Journal of Neurolinguistics 24 (2011) 338–351

Contents lists available at ScienceDirect

Journal of Neurolinguistics

journal homepage: www.elsevier.com/locate/jneuroling

Processing words in two languages: An event-related brain potential study of proficient bilinguals☆

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A R T I C L E   I N F O

Article history:
Received 19 July 2010
Received in revised form 27 October 2010
Accepted 28 October 2010

Keywords:
L2 processing
Bilingualism
Translation priming
ERPs

A B S T R A C T

In a previous study of native-English speaking university learners of a second language (Spanish) we observed an asymmetric pattern of ERP translation priming effects in L1 and L2 (Alvarez, Holcomb, & Grainger, 2003, Brain & Language, 87, 290–304) with larger and earlier priming on the N400 component in the L2 to L1, compared with the L1 to L2 direction. In the current study 20 native-Russian speakers who were also highly proficient in English participated in a mixed-language lexical decision task in which critical words were presented in Russian (L1) and English (L2) and repetitions of these words (within and between languages) were presented on subsequent trials. ERPs were recorded to all items allowing for comparisons of repetition effects within and between (translation) languages. The results revealed a symmetrical pattern of within-language repetition and between-language translation ERP priming effects, which in conjunction with Alvarez et al. (2003), supports the hypothesis that L2 proficiency level rather than age or order of language acquisition is responsible for the observed patterns of translation priming. The ramifications of these results for models of bilingual word processing are discussed.

☆ This research was supported by grant HD25889 and HD043251.
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0911-6044/$ – see front matter
doi:10.1016/j.jneuroling.2010.10.005

In one of the first studies to examine single word reading in two languages using ERP recordings, Alvarez et al. (2003) presented their participants with mixed lists of L1 and L2 words that they had to silently read for meaning. Critical words could be preceded by the same word versus a different word from the same language (measuring within-language repetition priming), or by a non-cognate translation versus a different word from the other language (measuring translation priming). One key result was that translation priming effects on the N400 ERP component tended to be larger and start earlier when primes were in L2 and targets in L1 than when primes were in L1 and targets in L2. This particular result is in line with the predictions of the Revised Hierarchical Model (RHM - Kroll & Stewart, 1994). According to this model, L2 words should automatically activate their translation equivalent in L1 via direct connections between lexical form representations, and should do so to a greater extent and more rapidly than L1 words activate their L2 translate. Translation priming from L2 to L1 would therefore be mostly driven by activation of the L1 target word's whole-word form representation by the L2 prime word, whereas priming from L1 to L2 would be mostly driven by activation of semantic representations by the L1 prime word.

However, this pattern stands in contradiction with other findings showing greater translation priming from L1 to L2 than vice versa. This is typically the case in studies using the masked priming paradigm (see Dunabeitia, Perea, & Carreiras, 2010, for review). Directly relevant to the present study is the work of Midgley, Holcomb and Grainger. (2009) combining masked priming and ERP recordings. In the Midgley et al. study, there was clear evidence for effects of L1 primes during the processing of L2 targets starting at around 250 ms post-target onset, whereas priming effects in the opposite direction appeared later and were overall smaller. More recently, however, Schoonbaert, Holcomb, Grainger, and Hartsuiker (2010) have shown that robust and early translation priming effects from L2 to L1 can be obtained in conditions similar to those tested by Midgley, Holcomb, and Grainger (2009) but with longer prime durations (100 ms). Both of these studies tested relatively unbalanced bilinguals with a clearly dominant L1. The results of Schoonbaert et al. suggest that the reduced effects of non-cognate translation primes in L2 seen with shorter prime durations might be due to limits in the amount of information that can be extracted from briefly presented L2 words.[1]

Therefore, the pattern of translation priming effects reported by Alvarez et al. (2003) might well reflect activation of L1 lexical form representations upon presentation of an L2 word, given sufficient processing time. However, while direct connectivity from L2 to L1 form representations might provide an efficient means of getting from an L2 word to meaning in beginning bilinguals, it is unlikely to remain so as proficiency in L2 increases. In one prominent account of visual word recognition in relatively fluent bilinguals, the Bilingual Interactive-Activation (BIA) model, inhibitory connections between word form representations from both languages are incompatible with the notion of excitatory connections between translation equivalents. In recent work, Grainger, Midgley, and Holcomb (in press) have proposed a developmental version of the BIA model (BIA-d) that describes the evolution from an RHM-style model of early L2 acquisition to the equivalent of the BIA model as an account of proficient bilingualism. According to Grainger et al., the excitatory connections established between lexical form representations in the early phases of L2 vocabulary acquisition, gradually diminish in strength. In this way, direct connections between L2 word forms and semantic representations gradually take over as the dominant way to access meaning when reading a word in L2. This account of proficient bilingualism therefore naturally predicts more symmetric patterns of performance as L2 proficiency approaches L1 proficiency, a pattern that has already been reported in a recent behavioral study (Dunabeitia et al., 2010). With respect to ERP data, we would also expect to see a qualitatively different pattern of translation priming effects with L2 primes and L1 targets compared with those seen in the studies of Alvarez et al. (2003) and Schoonbaert et al. (2010).

1. The present study

The major aim of the current study was to use ERP measures to examine the organization and processing of words in the first and second language of Russian–English bilinguals who were exposed

[1] It should be noted that the strong effects of L2–L2 repetition priming seen with short prime durations can be explained as form-level effects that are independent of fluency.

to their L2 (English) between ages 7 and 16 when they and their families left Russia and came to live in the United States. While their exposure to L2 did not occur until the late childhood – mid adolescence stage, these bilinguals had a high level of L2 proficiency at the time of testing and rated their English usage to be greater than 78% of all language use.

Alvarez et al.'s (2003) immediate repetition priming paradigm (word × presented on trial n is repeated, or its translation presented, on trial $n + 1$) was used to examine both within- and between-language repetition effects. In order to ensure lexical processing of the words a lexical decision task was employed. In this task participants were presented with a mixed stream of words in English and Russian. A proportion of the items was within-language repetitions and another portion was between-language repetitions (i.e., translations) of the previous word. The participants' task was to read each item and to press a button when they detected an occasional pseudoword that could resemble a real word in either language (e.g., "DLAG" or "БОЗОВА"). The pseudowords were included to ensure that participants attended to and analyzed all items in both languages. Critical items were Russian (L1) and English (L2) concrete and abstract nouns that did not require an overt response. As noted above, given the high proficiency level in L2 in our participants, we expect to see a symmetric pattern of non-cognate translation priming, with both L1–L2 and L2–L1 producing a pattern similar to the L1–L2 pattern seen in the Alvarez et al. (2003) study. On the other hand, if it is age-of-acquisition rather than relative proficiency in L1 and L2 that is driving the asymmetric pattern of priming effects seen in the Alvarez study, then the same asymmetric pattern should be found in the present study.

