Direction matters: Event-related brain potentials reflect extra processing costs in switching from the dominant to the less dominant language

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Abstract

Language switching is common in bilingual processing, and it has been repeatedly shown to induce processing costs. However, only a handful of studies have examined such costs at the sentence level, with a limited few among them having incorporated factors extensively studied in monolingual sentence processing, such as semantic expectedness. Using the event related potentials (ERP) technique, this study aimed at exploring whether switching costs were modulated by (1) switching directions, when switching happens between languages of different dominance, and by (2) semantic expectedness, as indicated by cloze probability. Twenty-two Mandarin-Taiwanese early bilinguals, with Mandarin being their dominant and Taiwanese their non-dominant language, participated in the study. They were instructed to listen to the stimuli attentively and to perform a word memory recognition task in 20% of the trials. The results showed that switching induced an LPC effect, suggesting that switched elements were harder to be integrated. More importantly, switching from the dominant to the non-dominant language demanded extra effort than switching in the other direction, as reflected by the PMN (detection of an unexpected sound), the N400 (indication of lexical access difficulty) and the frontal negativity (inhibition of the pre-activated representations), revealing that the dominant language provides better prediction of the upcoming word. Also, cloze probability interacted with switching, but only at an early stage, suggesting that semantic expectedness did not enduringly modulate the switching cost. Our results generally supported predictions from the Bilingual Interactive Activation Plus model (Dijkstra & van Heuven, 2002), showing that language use and sentence context can affect lexical processing in bilinguals.

Keywords: Bilingual Interactive Activation Plus model; Bilingual sentence processing; Language switching; Language dominance; Cloze probability; Cognitive control

1. Introduction

Most people can respond to another interlocutor immediately in conversations, or sometimes can even fill in a particular word that the other person fails to produce because people automatically predict upcoming words in speech (Li, 2001; Sacks, Schegloff, & Jefferson, 1974; Schegloff, 2000). However, there are circumstances in
which the prediction does not match what is actually perceived; in such cases, the input has to be reanalyzed (Friederici, Pfeifer, & Hahne, 1993). Speech becomes even more unpredictable when bilingual speakers are involved in a conversation because the speakers can freely switch back and forth between languages depending on the topics, interlocutors and social contexts (Grosjean, 2001, 2008; Myers-Scotton, 1998). Since language switching is such a common phenomenon in a bilingual society, it is one of the extensively studied topics in bilingual language processing.

In the domain of language production, behavioral studies reveal that people take longer to name a switched word, especially when the word is switched from L2 to L1 (e.g., Meuter & Allport, 1999). However, studies in language comprehension do not yield a consistent picture regarding switching direction, probably due to different materials, tasks and/or language proficiency of participants (Bobb & Wodniecka, 2013, Dijkstra, 2005; Van Hell & Witteman, 2009; van Hell, Litcofsky, & Ting, 2015). For example, experiments with single item materials find switching costs in either L2-L1 or L1-L2 direction. Using a priming paradigm with masked primes, Chauncey, Grainger and Holcomb (2008) observed a larger N400 for targets switched into L1 as compared to non-switched ones. In contrast, using a translation priming paradigm, Alvarez, Holcomb, and Grainger (2003) reported that stimuli switched from L1 to L2 taxed more cognitive effort than those switched in the other direction, as reflected by a larger N400 in the former case. Similarly, Phillips, Klein, Mercier, and de Boysson (2006) used a repetition priming paradigm and found that the N400 effect was present in processing auditory materials switched from L1 to L2 but not from L2 to L1.

Studies with sentential materials also find switching costs in either L1-L2 or L2-L1 direction. Moreno, Federmeier, and Kutas (2002) examined how English-Spanish bilinguals processed English sentences completed by an English expected word, an English synonym of the expected word (lexical switch), and a Spanish equivalent of the expected word (code switch). Their findings showed that, while the English synonyms elicited a stronger N400, the Spanish equivalents induced a stronger left anterior negativity (LAN) and late positive complex (LPC). The authors argued that the LAN effect could have resulted from different morphological agreements between Spanish and English and that the LPC effect might have reflected sentence reanalysis, as in semantically incongruous sentences or garden-path sentences in monolingual studies (Kim & Osterhout, 2005; Osterhout, Holcomb, & Swinney, 1994). Different from Moreno et al.’s study where the L1 (English) to L2 (Spanish) switching direction was investigated in English-Spanish bilinguals, Ng, Gonzalez, and Wicha (2014) and van der Meij, Cuetos, Carreiras, and Barber (2011) investigated sentences switched from L2 (English) to L1 (Spanish) in Spanish-English
bilinguals. As in the language switching condition (i.e., code switch) in Moreno et al.’s (2002) study, a LAN effect and an LPC effect were observed in Ng et al.’s (2014) study. However, the data pattern in van der Meij et al.’s (2011) research was less straightforward: while the high-proficient group showed the LAN, N400 and LPC effects, the low-proficient group demonstrated the N400 and LPC effects without the LAN.

Proverbio, Leoni, and Zani’s (2004) research was the first ERP study to explicitly manipulate the factor of switching direction in sentence context. The participants, who were interpreters and thus proficient in both Italian (L1) and English (L2), showed a larger N400 in comprehending L1-L2 switches than L2-L1 ones. Proverbio et al.’s finding of the asymmetric N400 effect in the L1-L2 direction was in line with those in Alvarez et al.’s (2003) and Phillips et al.’s (2006) single word studies, but the absence of the LAN and LPC effects did not replicate the patterns in Moreno et al.’s (2002) report. Later research suggested that the absence of an LPC effect can be contributed by factors such as participants’ language proficiency, predictability of a switch, and the nature of the experimental task (Brouwer, Fitz, & Hoeks, 2012; Kuperberg, 2007; Moreno, Rodriguez-Fornells, & Lanie, 2008; van Hell & Witteman, 2009). The observation that switching costs might be modulated by language proficiency was also supported by a recent behavioral study examining switching direction, which observed a switching cost from L1 to L2 and found the cost correlated with L2 proficiency (Bultena, Dijkstra and van Hel et al., 2015).

Taken together, previous results do not unequivocally depict the relationship between processing costs (and their underlying cognitive processes) and switching direction in language comprehension, although all of them demonstrate that language switching per se results in some processing cost, such as difficulty in lexical access to the switched word (N400: Alvarez et al., 2003; Phillips et al., 2006; Proverbio et al., 2004), difficulty of grammatical processing of the morphological structure of the switched word (LAN: Moreno et al., 2002; Ng et al., 2014; van der Meij et al., 2011), and/or more effort in integrating a switched element into a sentence (LPC: Moreno et al., 2002; Ng et al., 2014; van Der Meij et al., 2011).

