with more fixations on the target in the ENG-RUS-HEB condition. Thus, as depicted in Figure 3, the RUS-HEB condition, demonstrating competition only from the dominant language, exhibited the most distraction, followed by the ENG-RUS-HEB condition, with competition from both the dominant SL and the stronger L3 and then the ENG-RUS condition, with significant differences in eye-fixation proportions between all four conditions after 750 ms.

3.2. *SL-Hebrew*

3.2.1. Accuracy and reaction times

No significant differences between the conditions were found for accuracy or RTs. No pairwise comparisons were run on the resulting models. As demonstrated in Table 4, in both measures, participants performed at ceiling level in all conditions (see Supplementary Material 4 for Random Effects).

3.2.2. Eye-fixation proportions

As depicted in Figure 4, the model for SL-Hebrew showed that there were no significant differences between the control HEB condition

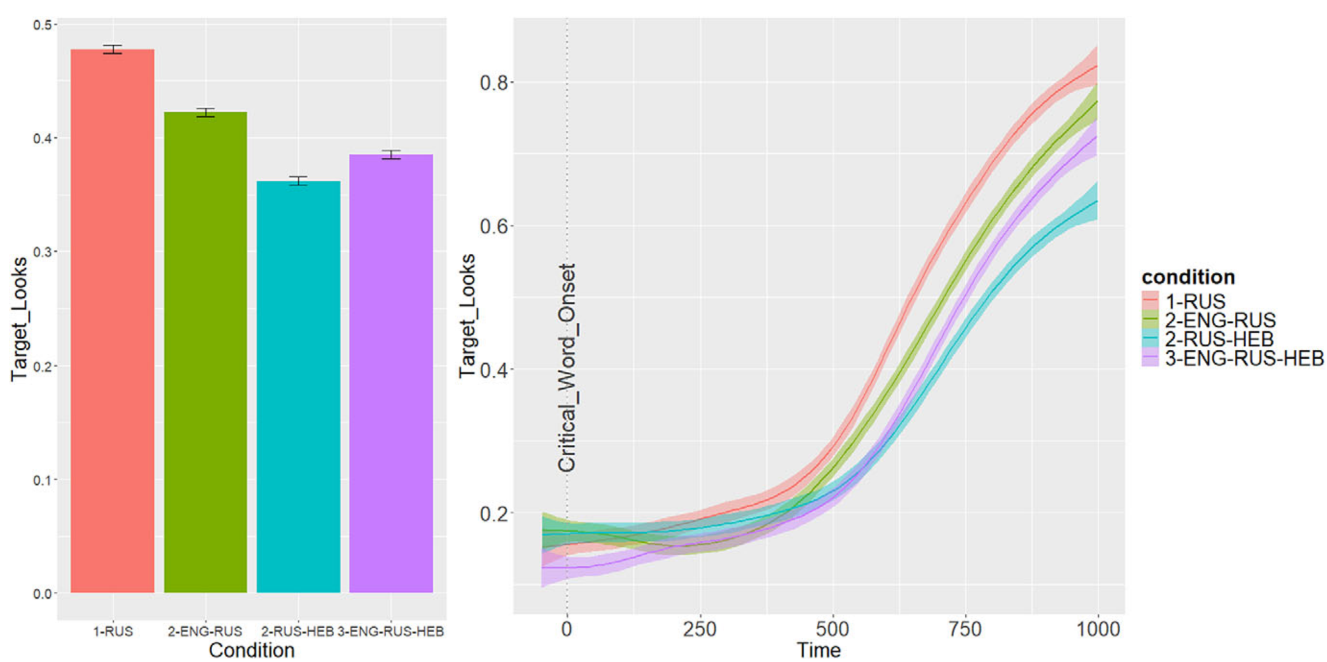

Figure 3. Mean eye-fixation proportions and time course analyses in HL-Russian.

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Table 4. Accuracy, RT and eye-fixation proportion regression modeling results for SL-Hebrew

	HEB vs RUS-HEB		HEB vs. ENG-HEB		HEB vs. ENG-RUS-HEB	
	Estimates, [CI]	*p*-value	Estimates, [CI]	*p*-value	Estimates, [CI]	*p*-value
Accuracy:	19.3731, 0.00 to Inf	0.979	19.1091, 0.00 to Inf	0.978	−0.3215, 0.00 to 435.06	0.922
Reaction Times:	−10.21, −153.19 to 132.78	0.889	−58.11, −201.09 to 84.88	0.426	19.11, −123.88 to 162.09	0.793
Eye Fixation Proportions:	0.02, −0.07 to 0.12	0.657	0.02, −0.07 to 0.12	0.656	−0.01, −0.11 to 0.08	0.786
Time since critical word onset:						
0.00, 0.00–0.00 **<0.001**	−0.00, −0.00 to 0.00	0.740	0.00, −0.00 to 0.00	0.579	0.00, −0.00 to 0.00	0.773

Note: The bottom row above shows the effect of “Time since critical word onset”, as well as its interaction with each language condition.