With respect to understanding the mechanisms involved in word recognition in general, the comparison of within-language repetition and between-language repetition (translation) effects in the present study should inform us about the relative roles of form and meaning in generating these effects. The translation equivalents tested in the present study were all non-cognates and because of the substantial differences in Russian and English had minimal orthographic and phonological overlap. Thus the pattern of translation priming effects should help determine how much of the within-language repetition effect is semantically driven versus how much is form driven.

Finally, the mixed-language presentation conditions used in the present study will allow us to examine how language switching affects ERPs in highly proficient bilinguals. Behavioral measures have systematically shown a cost in processing following a language switch compared to when the directly preceding word is from the same language (e.g., Grainger & Beauvillain, 1987; Thomas & Allport, 1999). There are currently two explanations for how these switch costs arise during word recognition in bilinguals. According to one position, switch costs arise within the bilingual language processing system, as the result of inhibitory control over total lexical activation within each of the bilingual's languages (Chauncey, Holcomb, & Grainger, 2008). With regard to ERP effects, this model predicts that N400s should be larger to words following a switch in language compared to words occurring after another word in the same language.

An alternative explanation of switch costs is that they arise outside of the language processing system as a result of competition between stimulus-response task schemas set up for the particular task at hand (Dijkstra & Van Heuven, 2002; Green, 1998; Thomas & Allport, 1999). This could actually work when different responses are indeed associated with the two languages (i.e., respond "X" when the word is in language A, and respond "Y when the word is in language B), but cannot account for switch effects in generalized lexical decision (respond "X" when the word is in language A or language B), the task used in the present study (see also Grainger & Beauvillain, 1987). Dijkstra and Van Heuven (2002) acknowledged this point, and suggested that decision-level adaptations could be the basis of language switch effects in this task. Therefore, according to this account of switch effects, we would not expect language switches to influence ERP components known to be related to lexical processing. Contrary to this prediction, however, Alvarez et al. (2003) reported robust language switch effects on the N400 ERP component in a paradigm similar to the one used in the current study. They found switch effects on both L1–L2 and L2–L1 switch directions. Switching from L1 to L2 resulted in larger N400s for L2 items, while switching from L2 to L1 resulted in smaller and later switch effects arising after the N400. Alvarez et al. argued that the asymmetrical nature of the language-switching effects they observed was due to the lower level of proficiency in

L2 of their participants. Within the framework of the BIA model, the speed with which a given word can activate its corresponding language node and subsequently inhibit activation in other language representations will depend on the fluency of processing that word. This explains why language-switching effects were stronger overall and emerged earlier from L1 to L2 than vice versa. According to this account, we should observe more symmetric patterns of language switching in the more proficient bilinguals to be tested in the present study.

2. Methods

2.1. Participants

Twenty participants (14 women) were recruited and compensated for their time. They were between 19 and 32 years of age and native (L1) speakers of Russian. Participants had been exposed to English (L2) between ages 7 and 16. The mean age of participants was 25 years (SD = 5.2). All reported to be right handed and had normal or corrected-to-normal visual acuity with no history of neurological insult or language disability.

2.2. Language assessment

Participants' Russian and English language use and skills were surveyed by questionnaire. Daily average estimates of language use were 21.5% for Russian and 78.5% for English (SD = 9.19%), with all participants reporting greater daily use of English. All participants reported using Russian only at home. English was also reported to be spoken at home by 17 of the 20 participants. All participants reported using only English in their work settings.

On a seven point Likert scale (1 = unable; 7 = expert) participants reported their abilities to read, speak and comprehend Russian and English as well as how frequently they read in both languages (1 = rarely; 7 = very frequently). The overall average of self-reported language skills in Russian (L1) was 6.1 (SD = 0.92) and in English (L2) was 7.0 (SD = 0.00). Our participants reported their average frequency of reading in Russian (L1) as 3.9 (SD = 2.68) and in English (L2) as 6.0 (SD = 1.34).

2.3. Stimulus material

The words that comprised the stimulus lists were gathered with help from our colleagues in the Russian Department at Tufts University. All stimuli were based on common English and Russian words between 3 and 10 letters in length. The 200 target words were all open class non-nouns, 100 in English and 100 in Russian. We also formed 80 pseudowords; 40 from English words (e.g., DLAG) and 40 from Russian words (e.g., БОЗОВА). Pseudowords were created by replacing one, two, or three letters in real English and Russian words that were not used as target words in the experiment.

Stimuli were arranged in lists such that eight different critical trials types were possible, four with English target words and four with Russian target words. Pseudowords were randomly mixed with the word trials. Trials with English target words could be either preceded by a trial with the same word (e.g., TRUCK–TRUCK, English within-language repetition trials), a different English word (e.g., MOUSE – TRUCK, English within-language unrelated trials), a Russian translation of the English target word (e.g., ГРУЗОВИК (*truck*) – TRUCK, English between-language repetition trials, from here on referred to as translation trials) or a Russian word that was unrelated to the English target word (e.g., МЫШЬ(*mouse*) – TRUCK, English between-language unrelated trials). Similarly, Russian target word trials could be either preceded by a trial with the same Russian word (e.g., ГРУЗОВИК(*truck*) – ГРУЗОВИК(*truck*), Russian within-language repetition trials), a different Russian word (e.g., МЫШЬ(*mouse*) – ГРУЗОВИК(*truck*), Russian within-language unrelated trials), an English translation of the Russian target word (e.g., TRUCK – ГРУЗОВИК(*truck*), Russian translation trials) or an unrelated English word (MOUSE – ГРУЗОВИК(*truck*), Russian between-language unrelated trials) (Fig. 1).