But why is it more difficult to perceive a switched component? More specifically, why is it harder to process a switched component in a certain switching direction? The control/activation levels of bilinguals’ two languages may provide an answer to the question. The Inhibitory Control Model (Green, 1998, henceforth IC model) claimed that switching in language production could induce costs because it involved a change in language schema for a given task and that any change of language involved overcoming the inhibition of the previous “language tags” that specified whether the lemmas belonged to L1 or L2 in the bilingual lexico-semantic
Furthermore, since language tags in L1 were usually highly activated and more efforts were needed to inhibit them, producing an L2-L1 switch should be more difficult than producing an L1-L2 one since it was more demanding to reactivate a strongly inhibited L1 tag. However, it should be noted that in production, the language of the target word must be specified at an early stage for the target lexical item, but in perception, the processing is driven by the visual/acoustic input. Therefore, predictions of processing costs in comprehension can be different from those derived from the IC model. For example, being a comprehension model, the Bilingual Interactive Activation Plus model (Dijkstra & van Heuven, 2002, henceforth BIA+) predicted switching costs in the L1-L2 direction. The model explicitly argued that the resting-level activation of words reflected the language user’s subjective frequency of words and that linguistic context (e.g., a proceeding sentence) could influence the activation of lexemes in the word identification system. Hence, if a word was switched into another language, a processing cost should be observed because the activation of the language node of a previous word did not disappear completely, which could make activation of the new language more effortful (Bultena et al., 2015). Furthermore, processing an L1-L2 switch should be more difficult than an L2-L1 one because, on top of the “lingering activation” of the previous language node mentioned above, an L1-L2 switch involved activation of low resting level L2 nodes, while an L2-L1 one required activation of high resting level L1 nodes. Due to its comprehension nature and its inclusion of linguistic context, we will discuss our results of the current study in light of the BIA+ model.

Now that we have discussed the switching issues in bilingual language processing, we can turn to a more basic question about sentence processing. Since natural language switching can happen within one sentence, it would be informative to find out if the abovementioned processing costs of switching can be further modulated by factors that have been heavily studied in monolingual sentence processing, specifically, cloze probability and contextual constraint.

A large body of sentence processing literature has explored effects of the cloze probability of the sentence-final word and those of the contextual constraints of a sentence. Cloze probability of a word is defined as the proportion of respondents using that particular word to complete a preceding context in an offline norming task, while contextual/sentence constraint is the degree to which the context establishes an expectation for a particular upcoming word, empirically defined as the cloze probability of the word with the highest probability (Kutas & Federmeier, 2011). Behavioral studies have found faster response time in processing high-cloze words than low-cloze ones (Schwanenflugel & Shoben, 1985). Also, ERP studies have repeatedly demonstrated that relative to high-cloze targets, low-cloze ones elicited a
larger negativity between 250 and 500 ms over central-parietal scalp sites (N400), revealing greater difficulty in lexical access (e.g., Federmeier, Wlotko, Ochoa-Dewald, & Kutas, 2007). In fact, the amplitude of N400 is graded with the cloze probability of a terminal word (DeLong, Urbach, & Kutas, 2005; Federmeier, 2007; Federmeier et al., 2007; Kutas & Hillyard, 1984; Thornhill & Van Petten, 2012), showing that sentence contexts can pre-activate semantic features of the upcoming word to a different degree, and that the reduced N400 signals processing benefits from a supportive context (Van Petten & Luka, 2012). Although no bilingual processing studies have particularly looked into the cloze probability factor, the effects of contextual constraint have been examined albeit without using language switching paradigms. Based on previous findings that cognates are processed faster (the cognate facilitation effect) and interlingual homographs slower (the interlingual homograph interference effect) than monolingual control words (e.g., Lemhöfer & Dijkstra, 2004; Von Studnitz & Green, 2002), researchers embed cognates and interlingual homographs in sentences with various contextual constraints to examine whether similar effects in single word processing can carry over to sentence processing. The results generally show that cognate facilitation and interlingual homograph interference disappear in high-constraint sentences but is still present in low-constraint ones (Libben & Titone, 2009; Schwartz & Kroll, 2006). This may be because high-constraint sentences have pre-activated certain semantic and lexical features of both cognates and interlingual homographs and thus these words are processed identically as control ones (Schwartz & Kroll, 2006). However, such a top-down contextual effect on lexical processing is recently challenged by Van Assche, Drieghe, Duyck, Welvaert, and Hartsuiker’s (2011) study. They found a facilitation effect of cognates in both high- and low-constraint sentences, which undermined the role of top-down semantic context.

To sum up, although language switching has been one of the heated topics in bilingual research, the switching phenomenon has not been systematically examined with cloze probability and sentence constraints—two factors that have been shown to be important in monolingual sentence processing. Therefore, the current study aimed to explore the relationship between language switching and cloze probability in a highly constrained bilingual sentence context and to find out whether and how switching costs can be further modulated by important factors in processing monolingual sentences.

The two languages used in the study are Mandarin and Taiwanese. Mandarin is the official and dominant language in Taiwan, while Taiwanese, which is derived from the Min Nan dialect and has developed into a natural language in the past 400 years, is the major dialect spoken by 70% of the populations and the less dominant
language of most people (especially for younger generations) due to its limited use in the society. Both languages belong to the Chinese languages, but they are not mutually intelligible. Due to the evolution of the Chinese languages and the intensive language contacts, Mandarin and Taiwanese share many grammatical structures (Cheng, 1985; Kubler, 1985); however, the phonetic inventories and phonological rules of the two languages differ greatly. In terms of segments, Mandarin has 22 consonants and 12 vowels (Zhao & Li, 2009), while Taiwanese has 18 consonants and 10 vowels, including syllable-final glottal stops that are absent in Mandarin (Chung, 1996). In addition, oral vowels and nasal vowels are phonemic contrasts in Taiwanese (e.g., /sa/ “to take” vs. /sã/ “clothes”), but not in Mandarin (e.g., [sà] and [sã] “to scatter”). With regard to the tone systems, Mandarin has 4 lexical tones with a few tone sandhi rules (i.e. phonological change at the juncture of words or morphemes), whereas Taiwanese has 8 lexical tones and much more extensive tone sandhi rules. Moreover, a sociolinguistic study verifies that language shift is happening in Taiwan (Sandel, Chao, & Liang, 2006), with the grandparents’ generation communicating mostly in Taiwanese, the parents’ generation in both Mandarin and Taiwanese, and the children’s generation mainly in Mandarin. The young adults were the group of our interest because they acquired both Mandarin and Taiwanese naturally, but used Mandarin more frequently since it is the official language in Taiwan and thus their dominant language.