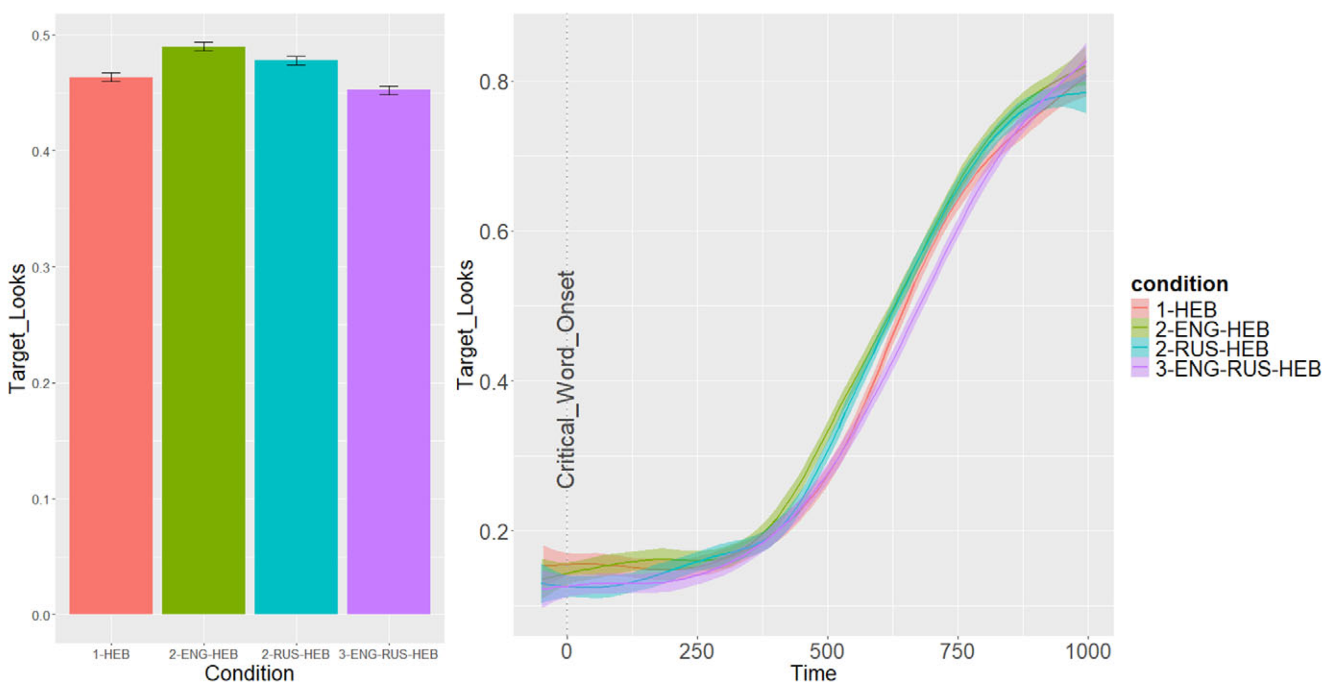

Figure 4. Mean eye-fixation proportions and time course analyses in SL-Hebrew.

Table 5. Accuracy, RT and eye-fixation proportion regression modeling results for L3-English

	ENG vs. ENG-RUS		ENG vs. ENG-HEB		ENG vs. ENG-RUS-HEB	
	Estimates, [CI]	*p*-value	Estimates, [CI]	*p*-value	Estimates, [CI]	*p*-value
Accuracy:	−16.64	0.743	−16.30	0.748	−17.40	0.731
Reaction Times:	197.69, −40.50 to 435.88	0.104	327.67, 89.49 to 565.86	**0.007**	154.18, −84.00 to 392.37	0.204
Eye Fixation Proportions:	−0.01, −0.10 to 0.09	0.913	−0.01, −0.11 to 0.09	0.833	0.03, −0.07 to 0.13	0.586
Time since critical word onset:						
0.00, 0.00–0.00 **<0.001**	−0.00, −0.00 to 0.00	**<0.001**	−0.00, −0.00 to −0.00	**<0.001**	−0.00, −0.00 to −0.00	**<0.001**

Note: The bottom row above shows the effect of “Time since critical word onset”, as well as its interaction with each language condition.

and the three co-activation conditions. Furthermore, there was no significant condition * time interaction. In other words, eye-fixation proportions did not differ between conditions. No pairwise comparisons were carried out for the Hebrew experiment since no effect of condition and/or any interaction with condition turned out to be significant.