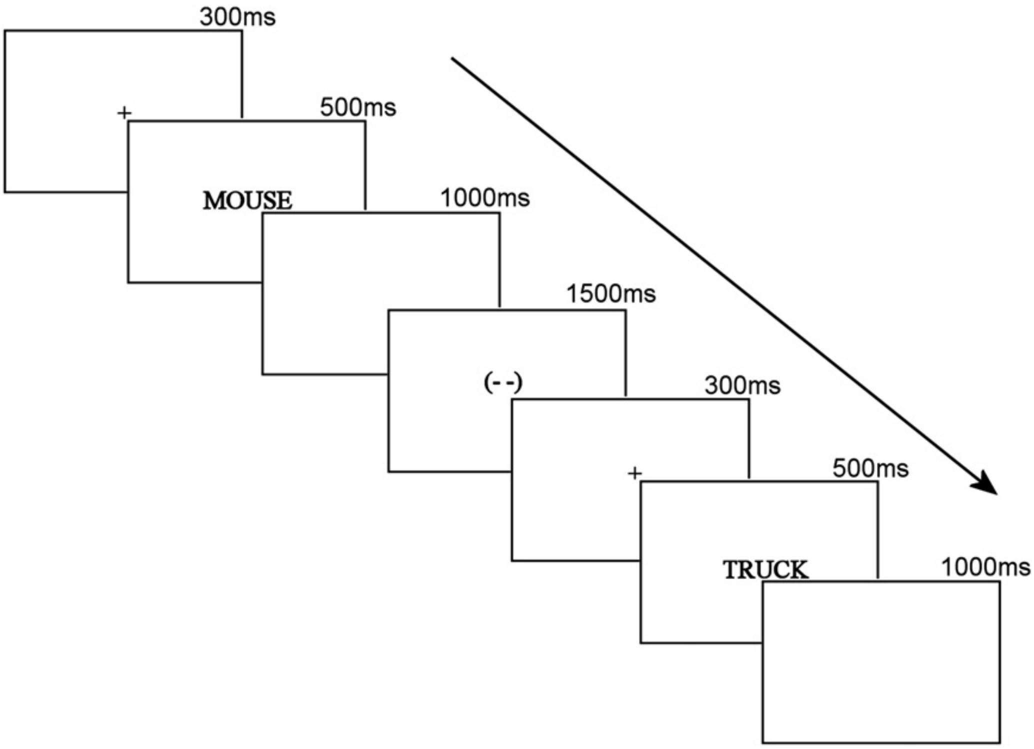

Fig. 1. Two example trials (English–English Unrelated).

2.4. Event-related potentials (ERPs) apparatus & laboratory

The experiment was run in the NeuroCognition Laboratory at Tufts University. All participants sat in a comfortable chair in a sound attenuating room while 32 channels of electrophysiological data were amplified using an SA Instruments Bio-amplifier system with 6 db cutoffs set at 0.01 and 40 Hz. The 32 channels of EEG were continuously sampled at 200 Hz throughout the experiment.

All visual linguistic stimuli were presented as white letters on a black background on a 19 inch color monitor. Participant responses were measured with a two-button response box that rested in the participant's lap.

2.5. Procedure

Upon arrival at the laboratory each participant was given a brief tour of the facility and were explained all of the procedures to be performed. After the participant consented to participate in the experiment, a language history questionnaire and a handedness inventory were completed. Following these procedures the participant was prepared for the ERP experiment by having electrodes attached (see below), and receiving instructions for the experimental task they were to perform. The participants were told to read all letter strings presented on the computer monitor and, whenever they saw a pseudoword (a letter string that was not a real word in Russian or English) they were to press a button on the response box resting in their lap (20% of trials).

Prior to the experimental ERP session participants were given practice in the task. Each trial in the experimental run started with a fixation cross, +, displayed for 300 ms and followed by a 150 blank screen. Immediately after the blank screen a target word or pseudoword was presented for 500 ms and followed by a 1000 ms blank screen. The blank screen was in turn followed by a 1500 ms end-of-trial stimulus, (–), which indicated that it was now permissible to move and blink one's eyes. The fixation cross of the next trial followed immediately. This trials structure emphasized the word-by-word nature of the stimulus lists, but also insured that the SOA between subsequent targets in the priming manipulation was always 3350 ms. This design allowed us to examine priming effects within both languages (by contrasting repeated target words with a matched set of words in the same language that were unrelated to the word on the previous trial that was in the same language), as well as translation priming between both languages (by contrasting target words that were translation equivalents to the target word on the previous trial with matched unrelated words from the prior trial). Another feature of this paradigm is that it allows for a direct comparison of language-switching effects both from L1 to L2 (by contrasting English target words preceded by unrelated English words to English target words preceded by unrelated Russian words) and L2 to L1 (by contrasting Russian target words preceded by unrelated Russian words with Russian target words preceded by unrelated English words).

2.6. Electrode placement

Thirty-two active tin electrodes were attached to the scalp and head. These were held in place by an elastic cap (Electro-Cap International) and in the case of face electrodes by adhesive collars (see Fig. 2 for the montage map). Two electrodes near the eyes were used for the purpose of detecting eye-related artifacts and eye movements; one below the left eye detected blinks and another to the right of the right eye detected horizontal eye movements. All of the above sites were referenced to an electrode located behind the left ear on the mastoid bone. The right mastoid was recorded and monitored to determine if there was asymmetry between the mastoids – there was not. All electrodes were kept below 5 K Ohms.

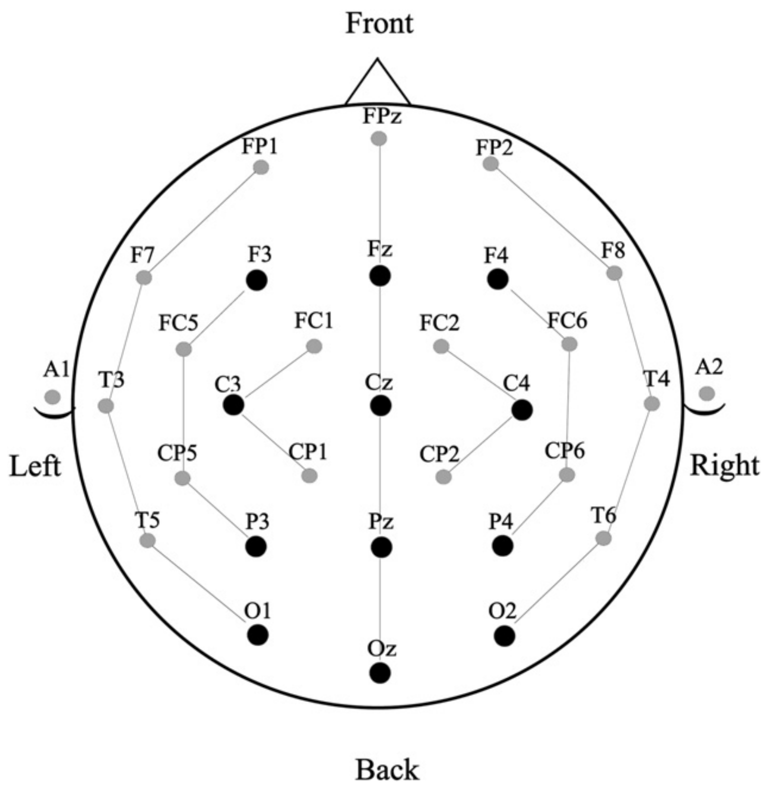

Fig. 2. Electrode montage with the 12 electrode sites used in analyses in black.