On a final note, Taiwanese does not have a standardized writing system, so language switching happens more commonly and naturally in the speaking than in the writing modality. Therefore, using auditory presentation in our experiment is more ecologically valid than using visual one. However, the use of auditory material may induce a brainwave component that was absent in the switching studies with visual stimuli that we have reviewed so far: the phonological mapping negativity (PMN) (Connolly & Phillips, 1994; Connolly et al., 1995). Connolly and Phillips (1994) manipulated semantic congruity and phonological expectedness of the initial phonemes in their experiment. Their stimuli were sentences completed by a semantically and phonologically expected word, a semantically expected but phonological unexpected word, a semantically unexpected but phonologically expected word, and a semantically and phonologically unexpected word. A double disassociation was found: while sentences ended with a semantically unexpected word elicited a larger N400, those terminated by a phonologically unexpected word elicited a PMN, which appeared as early as 200 ms and was more prominent over fronto-central sites, indicating a mismatch between the presented sound and the expected sound. The PMN effect has been replicated in many studies, in sentence contexts or word lists (Connolly, Service, D'Arcy, Kujala, & Alho, 2001; Desroches,
Newman, & Joanisse, 2009) and also in language switching studies with auditory stimuli (Phillips et al., 2006). In particular, Phillips et al. (2006) showed that both L1-L2 and L2-L1 switching directions elicited a PMN, suggesting that whenever there was a mismatch between an expected sound and a presented sound, a PMN would be present. In addition to the PMN, previous studies also reveal slightly different N400 morphology between visual and auditory modalities. An auditory N400 is reported to have an earlier onset and later offset compared with a visual N400 (Connolly, Phillips, & Forbes, 1995; Holcomb & Neville, 1990; Kutas & Federmeier, 2011). Such discrepancies can be attributed to the differences in presentation modalities—the presentation of a written word is immediate, but that of a spoken one can last for hundreds of milliseconds (Connolly et al., 1995).

In sum, the current study aimed at examining whether switching cost can be modulated by language dominance and cloze probability in auditory sentence comprehension. As described earlier, the BIA+ model predicted greater switching costs in the L1-L2 direction. However, Mandarin and Taiwanese are usually simultaneously acquired in Taiwan; hence, it is difficult, if not impossible, to define which language is L1 or L2 in a speaker. We thus made our prediction in the dimension of language dominance. Since Mandarin is more frequently used than Taiwanese due to the former’s dominant status in the society, the resting-level activation of the language nodes of Mandarin words should be higher, as those in L1. We expected to observe greater switching costs in the dominant to the non-dominant (henceforth, D-ND) direction than in the non-dominant to the dominant (henceforth, ND-D) direction, and to find modulation of cloze probability on switching costs, since low-cloze probability has been shown to influence sentence processing. Specifically, due to the use of auditory presentation, we hypothesized that a PMN effect should appear in response to unexpected words in both the low-cloze and switched conditions, but should be more so in the D-ND condition. We also expected that the N400 should be larger in the D-ND than in the ND-D direction and that it should appear earlier and last longer compared with those induced by visual stimuli. Finally, an LPC should be observed for the switched conditions since previous literature has shown that it is harder to integrate a switched element into a sentence. However, in light of the BIA+ model, the effect of switching should exert its effect on the language nodes within the word identification system. Since sentence integration happens outside the word identification system, the LPC should not be directly modulated by switching direction.

2. Materials and Methods
2.1 Participants

A total of 40 Mandarin-Taiwanese bilinguals (17 females, 20-36 years old, mean age: 25) were recruited for the current study. All the participants acquired both languages from birth, with Mandarin being the dominant and Taiwanese being the non-dominant language. To ensure the participants’ high proficiency in Taiwanese, both comprehension and production tests from a standardized Taiwanese proficiency test (General Taiwanese Proficiency Test, developed by the Taiwanese Language Testing Center at National Cheng Kong University) were administered. For the comprehension test, participants had to answer questions based on their understanding of the aurally presented conversations and a short article. As for the production test, participants were requested to complete a conversation in a specified scenario and to describe a set of pictures. Their production was recorded and rated by two linguistics graduate students who were also Mandarin-Taiwanese native speakers. Of the 40 participants, 10 were not qualified because of their poor performance in the Taiwanese proficiency test. After data pre-processing, another 8 participants were excluded from further ERP analysis due to excessive eye-blinking, muscle potentials and alpha waves. The reported results were obtained from the remaining 22 participants (6 females, 21-36 years old, mean age: 26). All the participants were right-handed as assessed by a simplified version of the Edinburg Handedness Inventory (Oldfield, 1971), and 5 reported having at least one left-handed blood relative. None of the participants reported a history of neurological or psychiatric disorder or recent use of psychoactive medications. Written informed consent was obtained from all participants. The experimental protocol was approved by the Research Ethics Office of National Taiwan University. Participants were paid 200 NT dollars per hour as compensation for their time.

2.2 Materials

The materials were auditory sentences consisted of two frames—the context frame and the target frame, with the former ranging from 8 to 13 syllables to build up a context to predict the upcoming word while the latter being a disyllabic noun at the sentence-final position. Half of the sentences were completed by an expected word (the High-cloze condition) and the other half by an unexpected but contextually plausible word (the Low-cloze condition). In addition to the cloze probability of the final word, we also controlled the language switching factor by manipulating the language of the context and that of the target. The context was presented either in Mandarin (the Mandarin context condition) or in Taiwanese (the Taiwanese context
condition), and the target was either kept in the same language as the context (the Non-switched condition) or switched into the other language (the Switched condition). Eight experimental conditions were thus created: High-cloze Mandarin Non-switched (H-MM), High-cloze Mandarin Switched (H-MT), High-cloze Taiwanese Non-switched (H-TT), High-cloze Taiwanese Switched (H-TM), Low-cloze Mandarin Non-switched (L-MM), Low-cloze Mandarin Switched (L-MT), Low-cloze Taiwanese Non-switched (L-TT), and Low-cloze Taiwanese Switched (L-TM). No interlingual homophones were included in our stimuli. Table 1 presents a set of example stimuli for each condition.

The cloze probability of the targets was obtained from a norming procedure conducted with native Mandarin speakers, none of whom participated in the main ERP experiment. Mandarin context frames (348 in total) were equally divided into four lists, with each list completed by an average of 30 participants (age range: 27 to 34). Participants were instructed to read each sentence frame and to write down three completions based on the order that came to their mind. Only participants’ first answer was taken into consideration in the computation of the cloze probability of a target word and synonyms provided by participants were treated as different lexical items. Context frames that were not completed by a common lexical word were excluded from the ERP experiment. The averaged cloze probability of the highest cloze targets was 69%; we thus considered the context frames in our study as of high constraint. As for the Low-cloze condition, all the target words were either selected from the remaining answers provided by the participants in the norming procedure or generated by one of the experimenters (CL, a native Mandarin-Taiwanese speaker). The averaged cloze probability for the Low-cloze condition was 0.1%.

The frequencies of the Mandarin Low- and High-cloze words were further controlled with the Word List with Accumulated Word Frequency in Sinica Corpus (http://elearning.ling.sinica.edu.tw/CWordfreq.html). Paired t-test revealed no significant differences in frequency between the High- and Low-cloze targets (High-cloze targets: 319; Low-cloze targets: 289; t(231) = .910, p=.364).

Since some of the Low-cloze words were generated by one of the experimenters, another pilot test was conducted to ensure that sentences with the low-cloze targets were plausible. The experimental sentences were divided into two lists. Within each list, half of the sentences were completed by High-cloze words and the other half by Low-cloze ones. Semantically anomalous filler sentences were also included in the lists. A separate group of Mandarin native speakers (N=21 for each list) were recruited to judge the plausibility of each sentence on a 5-point scale (1: very implausible, 5: very plausible). Only sentences that scored above 3 were considered acceptable and later included into the ERP experiment (High-cloze targets: 4.41;
Low-cloze targets: 4.01; \( t(231)=12.379, p<.001 \). Since the experimental sentences were high-constraint sentences, it was natural that High-cloze words looked more plausible than Low-cloze ones.