3.3. L3-English

3.3.1. Accuracy and reaction times

Our accuracy model found no significant differences between the control and the co-activation conditions, similar to both of the prior experiments (see Table 5). For RTs, a significant difference was found only between the ENG-HEB condition and the control ENG reference ($p = 0.007$), demonstrating a slow-down in the presence of a competitor compared with the control condition. Follow-up pairwise comparisons corroborated this effect at $p= 0.0495$, while no other significant effects were found between the conditions (see Appendix A3).

3.3.2. Eye-fixation proportions

Our model showed a significant effect of time since the onset of the critical word ($p < 0.001$), and all interactions between condition and time since critical word onset were significant (see Supplementary Material 5 for Random Effects). Follow-up pairwise comparisons using Tukey corrections (see Appendix A4) revealed that there were more looks to the target item in the control ENG condition than in both the ENG-HEB and ENG-RUS conditions in all three time frames and more than in the ENG-RUS-HEB condition starting from 500 ms from target word onset. There were more looks to the target item in the ENG-RUS-HEB condition than in both the ENG-HEB and ENG-RUS conditions across all three-time frames. Meanwhile, the ENG-HEB and ENG-RUS conditions differed in looks to target only during the 500-750 ms time frame, matching in proportions both early on and later into processing.

Thus, as depicted in Figure 5, the ENG-RUS and ENG-HEB conditions showed the most distraction (least proportional looks to target), followed by the ENG-RUS-HEB condition with significantly more looks to target, and the ENG control condition with the most.

4. Discussion

In the present study, we set out to investigate cross-linguistic lexical competition and co-activation among HL-Russian/SL-Hebrew/L3-English trilinguals. Contrasting the order of language acquisition, the proficiency assessment based on both self-ratings and MINT results demonstrated that participants were dominant in their SL-Hebrew, followed by their L3-English, with the lowest proficiency in their HL-Russian. This allows us to consider the order of acquisition and language dominance as separate variables, with the potential to contribute to our findings in different ways.

We aimed to investigate whether trilingual speakers exhibit phonological co-activation for cross-linguistic competitors in all three languages and to determine the dynamics of trilingual co-activation. Our null hypothesis posited no languages other than the prompting language will be activated at one time—a highly unlikely scenario based on previous work. This hypothesis was rejected. Non-targeted languages of trilingual speakers were all found to be activated to some degree in each of the experiments, in line with recent findings in L3 studies on word priming, production and cognate processing (see Lemhöfer, 2023; Lago et al., 2021 for an overview). However, the activation of the three languages was asymmetrical, suggesting that factors such as language proficiency, order of acquisition and others modulate cross-linguistic co-activation in trilingual processing.

Before interpreting our results, it is important to say a few words about the language background and experience of the participants, as this will contextualize our findings. As reported by their background questionnaires (Section 2.4), our participants were active multilinguals, with the vast majority using their full linguistic repertoire regularly starting from age 13, and only a small percentage—6%—using only one language throughout adolescence and adulthood. Especially notable is the fact that a vast majority of participants use at least two of their languages for media consumption; a majority use at least two languages at work and when communicating with friends, and nearly half of the participants report using at least two languages in day-to-day life. Chung-Fat-Yim et al. (2023) suggest that multilinguals whose languages are used across contexts exhibit different outcomes from those whose use of a particular language is restricted only to the home or workplace. Because of their use across multiple contexts, it is likely that our participants' languages are more prone to co-activation.

With this in mind, we now review the implications of our findings on accuracy—which were uniform across the board—