2.7. Data summary & analysis

Off-line average ERPs were formed for each condition and/or different stimulus type in an experiment. Averaging started 100 ms pre-stimulus onset (to provide a baseline) and continued for 1284 ms (256 points × 5 ms per point). Single trials of EEG were rejected if electrical activity exceeded a predetermined voltage level at either of the eye locations or if one of the scalp site amplifiers were to block.

ERPs were quantified by taking the mean amplitude in three temporal windows (baseline corrected for the −100 to 0 ms epoch) and included an early epoch (150–300 ms), a window surrounding the classic N400 (300–500 ms) and a late, post-N400 epoch (500–700 ms). These three epochs were analyzed separately in two sets of repeated measures analyses of variance (Geisser & Greenhouse, 1959). In one set of analyses examining priming effects there were factors of target LANGUAGE (Russian vs. English), TYPE-OF-PRIMING (repetition vs. translation), RELATEDNESS (related vs. unrelated), LATERALITY (Left vs. Midline vs. Right) and ANTERIOR–POSTERIOR (Frontal vs. Central vs. Parietal vs. Occipital). In a second set of analyses we examined language switch effects by analyzing only the trials where words on adjacent trials were unrelated (i.e., these without repetition or translation). The factors included were target LANGUAGE (Russian vs. English), SWITCHING (language switch vs. no switch) LATERALITY (Left vs. Midline vs. Right) and ANTERIOR–POSTERIOR (Frontal vs. Central vs. Parietal vs. Occipital). Significant interactions involving the TARGET LANGUAGE with either the PRIMING or the SWITCHING factors were followed up with planned analyses for each target language separately.

3. Results

3.1. Behavioral

Participants' mean reaction times to the pseudoword "go" trials was very similar for Russian (772 ms) and English (774 ms – $p > .05$).

3.2. ERP priming effects

As can be seen in Figs. 3 and 4 the grand average ERPs for both L1 and L2 target words reveal clear effects of repetition and translation priming for both languages starting as early as 150 ms and extending through to at least 700 ms.

3.2.1. 150–300 ms

In this first epoch there were no significant main effects of LANGUAGE, TYPE-OF-PRIMING or RELATEDNESS, although there were a number of significant interactions involving all three of these factors. For LANGUAGE there was an interaction with ANTERIOR–POSTERIOR distribution ($F(3,57) = 5.26$, $p = .019$). There was also a reliable TYPE-OF-PRIMING × RELATEDNESS × ANTERIOR–POSTERIOR interaction ($F(3,57) = 12.35$, $p < .0004$). Follow-up analyses comparing the two types of priming separately revealed that in the case of repetition priming repeated target words tended to be less positive than unrelated target words at anterior sites, while repeated items tended to be more positive than unrelated items at posterior sites (RELATEDNESS × ANTERIOR–POSTERIOR distribution interaction: $F(3,57) = 8.05$, $p = .0045$). The comparable comparison for translation priming did not reveal a significant difference (see Figs. 3–5).

3.2.2. 300–500 ms

In the middle window there were no main or interaction effects involving the LANGUAGE factor (all ps > 0.13). There were, however, several significant effects involving the TYPE-OF-PRIME and RELATEDNESS factors. These included the main effects of TYPE-OF-PRIME ($F(1,19) = 6.79$, $p = .0173$) and RELATEDNESS ($F(1,19) = 45.45$, $p < .0001$), as well as an interaction between these two variables and ANTERIOR–POSTERIOR distribution ($F(3,57) = 4.05$, $p = .0363$ – see Figs. 3–5 at 400 ms). Follow-up analyses comparing the two priming types separately revealed, for repetition priming, a robust main effect for RELATEDNESS ($F(1,19) = 32.1$, $p < .0001$) and RELATEDNESS × ANTERIOR–POSTERIOR distribution interaction ($F(3,57) = 11.51$, $p = .0006$). For translation priming there were main effects of RELATEDNESS ($F(1,19) = 5.67$, $p = .0279$) and a RELATEDNESS × LATERALITY interaction ($F(2,38) = 3.77$, $p = .033$ – see Figs. 3–5).