After the High- and Low-cloze words for each context frame were finalized in Mandarin, the sentences were translated into Taiwanese by one of the experimenters (CL) to create the oral version of the Taiwanese experimental trials. To ensure the accuracy of the translation, an online Taiwanese dictionary (http://twblg.dict.edu.tw/holodict_new/index.html) developed by the Ministry of Education in Taiwan was consulted during translation. The final translation was crosschecked by two native Mandarin-Taiwanese speakers to ensure its naturalness.

Due to the fact that the Taiwanese materials were translated from Mandarin ones, we had the concern that the well-controlled cloze probabilities for the High- and Low-cloze targets in the Mandarin materials might not be preserved when the context frame was presented in Taiwanese. A post-hoc Taiwanese cloze norming test was thus conducted to check the degree of “agreement” in cloze probability between the two languages. Twenty-three native Mandarin-Taiwanese speakers, who had passed a Taiwanese proficiency test (see the proficiency test in the Participants section) and did not participate in the Mandarin norming test, were recruited. The procedure of Taiwanese cloze norming was similar to the Mandarin one, except that the materials were presented to the participants aurally and that the participants had to provide the answers by speaking. Since people from different regions of Taiwan may use slightly different lexical forms in Taiwanese to represent the same concept (this is less a problem in Mandarin since Mandarin is the dominant and standardized language), synonyms produced by the participants were counted as the same lexical item to incorporate the regional differences. The results revealed that High- vs. Low-cloze target sets were comparable in Mandarin and in Taiwanese. For High-cloze words, more than half of the participants produced the Taiwanese equivalent previously translated from Mandarin in over 90% of the experimental sentences; for Low-cloze words, none of them were produced by more than half of the participants.

Both Mandarin and Taiwanese are tone languages and the experimental materials were presented aurally, so the tone sandhi rules in the two languages were taken into consideration when the experimental materials were being finalized. For example, a third tone would be changed into a second tone when followed by another third tone in Mandarin. Since in the current study each sentence stimulus was composed of a context frame and a target frame, if the syllables adjacent to a frame boundary (i.e., the last syllable of the context frame and the first syllable of the target frame) were both of a third tone, the former should become a second tone. We thus avoided such combinations when choosing Mandarin target words to keep the tone of
the final word of the context frames identical to its original/lexical tone. In Taiwanese, only the last syllable of a word in a sentence would be produced in its original tone and all the previous words would undergo extensive tone changes; therefore, concerns about possible tone changes adjacent to a frame boundary, as in the case of Mandarin, were irrelevant when Taiwanese was the context language. The finalized stimuli were 232 high-constraint context frames followed by 232 High- and 232 Low-cloze targets, with each stimulus having a Mandarin and a Taiwanese version. Although both languages share some segments, and 45% of our target words in Mandarin and Taiwanese share the same beginning consonants, the first syllables of these Mandarin and Taiwanese equivalents were different in the current study. The materials were divided into eight lists, each containing 232 sentences, to counterbalance across the eight experimental conditions such that no context or target was repeated within the same list. The lists were randomly assigned to participants and the presentation order of the sentence stimuli was randomized within each list.

The experimental materials were recorded by a male native Mandarin-Taiwanese speaker in a soundproof room. To keep the context frame identical across different conditions and to prevent anticipation of the upcoming sound of the target through coarticulation (i.e. a situation where the pronunciation of a sound is influenced by its neighboring sound) in connected speech, context frames and target frames were recorded separately and spliced together later. To reduce the overlap between the brainwaves from the context and those from the target, we used Audacity 1.3, a free sound-editing software (http://audacity.sourceforge.net), to edit in a 200-ms pause between the context and the frame. Since the abrupt pause between the context and the target might give a hint to the participants that the upcoming word was the target, we also inserted the same amount of silence between words so that no only the context-frame boundary, but also every word boundary in the context had a 200-ms pause. Although the sentences might sound unnatural due to the inter-word pauses, the unnaturalness was constant across conditions and should be cancelled out when we compared data between conditions. The duration of the target frame was 1200 ms (i.e., 600 ms for the target word and the remaining 600 ms for silence). The total duration of each sentence ranged from 4500 to 7700 ms, including 3300 to 6500 ms of the context frame and 1200 ms of the target frame. Twenty percent of the sentences were followed by an auditory probe word, either in Mandarin or Taiwanese, lasting for 600 ms. Half of the probe words were drawn from the contexts (but never the sentence-final target words), and the other half were disyllabic words not appearing in the sentence stimuli. All of the probes were content words, and the numbers of Mandarin and Taiwanese words were equal.
2.3 Procedure

The ERP experiment was conducted in the Neurolinguistics Lab at National Taiwan Normal University in Taiwan. The participants were asked to sign a consent form, and then interviewed with a demographic questionnaire, which included their health information, linguistic background, handedness, and language use. Then, an elastic cap with electrodes to measure brainwaves was put on the participants and they were guided to sit approximately 80 cm in front of a computer screen and to put their hands on a response box. The participants were instructed to listen to the sentences for comprehension. To ensure that they were paying attention, 20% of the sentences were followed by an auditory probe word. The participants had to judge whether the probe word had occurred in the sentence by pushing the Yes or No button. The button pressing was counterbalanced across the participants.

Each trial began with a 200 ms “ding” sound, along with a fixation point (“+”) at the center of the screen, which stayed on the screen until the sentence ended. Three hundred milliseconds after the ding sound, the auditory sentence stimulus was played. For 20% of the trials, an auditory probe word was played for 600 ms after the presentation of the target frame while a question mark appeared and stayed on the screen until the participants pressed the Yes or No button. The screen then turned blank for 1800 ms. Then a ding sound was played, along with a fixation point at the center of the screen, indicating the upcoming of the next trial. For trials without a probe word, the screen would go blank for 1800 ms after the target word and then a new trial would follow. See Fig. 1 for details of the procedure.

The participants were reminded that although this was an auditory experiment, they had to keep their eyes fixated on the cross on the screen. They should also minimize body movements (e.g., blinking, eye movements and muscle movements) due to the fact that any movements could contaminate the electrical signals. Ten practice trials were provided to familiarize the participants with the experimental procedure. When reliable performance was achieved, the main experiment started. The main experimental session was divided into four blocks, with a short break between blocks. The ERP recording time lasted about 30 to 45 minutes.

2.4 Data acquisition and analysis

E-prime 2.0 (Psychology Software Tools Incorporated) was used to present the experimental stimuli and record participants’ behavioral data. Electroencephalogram (EEG) was recorded from 32 electrodes according to the 10/20 system. Each channel was referenced to an average of the left and right mastoids for
both online and off-line analyses. Four additional electrodes (two on the outer canthus of each eye and two on the upper and lower ridge of the left eye) were placed to monitor blinks and horizontal eye movements. The impedance of all the electrodes was kept below 5 kΩ. EEG signals were continuously digitized at 1000 Hz, filtered between DC to 100 Hz (NuAmps, NeuroScan Incorporated). The amplifier rate (Gain) was 19.