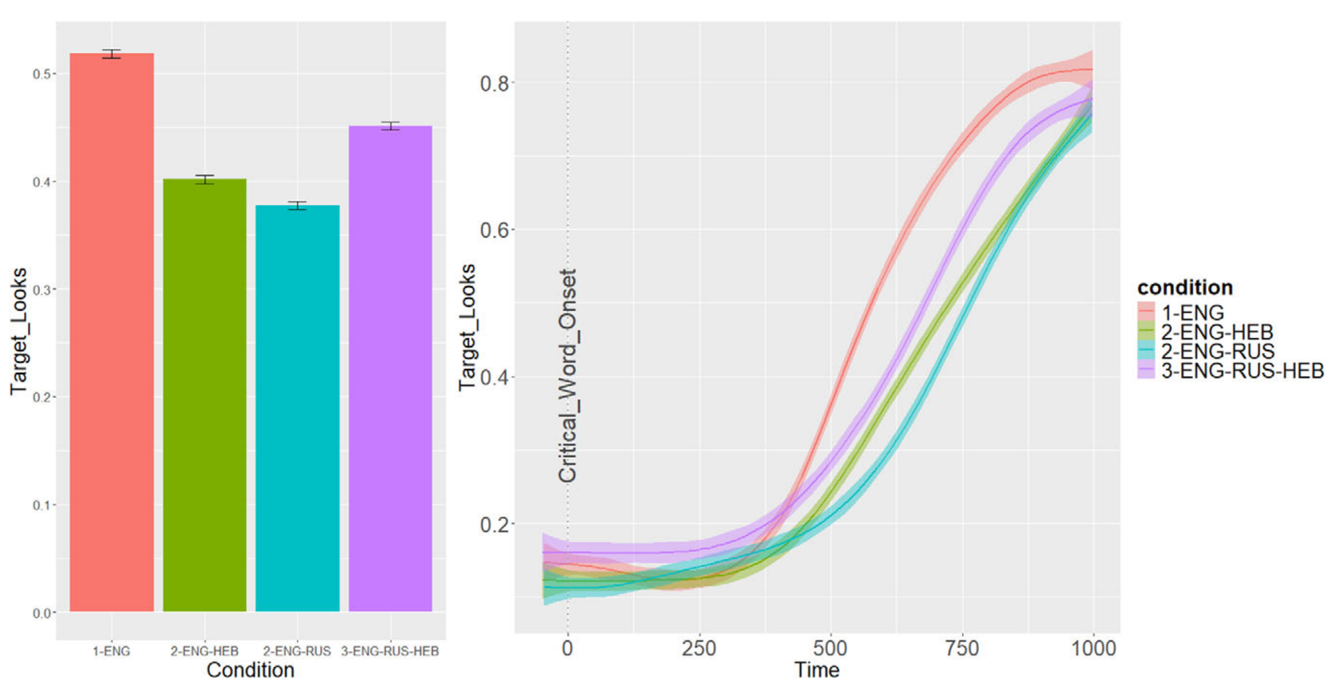

Figure 5. Mean eye-fixation proportions and time course analyses in L3-English.

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and RTs and eye-fixation proportions—which showed asymmetry—from each experiment separately, before drawing conclusions about the full picture. First, the accuracy of target selection did not differ based on competition conditions in any experiment. This is highly expected: by the time the critical word prompt is completed and any hesitation caused by overlapping cross-linguistic signals is overcome, participants should be able to accurately identify the target item (see also Prinzmetal et al., 2005, and van Ede et al., 2012, who show that accuracy and RTs invoke distinct cognitive processes).

Similarly, RTs did not differ between conditions in the Russian and Hebrew experiments, despite significant distinctions in proficiency. In the English experiment, however, RTs were significantly slower in the ENG-HEB condition than in the ENG control condition, while all other conditions matched. It makes sense that competition from the strongest language would lead to slower RTs, echoing bilingual findings from Ju and Luce (2004), Blumenfeld and Marian (2007) and others. However, it is then peculiar that no slow-down was observed in the RUS-HEB condition compared with RUS, or from the ENG-RUS condition, also featuring competition from a stronger language, for that matter. This is particularly surprising, as L3-English proficiency was higher than HL-Russian, such that we might expect the more dominant language to have more of an effect when processing in a weaker one. Additionally, note that the ENG-RUS-HEB condition, which also involved competition from the dominant Hebrew, did not yield slower RTs. Thus, we present two possible interpretations. The first is that this RT effect results from the particular configuration of stimuli selected for the English experiment, especially as compared with the Russian experiment. Furthermore, increased awareness of the testing paradigm, with English being tested last in a consecutive set, may have contributed to the observed effect. This explanation could be ruled out with an extensive analysis of the stimuli properties or by alternating the order of the experiments, as detailed in Section 4.1. A second alternative explanation invokes order of acquisition and the L1 status factor, where despite higher overall proficiency in the L3 than the L1/HL, the former is more susceptible to distraction from the dominant SL. This partially reflects the effects described in Cabrelli and Iverson (2024), who found that HL-Spanish (SL-English dominant) speakers behaved similarly to L1-Spanish (Spanish dominant) speakers, and crucially differently from L2-Spanish (English dominant) speakers, on an L3 acceptability judgment task, thus differentiating dominance and order of acquisition. Although the present study considers L1/L3 rather than L1/L2 dynamics, the same principle is proposed to hold.