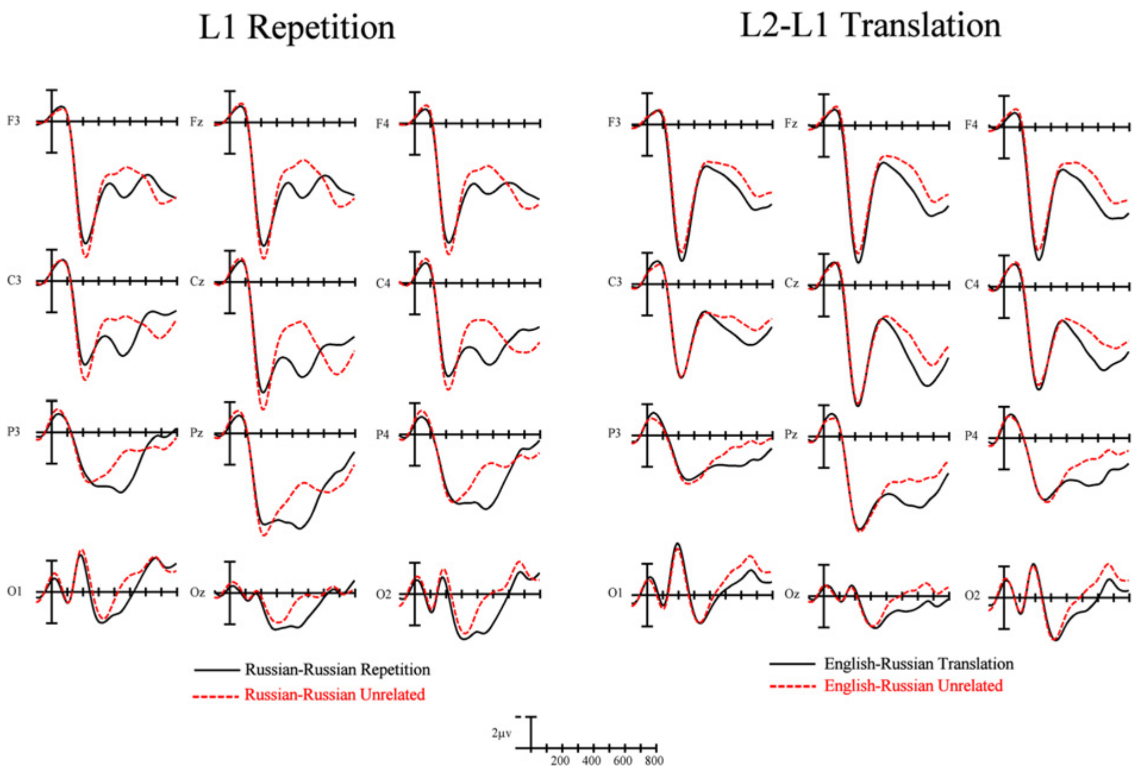

Fig. 3. ERPs to L1 target words in the four relatedness conditions at the 12 electrode sites used in the data analyses. ERPs on the left side are from Russian target words that were repetitions of the word from the previous trial compared to Russian target words that were preceded by an unrelated word in Russian. On the right side are ERPs from Russian target words preceded by an English word that was a direct translation compared to Russian target words preceded by an unrelated English word.

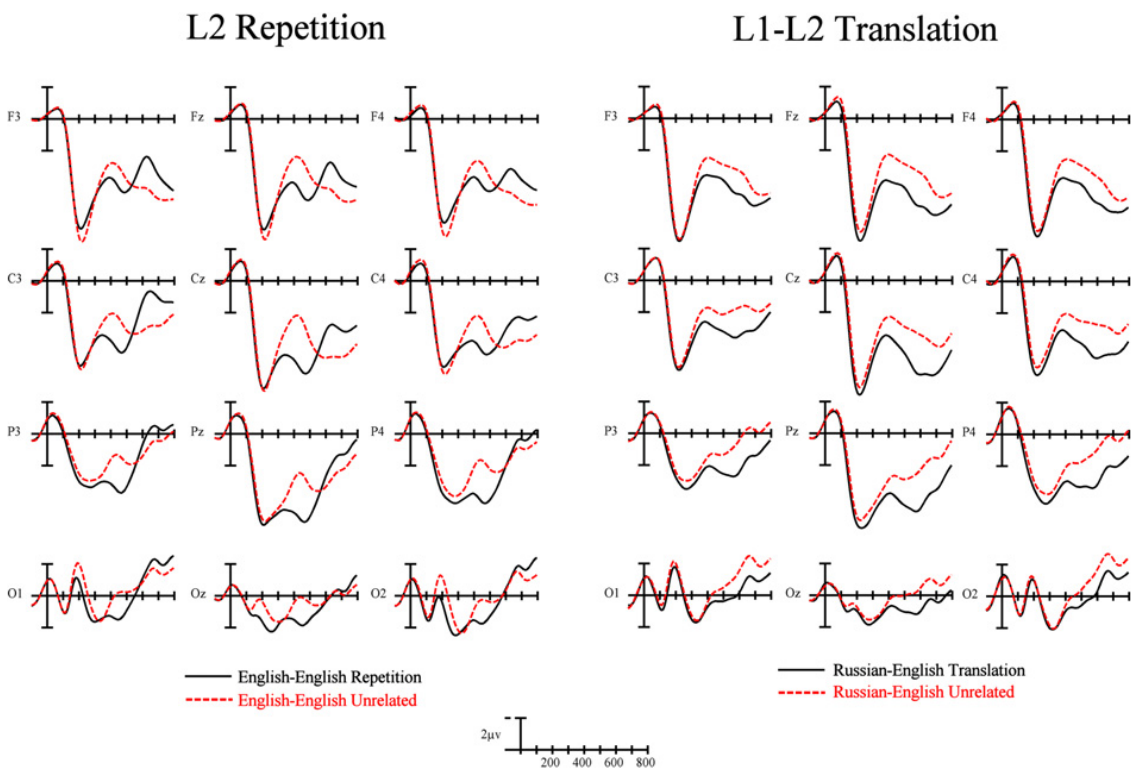

Fig. 4. ERPs to L2 target words in the same relatedness conditions as Fig. 3.