The EEG data were processed with EEGLAB (Delmore & Makeig, 2004) and ERPLAB (Lopez-Calderon & Luck, 2014) in Matlab (MathWorks, Inc.). To begin with, the EEG channel operation was conducted to convert the four monopolar eye-movement monitoring channels to two bipolar channels (VEOG and HEOG). Then the continuous EEG file was epoched from -100 to 1000 ms of the stimulus (target words) onset. Baseline correction was then applied with the pre-stimulus -100 to 0 ms interval. An Infinite Impulse Response (IIR) filter was applied to each condition, with the band-pass value set at 0.01 Hz to 30 Hz, 12 dB/oct. Artifact rejection was carried out by reviewing the sweeps automatically and was double-checked manually. Sweeps contaminated by excessive blinking, body movements, skin potentials, and amplifier saturation were rejected. The overall rejection rate was 25%, and the following were the rejection rate for each condition: H-MM: 22.0%, H-MT: 27.1%, H-TT: 27.5%, H-TM: 26.2%, L-MM: 22.8%, L-MT: 23.3%, L-TT: 22.7%, and L-TM: 27.6%. We then sorted and averaged artifact-free epochs based on the event codes referring to the experimental conditions. Finally, grand average was conducted by averaging all the participants’ averaged ERP data with the same experimental conditions. Six regions were chosen to characterize the scalp distribution of experimental manipulations: left-frontal (average of FC3 and C3), medial-frontal (FCz and Cz), right-frontal (FC4 and C4), left-parietal (CP3 and P3), medial-parietal (CPz and Pz), and right-parietal (CP4 and P4). Omnibus four-way repeated-measures ANOVAs were carried out with the factors of Cloze probability (High, Low), Context language (Mandarin, Taiwanese), Switching (Non-switched, Switched), and Region (Left-frontal, Medial-frontal, Right-frontal, Left-parietal, Medial-parietal, and Right-parietal) on the mean amplitudes in three measurement windows: 250-350 (Connolly & Phillips, 1994), 350-550 (Kutas & Federmeier, 2011) and 600-900 ms (Van Petten & Luka, 2012). Follow-up paired t-tests were performed and Bonferroni corrected when interactions were observed. When the Mauchly’s test of Sphericity was violated, Greenhouse-Geisser correction was applied to adjust the p-values.

Before entering the Results section, it is important to point out that the calculation of switch costs in previous studies was conducted by two different kinds of comparisons. One comparison kept the target language identical and measured the
switch costs by comparing targets preceded by a different or the same context language (e.g., L2-L1 vs. L1-L1, see Meuter & Allport (1999) and Proverbio et al. (2004)). The other comparison kept the context language identical and calculated the switch effect by comparing the same or different language use of the target word (e.g., L2-L1 vs. L2-L2, see Moreno et al. (2002), Ng et al. (2014) and van Der Meij et al. (2011)). Each type of comparison had its own focus of interest. When the target word was identical, as in the first type of comparison, any observed effect between the switched and non-switch conditions could be attributed to the target word’s use of a different language from the preceding context (word or sentence). In contrast, with the context being fixed, as in the second type of comparison, it was possible to examine whether and how switching was modulated by effects of the sentence context, such as cloze probability. For the current study, we adopted the second kind of comparison to measure the switch costs.

3. Results

3.1 Behavioral results

Participants’ accuracy rate and response time were calculated. The overall accuracy rate of the word recognition memory task was 98.4%. Response times to probe words that had occurred in the sentence context were significantly shorter than those that had not (present: 1164 ms; absent: 1259 ms; t(21)=2.889, p<.01). Both accuracy rate and different response times indicated that participants were paying attention in the experiment.

3.2 ERP results

The focus of the study was to explore whether processing costs of language switching were related to switching direction and whether switching costs could be modulated by cloze probability. The context was presented in Mandarin or in Taiwanese. The switching direction was controlled by the language use of the context and that of the target frames, and the factors of language switching and cloze probability were manipulated at the sentence-final target noun. The ERP data were obtained from the sentence-final targets.

Fig. 2 shows the grand average ERPs to Switched (D-ND, ND-D) and Non-switched (dominant to dominant language, henceforth, D-D; non-dominant to non-dominant language, henceforth, ND-ND) targets in Mandarin and Taiwanese sentence contexts, collapsed across cloze probability. Early components such as the P1 (100 ms) and N1 (150 ms) can be observed in all conditions. Following these
responses, an early negative shift is detected around 200 to 250 ms across the scalp, especially in the D-ND condition. This widespread negativity continues and peaks between 400 and 600 ms (N400), with the largest amplitude in the D-ND condition compared with the other three conditions. A closer look at the figure reveals that the negativity seems to last longer over the frontal site. While the brainwave in the ND-D condition appears to be more positive at the posterior sites at a later measurement window, it does not seem to differ from those in the D-D and ND-ND conditions by 600 ms. Fig. 3 illustrates the topographic maps of the switching effect in different switching directions.

Fig. 4 presents the grand average ERPs to Switched and Non-switched targets in High-cloze and Low-cloze contexts, collapsed across Context languages. Early components such as the P1 (100 ms) and N1 (150 ms) can be observed in all conditions. Starting from 200 ms, the High-NonSwitched condition starts to diverge from the other three conditions. It remains positive-going, with a peak around 300 ms, then shifts to negative-going with a small peak around 500 ms (N400). In contrast, the brainwaves in the rest of the conditions become more negative from 200 ms and peak between 400 and 600 ms (N400). The N400 amplitudes in the Low-NonSwitched and Low-Switched conditions seem to be the largest among the four conditions. Fig. 5 shows the topographic maps of the cloze probability effect in the Switched and Non-switched conditions, respectively.

In order to statistically test the patterns described in the visual inspection and to see whether the ERP components reviewed in Introduction (PMN, N400, LPC) could also be observed in the data, omnibus four-way repeated-measures ANOVAs were carried out with the factors of Cloze probability (High-cloze, Low-cloze), Context language (Mandarin, Taiwanese), Switching (Non-switched, Switched), and Region (Left-frontal, Medial-frontal, Right-frontal, Left-parietal, Medial-parietal, and Right-parietal) on the mean amplitudes in the measurement windows of 250-350, 350-550 and 600-900 ms. Results of the ANOVA analyses are summarized in Table 2. In the following, we report the statistical results in the three measurement windows.

3.2.1 250-350 ms: PMN, early N400, and frontal negativity

We expected to observe a PMN when the participants heard an unexpected sound in the Low-cloze and Switched conditions. Our analysis on the mean amplitude showed a main effect of Switching ($F(1, 21)=11.507, p<.005$) and a significant two-way interaction of Cloze probability and Switching ($F(1, 21)=6.898, p<.05$). Post-hoc paired t-tests revealed that the amplitude in the High-NonSwitched condition was significantly weaker than those in the rest of the conditions (High-NonSwitched
vs. High-Switched: \( t(21)=4.482, p<.001 \); High-NonSwitched vs. Low-NonSwitched: \( t(21)=5.318, p<.001 \); High-NonSwitched vs. Low-Switched: \( t(21)=4.480, p<.001 \); High-Switched vs. Low-Switched: \( t(21)=.513, \ p=1 \); Low-NonSwitched vs. Low-Switched: \( t(21)=.559, p=1 \); High-Switched vs. Low-NonSwitched: \( t(21)=.007, p=1 \), suggesting that the PMN was elicited when the perceived sound did not match the expected input.