Although this had not been the case for RTs, when considering eye-fixation proportions in the HL-Russian experiment, the RUS-HEB condition showed the most distraction, with the fewest eye-fixations to target compared to the RUS control condition. The ENG-RUS-HEB condition had the next-most distraction, followed by ENG-RUS, although all three conditions differed significantly both from the baseline RUS and from one another. Thus, although no significant changes in RTs were observed as a factor of condition, competition from both stronger languages separately and together clearly yielded distraction in weaker-language processing, supporting the pattern found in Marian and Spivey (2003b) as predicted in the alternate hypothesis for RQ2.

In the SL-Hebrew experiment, as with RTs, no differences between conditions were found for eye-fixation proportions: upon hearing a stimulus in the dominant language, participants looked to the target image equally, regardless of other images on the slide. This mirrored findings from the weakest HL-Russian, where all conditions differed from one another, such that any competition triggered co-activation, thus demonstrating an asymmetry between the directionality and the magnitude of co-activation across languages of different levels of proficiency (Marian & Spivey, 2003b; Weber & Cutler, 2004). Furthermore, this finding contradicts that of Spivey and Marian (1999), who found activation of the weaker language during dominant-language processing, and shows that when trilinguals process auditory input in their most proficient language, they can more easily inhibit competition from their weaker languages.

In the L3-English experiment, which was the only one to see co-activation effects in RTs, eye-fixation proportions showed similarities and differences with both of the previous two experiments. As with HL-Russian, in L3-English, all competition conditions differed significantly from the control condition. However, unlike in the HL-Russian experiment, in L3-English, the ENG-RUS and ENG-HEB conditions both showed comparable levels of distraction. The co-activation of Russian competitors echoes findings from Zhu and Mok (2023), who observed co-activation effects between the two weaker languages of trilinguals in lexical decision tasks, further demonstrating how even the weakest language can be co-activated by the weaker one in a three-language system and that this can even reach the level of stronger-language co-activation. Notably, the activation of the less-proficient Russian competitor during the processing of a stronger language supports findings from Spivey and Marian (1999), in direct contrast to the SL-Hebrew experiment, and recalls the conclusion from Van Hell and Dijkstra (2002) that some co-activation effects may be observed in trilinguals only once a particular proficiency threshold has been reached. It appears that, whether because of its proficiency being significantly lower than SL-Hebrew or because of its status as the third language, L3-English has not achieved the level needed to inhibit distraction from the other languages.

Still, it is surprising that the ENG-RUS condition showed significantly more distraction than the ENG-RUS-HEB condition, which included competition from the dominant language. One potential explanation for our results is that, in the presence of two competitors, participants allocate less attention to any single competitor because of the presence of multiple competitors. When they give each competitor less consideration, their attention is ultimately directed more toward the target. The results from the eye-fixation proportions are notably different from those of the RTs in this experiment. While the ENG-HEB condition showed both the slowest RTs and the lowest proportion of fixations to the target, the ENG-RUS condition also showed a comparably low proportion of fixations to the target yet did not impact RTs. This discrepancy points to the importance of carefully selecting appropriate methods for mapping the target phenomenon, as different methodologies may not yield identical findings. In the case of the present study, eye-fixations measured on-line processing, while RTs reflected the timing of lexical selection. Thus, considering that significant differences between conditions were observed during processing but not at the response level, it is likely that competition was resolved before lexical selection. This follows Franco-Watkins and Johnson's (2011) claim that eye-tracking is more sensitive to patterns in information processing.

Taken together, our results point to the high interactivity of the multilingual lexicon, in line with Shook and Marian's (2013) BLINCS model proposed for bilingual lexicons. Supporting many previous studies on bilingual co-activation, we did not find

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competition effects from weaker languages in dominant language processing. However, we did find differences in co-activation patterns between the HL and the L3, pointing to a distinction between language proficiency and order of acquisition. In the HL-Russian experiment, co-activation reached different levels based on proficiency, with significantly more distraction in the RUS-HEB condition than in the ENG-RUS. By contrast, in the L3-English experiment, the ENG-RUS condition—with competition from the weaker language—showed distraction *on par* with the ENG-HEB condition—with competition from the stronger one. This pattern was further distinct from that observed in SL-Hebrew, where no co-activation was found from either weaker language.

Additionally, while the ENG-RUS-HEB condition in the HL-Russian experiment showed more distraction than the ENG-RUS condition, indicating that the presence of dominant Hebrew causes stronger competition than only the presence of stronger-but-not-dominant English, this was reversed in the L3-English experiment, where participants looked at the target significantly less in the presence of an HL-competitor than in the presence of both an HL *and* an SL competitor. Thus, we found that relatively stronger languages were always co-activated in weaker-language processing, but that relatively weaker languages were sometimes (but not always) co-activated in stronger-language processing. To further dig into whether these findings tie more into proficiency or order of acquisition, future work should consider a similar experimental paradigm with the L3 being weaker than the L1.