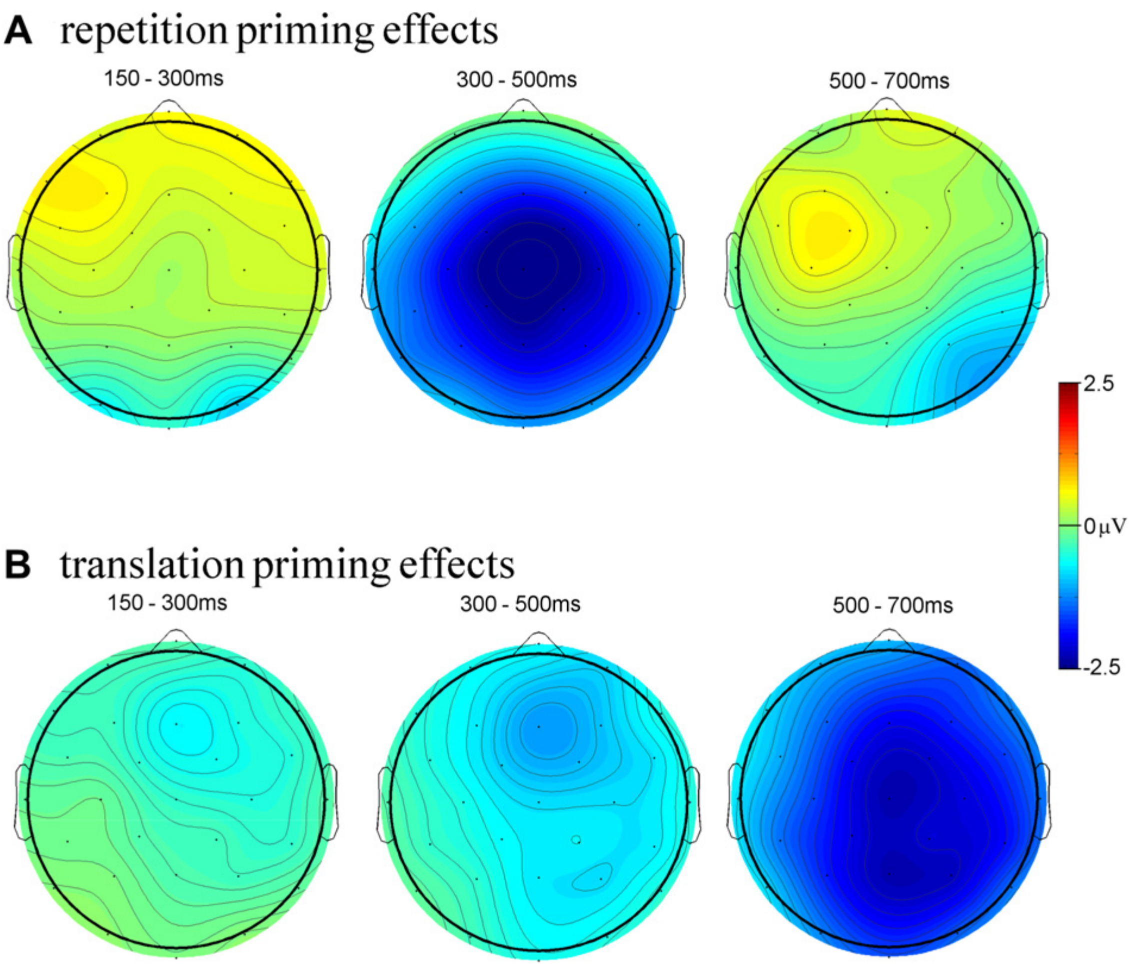

Fig. 5. Voltage maps reflecting the subtraction of the related conditions from the unrelated conditions showing (A) repetition effects and (B) translation effects.

3.2.3. 500–700 ms

In the final analysis epoch there continued to be robust effects of RELATEDNESS (main effect $F(1,19) = 12.45$, $p = .0022$) that differed across the scalp site (RELATEDNESS × LATERALITY interaction: $F(2,38) = 14.13$, $p = .0003$) and TYPE-OF-PRIMING (TYPE-OF-PRIMING × RELATEDNESS: $F(1,19) = 12.72$, $p = .0021$; TYPE-OF-PRIMING × RELATEDNESS × ANTERIOR-POSTERIOR distribution: $F(3,57) = 5.49$, $p = .0125$). We also performed follow-up analyses examining the two types of priming, separately. In the case of repetition priming, towards the front of the head repeated targets tended to be more negative-going than unrelated targets, but at more posterior sites the differences between conditions were smaller (RELATEDNESS × ANTERIOR–POSTERIOR distribution: $F(3,57) = 4.31$, $p = .0243$; see Fig. 5A). For translation priming, the contrasts involving translation and between-language unrelated targets showed robust overall priming effects (main effect of RELATEDNESS ($F(1,19) = 25.71$, $p = .0001$)) as well as a differing priming pattern as a function of scalp distribution (RELATEDNESS × ANTERIOR–POSTERIOR distribution $F(3,57) = 3,79$, $p = .0377$). Translation priming effects, with consistently more negative-going ERPs for unrelated targets than for translation targets, tended to be larger at central and parietal sites than at frontal and occipital sites (Fig. 5B). Importantly, as in the previous epoch, there were no main effects or interactions involving the LANGUAGE variable.

3.3. ERP language-switching effects

As can be seen in Fig. 6, unrelated targets produced language-switching effects both for L1-L2 and for L2-L1 switches.

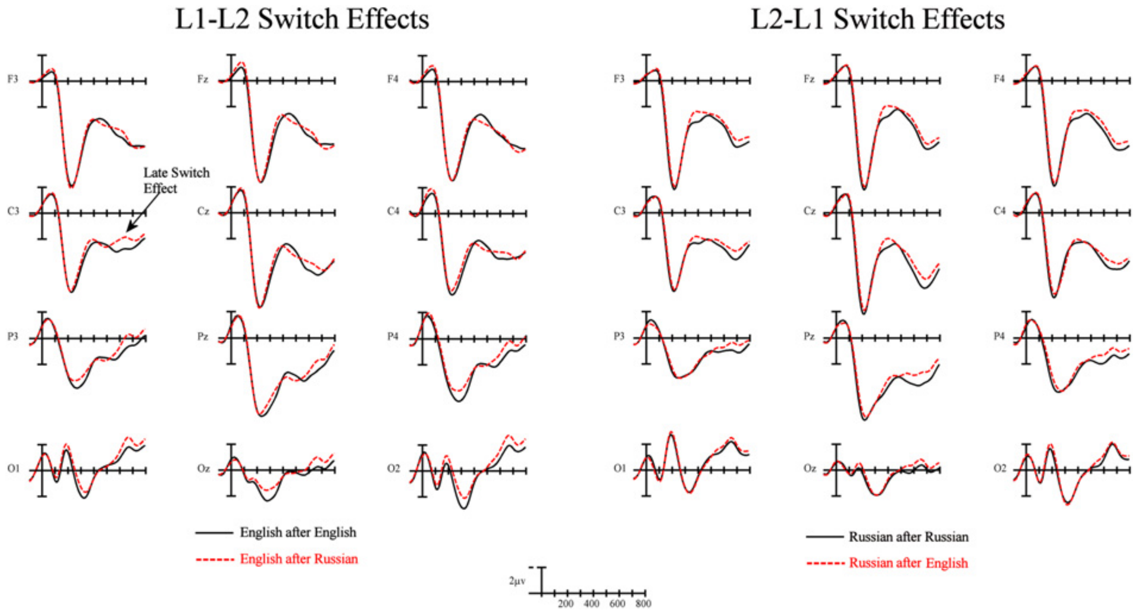

Fig. 6. L1–L2 and L2–L1 switch effect ERPs.

3.3.1. 150–300 ms

In the first epoch there were no significant effects of language switching.

3.3.2. 300–500 ms

In the middle epoch there were small effects of SWITCHING as a function (LATERALITY and ANTERIOR–POSTERIOR distribution: $F(6{,}114) = 2.19$, $p = .0491$). Switch trials produced somewhat more negative-going ERPs than non-switch trials at midline and left hemisphere central and anterior sites.

3.3.3. 500–850 ms

Small SWITCHING effects continued into the final analysis epoch, again varying as a function of scalp distribution (SWITCHING × LATERALITY × ANTERIOR–POSTERIOR distribution $F(6{,}114) = 2.29$, $p = .0477$).