The existence of the PMN was further supported by the finding of the N400 in this latency window with an early onset and a posterior scalp distribution. There were main effects of Cloze \( (F(1, 21)=11.892, p<.005) \) and Region \( (F(5, 105)=13.288, p<.001) \), modulated by a Cloze x Region interaction \( (F(5, 105)=3.472, p<.05) \). Post-hoc paired t-tests revealed that the negativity induced by Low-cloze targets was significantly stronger than that by the High-cloze targets over the parietal sites (Left-frontal: \( t(21)=1.919, p=.414 \); Medial-frontal: \( t(21)=2.737, p=.072 \); Right-frontal: \( t(21)=2.459, p=.138 \); Left-parietal: \( t(21)=3.239, p<.05 \); Medial-parietal: \( t(21)=4.852, p<.001 \); Right-parietal: \( t(21)=3.901, p<.01 \). We believed that this was a typical N400 effect for cloze probability with an early onset, probably due to the auditory presentation of the stimuli. Therefore, it was likely that the PMN, which had been reported to have a frontal-central distribution in the literature but did not show such a pattern in our data, actually overlapped with the N400, which was significantly more prominent at the posterior part of the brain. See Fig. 5 for the topographic maps of the negative brainwaves.

We then examined the effect of switching direction. There were a main effect of Context language \( (F(1, 21)=6.879, p<.05) \) and a significant two-way interaction of Context language x Switching \( (F(1,21)=20.738, p<.001) \). Post-hoc paired t-tests indicated that the D-ND condition elicited a larger negativity than the D-D one \( (t(21)=5.579, p<.001) \), but such an effect was absent between ND-D and ND-ND \( (t(21)=.655, p=1) \). The widespread negativity elicited by the D-ND condition could be the PMN and the N400, but we also believed that this negativity might reflect a different underlying process, as it continued into later measurement windows. We will come back to address this at the Discussion section. Finally, we did not find other 2-, 3- or 4-way interactions.

In sum, our data showed that the PMN was evident when participants heard an unexpected sentence completion in Low-cloze and/or Switched targets. We also observed a typical N400 with an early onset that was stronger in response to the Low-cloze targets than to the High-cloze ones over the parietal sites. Finally, we found an asymmetric processing cost in different switching directions: while the D-ND condition induced a stronger negativity than its D-D baseline, there was no difference between the ND-D and the ND-ND conditions.
3.2.2 350-550 ms: Frontal negativity and N400

Since previous literature has found the association between switching and N400 (sometimes LAN), and our brainwave data did show a sustained, widespread negativity, we analyzed data during 350-550 ms to see if a similar finding could be replicated in our study. Indeed, we found a significant effect of Switching \((F(1, 21)=7.663, p<.05)\), but it was modulated by a Switching x Context language interaction \((F(1, 21)=24.684, p<.001)\), showing that the negativity was sensitive to switching direction, not simply to switching per se. Follow-up t-tests revealed that while the D-ND condition was more negative than the D-D condition \((t(21)=5.003, p<.001)\), the ERP response to the ND-D condition did not differ from that to the ND-ND condition \((t(21)=-1.221, p=.472)\). Although the negativity was widespread, as the Switching x Context language interaction was not further modulated by Region, the top row of the topographic maps in Fig. 3 revealed clear concentrations on the frontal and the posterior sites among the negativity during 350-550 ms. We believed that the widespread negativity was composed of a frontal negativity and an N400, which could not be further differentiated with our statistical analysis because of the proximity of these two components. Our view of the existence of a frontal negativity was further supported by the observation of the typical N400 in this measurement window. We found a significant Cloze effect \((F(1, 21)=19.331, p<.001)\), modulated by the interaction of Cloze x Region \((F(5, 105)=9.476, p<.001)\). Post-hoc paired t-tests revealed a strong typical N400 effect: amplitudes in the Low-cloze conditions were more negative than those in the High-cloze ones, especially over the parietal sites (Left-frontal: \(t(21)=2.954, p<.05\); Medial-frontal: \(t(21)=4.043, p<.01\); Right-frontal: \(t(21)=3.392, p<.05\); Left-parietal: \(t(21)=4.142, p<.001\); Medial-parietal: \(t(21)=5.443, p<.001\); Right-parietal: \(t(21)=4.449, p<.001\) (see Fig. 5). Importantly, we did not observe an interaction between Switching x Cloze, which was observed during 250-300 ms and was used to argue that the observed negativity was the PMN. It is worth noticing that Cloze probability did not interact with Context language, either, confirming that the High-cloze vs. Low-cloze target sets were comparable in Mandarin and in Taiwanese, as we double checked in the post-hoc test described in the Materials section. Finally, no other 2-, 3- or 4-way interactions were found.

Taken together, our data showed that the D-ND condition induced a frontal negativity and a stronger N400 compared with the D-D condition during 350-550 ms, and that the PMN disappeared (as indicated by the absence of the Cloze probability x Switching interaction) during this latency window.
3.2.3 600-900 ms: Frontal negativity, sustained N400, and LPC

We intended to find out if there was an LPC effect associated with language switching in our data. Also, visual inspection of Fig. 2 suggested that the D-ND condition elicited a sustained negativity in this measurement window, so it would be informative to find out if this observation could be statistically verified. Our analysis revealed a main effect of Context language \((F(1, 21)=14.382, p<.005)\), modulated by an interaction of Context language x Switching \((F(1, 21)=21.494, p<.001)\). Pairwise comparisons revealed that the D-ND condition induced a stronger negativity than the D-D one \((t(21)=3.538, p<.005)\), while the ND-D condition induced stronger positivity (LPC) than the ND-ND one \((t(21)=-2.861, p<.05)\). However, a closer look at Fig. 2 revealed that, although the D-ND condition induced more negative brainwaves than the D-D one, the brainwaves actually became positive-going during this measurement window. Also, although not statistically supported by a Switching x Context language x Region interaction, Fig. 3 shows that the negativity elicited by the D-ND condition was more frontal-oriented, while the positivity elicited by the ND-D condition was more focal over the parietal sites, a classic distribution for the LPC effect.

There were again main effects of Cloze probability \((F(1, 21)=8.631, p<.01)\) and Region \((F(5, 105)=2.357, p<.05)\), modulated by the Cloze x Region interaction \((F(5, 105)=10.260, p<.001)\). Follow-up analysis indicated that the Low-cloze condition was more negative than the High-cloze one over the Medial- and Right-parietal sites (Left-frontal: \(t(21)=.768, p=1\); Medial-frontal: \(t(21)=1.481, p=.918\); Right-frontal: \(t(21)=1.605, p=.744\); Left-parietal: \(t(19)=2.319, p=.186\); Medial-parietal: \(t(21)=5.410, p<.001\); Right-parietal: \(t(21)=3.954, p<.01\)), suggesting a sustained N400 effect, starting from the 250-350 ms latency window and continuing into the 350-550 ms and 600-900 ms latency windows (see Fig. 5).