Overall, the findings from all three experiments support the proposal that all three languages of a trilingual are active—or available for activation—at all times, supporting the notion that trilingual processing functions similarly to bilingual processing (Lago et al., 2021; Szubko-Sitarek, 2011), yet demonstrate that three-way activation patterns are asymmetrical—such that bilingual notions cannot be wholly applied—and must be studied further (Lijewska, 2022; Kashevarova, 2023).

4.1. Limitations and future directions

Although the current study made a considerable contribution to our understanding of the dynamics of trilingual language co-activation, it is not without limitations. First, it is possible that doing all three language tasks consecutively in such a short time frame could have affected performance. Ideally, this experiment would be spread out into several, and/or longer, sessions, to limit interaction between the languages. Moreover, by nature of having the same images in both the MINT and the eye-tracking tasks, respectively, the last language tested (in the present study—English) is necessarily at an advantage at least in familiarity with the stimuli and the concept of the experiment (see Liu et al., 2025 for an overview of the effects of item repetition on asymmetrical co-activation results). Therefore, a future iteration of this study could alternate the order of languages to control for familiarity effects.

Regarding the stimuli themselves, a future iteration of such an experiment could control for additional factors beyond phonological overlap, such as stress patterns (see Martínez-García, 2019). The current experiment was limited by the testing materials we had at hand; a further study could investigate the linguistic features of the experimental items cross-linguistically, including frequency, neighborhood density and more. Furthermore, to rule out stimuli effects as determiners of outcomes, a replication of the current study using different stimuli (in the same or a different language triad) would provide important insights into the stability of our findings. Additionally, rather than considering fixations to the target in the presence of different combinations of distractors, a future study could compare fixations to a particular distractor compared with another or to neutral control items.

In fact, even beyond exploring the effect of stimuli, more studies using the trilingual experimental paradigm described in the present work are needed to shed light on the phenomenon of trilingual cross-linguistic co-activation. Specifically, as our participants used all three languages across many facets of everyday life, it would be valuable to compare our findings with trilinguals whose language use is less distributed, as this would allow us to consider the effects of active multilingual language use on cognitive outcomes. Alternatively, or additionally, it would be interesting to consider new trilingual contexts, beyond the classic L1 > L2 > L3, as we began to do in the present work. This could include scenarios such as L1-dominant or HL speakers immersed in an L3 environment, allowing for manipulation of the dominance and language use parameters. While the current study focused on group-level trends, it is clear that individual differences in language use and proficiency could have an important impact on processing outcomes, and should be investigated in future work. Finally, because of the experimental design wherein we separately primed and tested three experiments, we presented findings from each experiment individually but did not directly compare these results to each other. Future research should set out to make this direct comparison to understand the dynamics between the three languages more clearly.

5. Conclusion

The present study introduced an auditory 4-image visual world eye-tracking paradigm, examining 2-language and 3-language co-activation in a trilingual context for the first time, aiming to investigate phonological co-activation and competition in HL-Russian/SL-Hebrew/L3-English adult trilinguals. Co-activation was absent for weaker languages when processing the dominant SL-Hebrew. When processing the weakest HL-Russian, co-activation was observed with both more-dominant languages, while in L3-English co-activation was observed with both the weaker HL-Russian and the stronger SL-Hebrew. Effects of competitor type and number varied depending on the language and its status. These asymmetrical findings highlight the unique nuances of the trilingual scenario, which is not the sum of several bilingual scenarios in one. Rather, processing and co-activation differ based on the status (proficiency and order of acquisition) of the language being heard and on that of its competitor(s). Future research should expand on this work by exploring new language triads and diverse trilingual participants.

Supplementary material. To view supplementary material for this article, please visit http://doi.org/10.1017/S1366728925000252.

Data availability statement. The data that support the findings of this study are openly available at https://osf.io/d2a5z/?view_only=7a91378846a04fd3b97a18bfe6eca352.

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Competing interests. The author(s) declare none.