4. Discussion

In a word-by-word lexical decision task with Russian–English bilinguals we found evidence for robust ERP priming effects starting as early as 150–300 ms for target words repeated within both languages in contrast to comparable target words that were not repeated (i.e., that were unrelated to the previous word). This early priming effect took the form of a larger posterior negativity and anterior positivity for unrelated compared to repeated target words. No such early priming effect was found for these same target words when the word on the prior trial was a translation equivalent from the other language. This suggests that the early priming effect results from an overlap in processing at the form level. In the N400 measurement window (300–500 ms) we again found evidence for repetition priming effects for both Russian (L1) and English (L2) targets, however, in this epoch we also now found translation priming effects, although they were somewhat smaller than the comparable repetition effects (see Figs. 5 and 6). In other words, the N400 was attenuated by words repeated within the L1 and the L2 and, to a lesser extent, by the prior presentation of the translation equivalent in the other language. Importantly, the pattern of repetition and translation effects did not differ significantly for the two languages. In the post-N400 window (500–700 ms) there were again robust repetition and translation priming effects. However, in this window repetition effects actually tended to reverse in polarity (repeated more negative that unrelated) at anterior sites in both languages. Translation priming effects on the other hand continued to be dominated by larger negativities to unrelated target words compared to targets that were translations of the prior prime word across the scalp. This pattern of repetition and translation priming effects is summarized in Fig. 7 showing the difference waves averaged across the two languages.

4.1. Translation priming in proficient bilinguals

The present study provides further evidence for non-cognate translation priming effects in proficient bilinguals that do not depend on the direction of the translation. Dunabeitia et al. (2010) had already shown symmetric translation priming in proficient bilinguals in a masked priming paradigm with the lexical decision task. Basque–Spanish bilinguals showed strong behavioral effects when primes were in L2 and targets in L1 and vice versa. The present study extends this finding to a trial-by-trial priming paradigm with ERP recordings, and shows that the symmetric pattern extends across the entire time-course of target word processing. In prior research testing less proficient bilinguals in the same paradigm (Alvarez et al., 2003), priming from L2 to L1 was found to arise earlier and was stronger in the time-window of the N400 component than priming from L1 to L2. This was taken as evidence for the automatic translation of the L2 word into its translation equivalent in L1, causing activation of the L1 word form

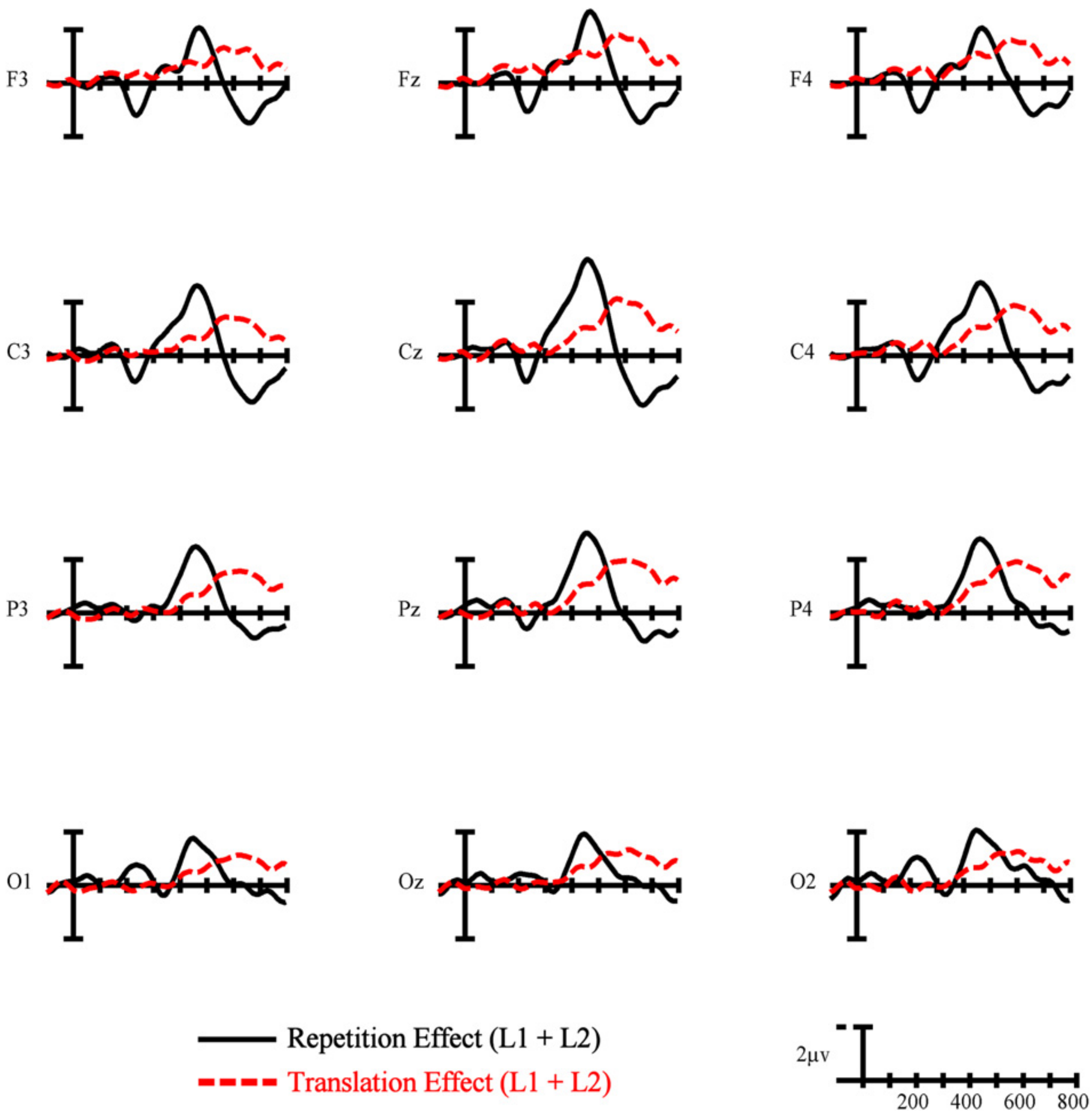

Fig. 7. ERP difference waves for repetition priming (repetition – unrelated) and translation priming (translation – unrelated) averaged across L1 and L2.

representation prior to presentation of the L1 target word, and generating a pattern of early translation priming effects that resembled L1–L1 repetition priming. This pattern was clearly not observed in the present study. If anything, the N400-like translation priming effects emerged slightly later from L2 to L1 than L1 to L2. Thus, when compared with the Alvarez et al. study, L2–L1 translation priming effects emerged later in the present study (see Fig. 8). This is evidence that the early translation priming effect from L2 to L1 seen in the Alvarez et al. (2003) study can be attributed to the relatively low proficiency level in L2 of the participants that were tested in that study. Furthermore, given that our participants were also late learners of their L2, age-of-acquisition can be excluded as a factor driving the asymmetric pattern seen in the Alvarez et al. study.