There was a marginal significance in the interaction between Switching and Region \((F(5, 105)=3.458, p<.05)\), but paired t-tests revealed no significant results after Bonferroni correction. The interaction between Context language and Region was also marginal \((F(5, 105)=3.064, p<.05)\). Followed-up comparisons showed that brainwave responses to the Mandarin context were more negative than those to the Taiwanese context among all regions except the right parietal site (Left-frontal: \(t(21)=-4.325, p<.001\); Medial-frontal: \(t(21)=-3.656, p<.01\); Right-frontal: \(t(19)=-3.312, p<.05\); Left-parietal: \(t(21)=-3.883, p<.01\); Medial-parietal: \(t(21)=-3.715, p<.01\); Right-parietal: \(t(21)=-2.423, p=.15\)). The results revealed that sentences might be processed differently when presented in different languages in the later measurement window. No other main effects or 2-, 3- and 4-way interactions were found.

In sum, our analysis verified that the LPC was sensitive to switching per se
and that the sustained negativity was more prominent in the D-ND condition. We also observed the sustained N400 effect over the parietal sites sensitive to the cloze probability manipulation.

4. Discussion

Previous literature has consistently shown that language switching induces processing costs, but whether and how switching direction modulates such costs is less clear. Also, cloze probability has been repeatedly shown to influence monolingual sentence processing, but whether it also affects bilingual sentence processing is unknown. In the current study, we explored the effect of switching direction between languages of different dominance in early bilinguals at the sentence level and manipulated cloze probability to see if switching costs could be influenced by the semantic expectedness of the switched word.

We would like to start our discussion with cloze probability due to its well-studied effect in the monolingual literature. We predicted that cloze probability should have an impact on switching costs, and indeed our results revealed that the switching cost was affected by cloze probability, but only at an early stage (i.e., 250-350 ms). We argued that this modulation was realized as a PMN in all the unexpected conditions when compared with the High-NonSwitched condition. The emergence of the PMN was expected, because the phonological features of the anticipated word should had been pre-activated by the context, so when the phonological input of the incoming target did not match the pre-activated features, as in the Low-cloze or Switched condition, or combined, a PMN was induced. After the phonological stage was passed, Cloze and Switching no longer interacted with each other but exerted their influence on sentence processing independently. The interaction between Cloze and Switching during 250-350 ms and their independent influence on processing in later measurement windows can be explained with the BIA+ model. As Dijkstra (2005) pointed out, linguistic context, such as a preceding sentence, can interact directly with the word identification system. It is possible that the pre-activated semantic representation by the sentence context had also pre-activated candidate lexical or sublexical phonological representations, which in turn pre-activated the context-related language node. Therefore, when the phonological representation and language node of the incoming word did not match those pre-activated by the context, a PMN was induced, reflecting the detection of such mismatches. After the phonological and language node mismatches were identified, the brain then encountered the mismatch of the semantic representation between the incoming word and the predicted word, which was indexed by the N400
Cloze effect at the parietal site (Federmeier et al., 2007; Kutas & Federmeier, 2000; Thornhill & Van Petten, 2012) from 250-350 ms to 600-900 ms. The earlier onset and the longer duration of the N400 were probably due to the auditory nature of the stimulus presentation, as we predicted in the Introduction. Therefore, our study extends the literature on sentence processing and shows that semantic unexpectedness also adds difficulty to lexical access in bilingual sentence processing.

After discussing the influence of cloze probability, we now examine the hypothesis that processing costs can be influenced by the switching direction between languages of different dominance; specifically, the D-ND switch should be more difficult to process than the ND-D one, as inferred from the BIA+ model (Dijkstra, & van Heuven, 2002). Indeed, our results revealed asymmetric processing costs: compared with hearing a non-switched sentence: hearing an ND-D switch induced an LPC at 600-900 ms, while hearing a D-ND switch induced not only the LPC, but also a widespread negativity throughout the three latency windows, possibly including the PMN (250-300 ms), the N400 (250-900 ms) and a frontal negativity (250-900 ms or 350-900 ms). Fig. 3 clearly captures the differences between the two switching directions. We will discuss each of the ERP components below and then summarize our discussion about the asymmetric costs in switching direction in the context of the BIA+ model.

Previous studies on language switching reveal an LPC effect (Moreno et al., 2002; Ng et al., 2014; van der Meij et al., 2011). The LPC effect in the ND-D condition was statistically verified in our study while that in the D-ND condition was not. In fact, although the positive-going tendency was clear in the D-ND condition, the brainwave was still more negative than that in the D-D condition. We argued that the LPC was actually present in the D-ND condition but attenuated by the co-occurring widespread negativity (see Figs. 2 & 4), which will be discussed later. Since the LPC was usually associated with sentence integration problems, our results suggested that bilingual listeners had greater difficulty integrating a switched than a non-switched word into the current sentence context.

The negativity elicited by the D-ND condition needs further explanation. It was more prominent over the frontal site from 250 ms and seemed to sustain till the end of the epoch. The frontal negativity in the early measurement window could well be the PMN discussed above. However, it should be noted that the PMN effect was stronger in the D-ND direction in the current study whereas it was observed in both L1-L2 and L2-L1 switches in Phillips et al. (2006). The inconsistency might arise from the use of different experimental paradigms. Phillips et al. (2006) adopted a repetition and translation priming paradigm, in which a very specific word could be generated prior to its acoustic presentation. However, in our study, a sentence context
of the dominant language seemed to create a “better” prediction for the upcoming word than the non-dominant context. This better prediction may be due to the dominant language’s standardized use in the media, school and/or other occasions, in contrast to the more diverse word use of the non-standardized, non-dominant language across different geographical regions. Hence, when compared with the non-switched conditions, a D-ND switch induced a strong PMN but not an ND-D switch.

Other than the PMN, the frontal negativity in the 250-300 ms measurement window could also be a PMN overlapped by a different negativity associated with a different cognitive process, which could not be statistically distinguished due to their proximity. This speculation was verified in later measurement windows, as will be explained below.

Around 450 to 550 ms in Fig. 3, it was clear that another source of negativity emerged over the right parietal site in the D-ND condition, which, combined with the frontal negativity, formed a widespread negativity and lasted till later measurement windows. We will discuss the parietal negativity first and the frontal negativity later. We argued that the parietal negativity in response to the D-ND switch should be an N400 effect because it was comparable with the N400 effect induced by switches in the L1-L2 direction in previous research (Alvarez et al., 2003; Phillips et al., 2006; Proverbio et al., 2004). But why did such an effect occur only when the context language is the dominant one? We argued that the asymmetric cost (or lack of benefit, see Van Petten & Luka, 2012) might reflect the ecological reality of switching between dominant and non-dominant languages in Taiwan. Since the participants’ dominant language is Mandarin, even though a conversation is carried out in Taiwanese, Mandarin words would still frequently appear during the course of the conversation due to the participants’ smaller Taiwanese vocabulary size resulting from its limited use in various social domains (e.g., media, schools, public administrations, etc.). Consequently, Mandarin is always highly active, even though the context language is Taiwanese. In contrast, when a conversation is carried out in Mandarin, the participants can easily express their thoughts with the language and the switching to Taiwanese is usually “marked” for particular sociolinguistic functions, such as being humorous or trying to shorten the social distance between the interlocutors. Therefore, since the participants have been used to Taiwanese-Mandarin/ND-D switching in both production and comprehension in everyday life, providing a Taiwanese context was like providing no language context, and thus no benefit (indicated by a reduced N400) was gained when comparing the ND-ND condition with the ND-D one. On the other hand, the Mandarin context provided a benefit for predicting the language of the upcoming word, and thus the
D-D condition evoked a weaker N400 than the D-ND one.