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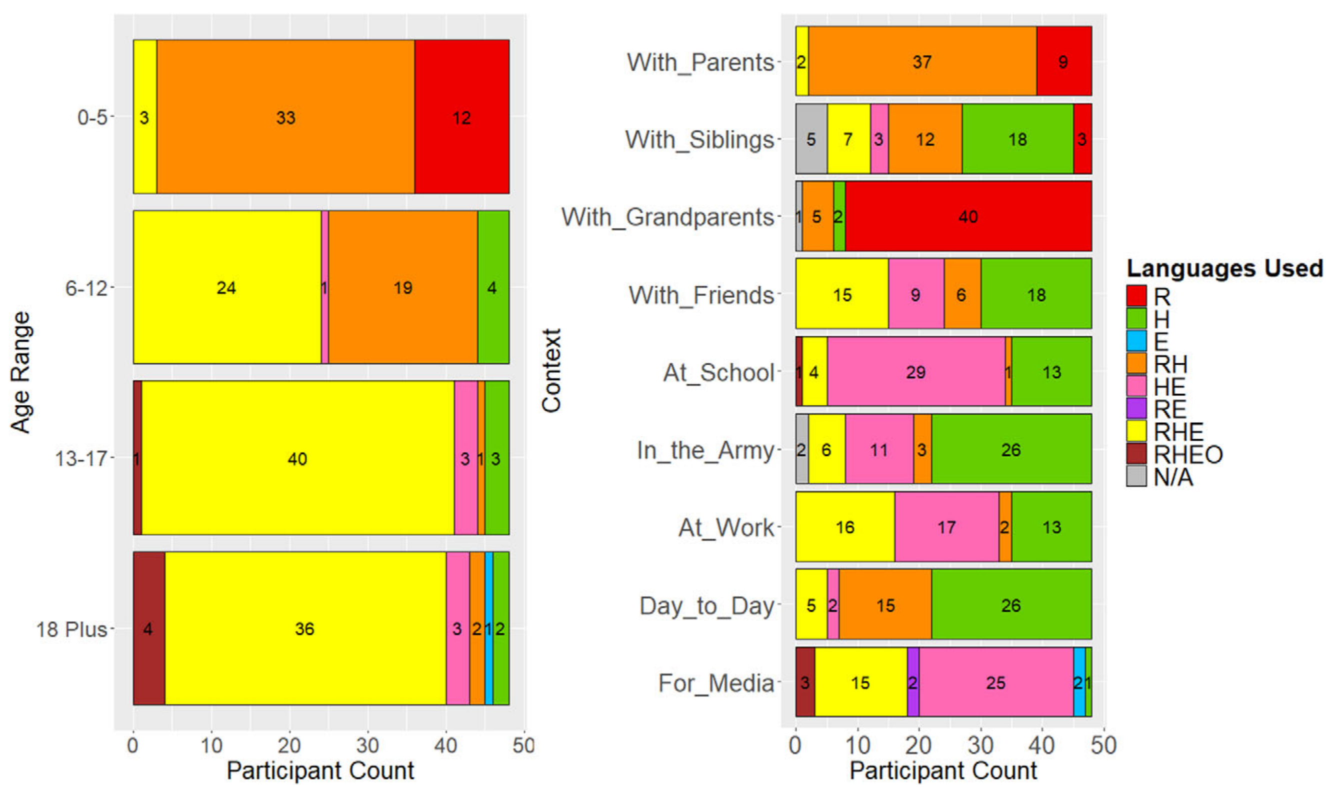
Appendix



Appendix A1. Language Use Across Ages (left) and Contexts (right)

Note: R = Russian, H = Hebrew, E = English, RH = Russian and Hebrew, HE = Hebrew and English, RE = Russian and English, RHE = Russian, Hebrew and English, RHEO = Russian, Hebrew, English and Other(s)