The results of the present study suggest that as proficiency in L2 increases, any automatic translation of L2 word forms into their L1 translation equivalents decreases. The standard account of such automatic translation processes is in terms of direct connectivity between the word form representations of translations equivalents, as described in the RHM (Kroll & Stewart, 1994). Therefore, within this theoretical framework, and as argued by Grainger et al. (in press), the connections between the word form representations of translation equivalents would appear to decrease in strength as L2 proficiency increases. It is the gradual decrease in strength of these excitatory connections that enables the integration of L2 word form representations into a common lexical network for both languages, as postulated in the BIA model (Dijkstra & Van Heuven, 2002; Grainger & Dijkstra, 1992; van Heuven, Dijkstra, & Grainger, 1998).

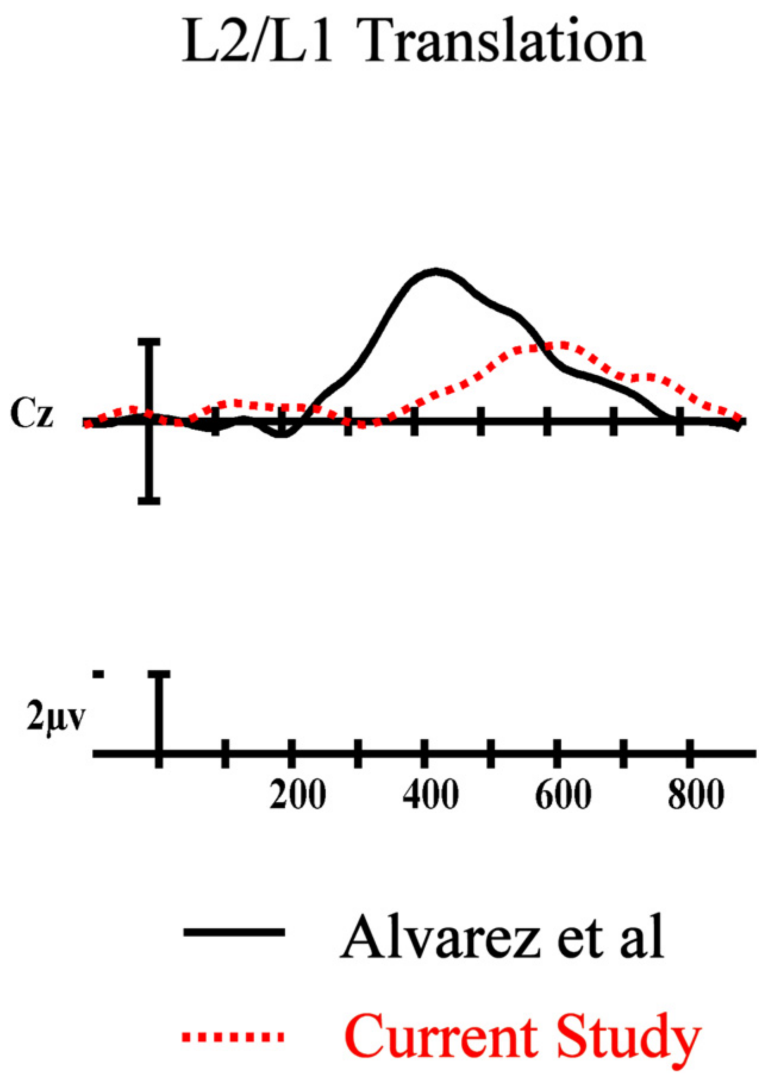

Fig. 8. Comparison of ERP difference waves (repetition – unrelated) for L2–L1 translation priming in the Alvarez et al. (2003) study and the present study.

4.2. Language-switching effects in proficient bilinguals

In the present study we were also able to examine the effects of changing languages from trial to trial by contrasting target words following a switch from one language to the other, to target words following an unrelated word in the same language. Alvarez et al. (2003) reported asymmetric switch effects, with an increase in N400 amplitude that was greater for switches from L1 to L2 than switches from L2 to L1. Here we found switch effects in the same time-window as in the Alvarez et al. study, but they were smaller in amplitude, and did not differ significantly as a function of the direction of the switch. ERP amplitudes were again found to be more negative-going following a change in language compared with trials where there was no language switch. This provides an important confirmation of the switch effects reported by Alvarez et al. (2003), and shows that such switch effects also arise in highly proficient bilinguals, with similar patterns emerging for L2–L1 switches as L1–L2 switches.

This result provides further evidence against the task-schema account of language-switching effects (Green, 1998), at least for switch effects observed during language comprehension (Thomas & Allport, 1999). Here the task was generalized lexical decision (Grainger & Beauvillain, 1987), and participants only responded to pseudoword stimuli (letter strings that were neither a word in their L1 nor their L2). It is therefore difficult to imagine how a language-specific task schema could have been used by the participants in our experiment. More evidence against a task-schema account of language-switching effects has been provided by Chauncey, Grainger, and Holcomb (2008), and Chauncey, Grainger, and Holcomb (in press), in their investigation of language-switching effects in the masked priming paradigm. In these studies, participants responded to clearly visible targets words that were blocked by language, and the language of a briefly presented, pattern-masked prime word was manipulated. The language-switching effects seen in the Chauncey et al. studies therefore likely reflect automatic fast-acting mechanisms whereby activation of a word representation in one language has an immediate consequence on the activation level of word representations in the other language.

Grainger et al. (in press) have recently described an account of language-switching effects within the framework of the BIA model that draws a key distinction between exogenous (stimulus-driven) and endogenous (goal-driven) effects. Grainger et al. (in press) point out that although the task-schema account of language-switching effects makes sense for endogenous effects of language switching (i.e., those observed in language production), it does not provide an appropriate account of exogenous switch effects seen in language comprehension. On the other hand, the BIA model provides an integrated account of endogenous and exogenous language switching effects (Grainger et al., in press). More precisely, this account of language switching effects predicts that the size of switch effects in language comprehension (exogenous switch effects) should be determined by the relative proficiency in each language. The shift from asymmetrical effects in the Alvarez et al. (2003) study to the symmetrical pattern seen in the present study is evidence in favor of this approach.

5. Conclusions

Russian (L1) native speakers who were highly fluent in English (L2) showed a symmetrical pattern of within-language repetition and between-language translation priming effects in the ERPs generated by mixed lists of words. These results imply that prior findings of asymmetric priming effects as a function of target language (Alvarez et al., 2003) were due to the relatively low proficiency level in L2 of the participants in that study. The same conclusions can be drawn with respect to the symmetric pattern of language-switching effects found in the present study, which again contrasted with the asymmetrical pattern reported by Alvarez et al. Overall, the results are in favor of the BIA model's account of word comprehension in proficient bilinguals, and Grainger et al.'s (in press) account of how increasing proficiency in L2 modifies the connectivity between form and meaning representations in L1 and L2.

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