Appendix A2. Pairwise Comparisons for Eye-Fixation Proportions in HL-Russian

250–500 ms since target word onset					
Contrast	Estimate	SE	df	t.ratio	p.value
(1-RUS)—(2-ENG-RUS)	0.03417	0.00722	23756	4.731	<.0001
(1-RUS)—(2-RUS-HEB)	0.02639	0.00721	23756	3.661	0.0014
(1-RUS)—(3-ENG-RUS-HEB)	0.04390	0.00725	23756	6.052	<.0001
(2-ENG-RUS)—(2-RUS-HEB)	−0.00778	0.00721	23756	−1.079	0.7022
(2-ENG-RUS)—(3-ENG-RUS-HEB)	0.00973	0.00725	23756	1.341	0.5366
(2-RUS-HEB)—(3-ENG-RUS-HEB)	0.01751	0.00724	23756	2.419	0.0736
500–750 ms since target word onset					
Contrast	Estimate	SE	df	t.ratio	p.value
(1-RUS)—(2-ENG-RUS)	0.06228	0.00873	23852	7.134	<.0001
(1-RUS)—(2-RUS-HEB)	0.13071	0.00875	23852	14.941	<.0001
(1-RUS)—(3-ENG-RUS-HEB)	0.12126	0.00868	23852	13.975	<.0001
(2-ENG-RUS)—(2-RUS-HEB)	0.06843	0.00880	23852	7.776	<.0001
(2-ENG-RUS)—(3-ENG-RUS-HEB)	0.05899	0.00873	23852	6.757	<.0001
(2-RUS-HEB)—(3-ENG-RUS-HEB)	−0.00944	0.00875	23852	−1.079	0.7021
750–1000 ms since target word onset					
Contrast	Estimate	SE	df	t.ratio	p.value
(1-RUS)—(2-ENG-RUS)	0.0706	0.00855	23756	8.256	<.0001
(1-RUS)—(2-RUS-HEB)	0.1855	0.00854	23756	21.737	<.0001
(1-RUS)—(3-ENG-RUS-HEB)	0.1154	0.00859	23756	13.438	<.0001
(2-ENG-RUS)—(2-RUS-HEB)	0.1149	0.00854	23756	13.465	<.0001
(2-ENG-RUS)—(3-ENG-RUS-HEB)	0.0448	0.00859	23756	5.216	<.0001
(2-RUS-HEB)—(3-ENG-RUS-HEB)	−0.0701	0.00857	23756	−8.183	<.0001

Appendix A3. Pairwise Comparisons of Reaction Times to Target for L3-English

Contrast	Estimate	SE	df	t.ratio	p.value
(1-ENG)—(2-ENG-HEB)	−327.7	121	36	−2.698	0.0495
(1-ENG)—(2-ENG-RUS)	−197.7	121	36	−1.628	0.3763
(1-ENG)—(3-ENG-RUS-HEB)	−154.2	121	36	−1.270	0.5878
(2-ENG-HEB)—(2-ENG-RUS)	130.0	121	36	1.070	0.7095
(2-ENG-HEB)—(3-ENG-RUS-HEB)	173.5	121	36	1.429	0.4903
(2-ENG-RUS)—(3-ENG-RUS-HEB)	43.5	121	36	0.358	0.9840

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Appendix A4. Pairwise Comparisons of Eye-Fixation Proportions in L3-English

250–500 ms					
Contrast	Estimate	SE	df	t.ratio	p.value
(1-ENG)—(2-ENG-HEB)	0.03564	0.00699	23996	5.099	<.0001
(1-ENG)—(2-ENG-RUS)	0.03013	0.00700	23996	4.302	0.0001
(1-ENG)—(3-ENG-RUS-HEB)	−0.00643	0.00698	23996	−0.922	0.7929
(2-ENG-HEB)—(2-ENG-RUS)	−0.00551	0.00700	23996	−0.787	0.8605
(2-ENG-HEB)—(3-ENG-RUS-HEB)	−0.04208	0.00698	23996	−6.032	<.0001
(2-ENG-RUS)—(3-ENG-RUS-HEB)	−0.03657	0.00699	23996	−5.231	<.0001
500–750 ms					
Contrast	Estimate	SE	df	t.ratio	p.value
(1-ENG)—(2-ENG-HEB)	0.1858	0.00876	23900	21.209	<.0001
(1-ENG)—(2-ENG-RUS)	0.2428	0.00876	23900	27.720	<.0001
(1-ENG)—(3-ENG-RUS-HEB)	0.1350	0.00880	23900	15.349	<.0001
(2-ENG-HEB)—(2-ENG-RUS)	0.0570	0.00876	23900	6.510	<.0001
(2-ENG-HEB)—(3-ENG-RUS-HEB)	−0.0508	0.00880	23900	−5.775	<.0001
(2-ENG-RUS)—(3-ENG-RUS-HEB)	−0.1078	0.00880	23900	−12.259	<.0001
750–1000 ms					
Contrast	Estimate	SE	df	t.ratio	p.value
(1-ENG)—(2-ENG-HEB)	0.1287	0.00819	23996	15.713	<.0001
(1-ENG)—(2-ENG-RUS)	0.1472	0.00821	23996	17.934	<.0001
(1-ENG)—(3-ENG-RUS-HEB)	0.0704	0.00818	23996	8.608	<.0001
(2-ENG-HEB)—(2-ENG-RUS)	0.0185	0.00821	23996	2.253	0.1093
(2-ENG-HEB)—(3-ENG-RUS-HEB)	−0.0583	0.00818	23996	−7.136	<.0001
(2-ENG-RUS)—(3-ENG-RUS-HEB)	−0.0768	0.00819	23996	−9.379	<.0001