Although the parietal negativity could well be the N400, the co-occurring frontal negativity, which might have started since the 250-300 ms measurement window, was less certain. It should not be the PMN because the PMN effect was usually not as sustained (e.g., Phillips et al., 2006) and that the Switching x Cloze interaction (which we argued to be related to the PMN in the early measurement window) disappeared in the 350-550 measurement window.

If the frontal negativity was not the PMN, then what could it be? Studies on language switching between English and Spanish have often reported a frontal negativity, but the authors usually interpret it as a LAN and attribute its occurrence to grammatical processing induced by inflectional differences between the two languages (Moreno et al., 2002; Ng et al., 2014; van der Meij et al., 2011). An interpretation of our frontal negativity as a LAN was unlikely because Mandarin and Taiwanese, both being analytic languages, lack the kind of morpho-syntactic inflections in nouns as in English and Spanish. Instead, we argued that the frontal negativity might indicate cognitive control, as being repeatedly reported in ambiguity-related studies (Lee & Federmeier, 2006, 2009, 2012; Nieuwland, Otten, & Van Berkum, 2007; Nieuwland & Van Berkum, 2006). For example, Lee and Federmeier (2012) suggested that a frontal negativity could be associated with the suppression of competing representations of irrelevant meanings when subjects processed Noun/Verb homographs (e.g., park). In our study, the participants had to inhibit the unwanted semantic representation, the phonological representation and the language node, which were pre-activated by the sentence context but did not match those of the incoming word. Logically speaking, the inhibition should be equally strong for both D-ND and ND-D switches. However, as we described earlier, in real language use, the participants encounter ND-D switches more often than D-ND ones, when compared with their respective non-switched conditions (i.e., the ratio of switched vs. non-switched sentences is higher in ND-D vs. ND-ND than in D-ND vs. D-D). Therefore, due to their relative frequency in everyday life, an ND-D switch did not pose too much challenge for the participants, but a D-ND switch did. In addition to the relative frequency of D-ND and ND-D switches, the standardized, dominant language context also created a better prediction for the upcoming word, as mentioned earlier. Therefore, stronger inhibition was needed to suppress the more active, pre-activated representations/nodes in the dominant language, resulting in more efforts of inhibition in the D-ND condition than in the ND-D one.

In fact, research has demonstrated that cognitive control plays a crucial role in accomplishing language-switching tasks (e.g., Abutalebi et al., 2007; Abutalebi, Miozzo, & Cappa, 2000; Hervais-Adelman, Moser-Mercer, & Golestani, 2011), and
we believe that the frontal negativity found in our study might be related to the network described in Abutalebi et al.’s (2007) research, which reported a neural network consisting of the anterior cingulate cortex and the left caudate when participants heard a switch into the weaker language (i.e., the less exposed language in their study). Nevertheless, with data from 32 electrodes, we were not able to perform source localization to confirm our hypothesis. Future explorations can adopt neuroimaging techniques with both ideal temporal and spatial resolution, such as combined EEG and fMRI, to resolve this issue.

Now we will summarize the above interpretations of the PMN, N400, LPC and the frontal negativity with regard to switching direction in the context of the BIA+ model. When a bilingual hears a word in isolation, the language node and the phonological representations of both languages, along with the shared semantic representation, would be activated due to the nonselective/parallel nature of lexical access of the BIA+ model. However, when hearing a sentence, the context-relevant representations of the upcoming word would be pre-activated by the sentence context. If the incoming word is the semantically and phonologically expected word (i.e., the High-NonSwitched condition), the listener can easily process the word and integrate it into the sentence. However, if something semantically and/or phonologically unexpected is detected, then the listener would encounter difficulty and has to adjust accordingly, including activating nodes/representations of the incoming word and inhibiting pre-activated nodes/representations of the non-target word, as well as working harder to integrate the unexpected word into the current sentence. The activation of representations of the incoming word occurs within the word identification system while the inhibition and integration should appear outside the word identification system of the BIA+ model.

The detection of the unexpectedness was first revealed by the PMN and the early N400 during 250-350 ms, indexing the activity of the word identification system in the BIA+ model. These components were induced by the mismatches between the context-activated phonological representations and language nodes (PMN) as well as the semantic representations (N400) and those activated by the actual word in the word identification system. Since the dominant language context seemed to create a better prediction for the upcoming word (as discussed above), the pre-activated representations in a D-ND switch were more activated than those in an ND-D switch, and thus stronger PMN and N400 were induced in the former than the latter.

The unwanted representations/nodes needed to be inhibited, and the sustained frontal negativity, probably starting from 250-350 ms and lasting till later measurement windows, reflected such a process. It is possible that the frontal negativity reflected the activity of the task/decision subsystem in the BIA+ model.
The reason that stronger frontal negativity was observed in a D-ND switch was probably due to its relatively lower frequency in daily life compared with an ND-D switch, and/or due to the more activated status of the pre-activated language node or representations in the D-ND condition because of better prediction of the dominant language context. It is also possible that the inhibition was not only to suppress pre-activated language node and lexical representations by the context, but also to inhibit co-activated non-target lexical representations due to nonselective/parallel access to both languages. However, the BIA+ model does not assume the suppression of co-activated, non-target representations, so such inhibition cannot be discussed in light of this model.

The activation of the semantic representation and other lexical representations of the incoming word was revealed by the sustained N400, which reflects the continuing activity of the word identification system. The N400 in response to a D-ND switch was stronger than that to an ND-D one because the former requires the activation of representations and nodes in the non-dominant language, which are usually of lower resting activation level; therefore, more efforts were needed in this condition. It is possible that the co-occurring frontal negativity mentioned above may also index greater effort in the selection of the non-dominant language node and representations, but since the BIA+ model did not assume influence from the task/decision system to the word identification system due to the encapsulated nature of the latter, discussion about such selection within the BIA+ model was impossible. Future study is needed to address the association between frontal negativity and target selection and to clarify the relationships between the word identification system and the task/decision system in the BIA+ model.

Finally, the reanalysis or reintegration of the switched element into the sentence was indicated by the LPC. This sentence-level process should be controlled by systems outside those specified in the BIA+ model, or at least outside the word identification system. Therefore, the switching direction no longer exerted its effect here since the direction effect should be closely related to the activation level of nodes/representations of the dominant and non-dominant languages in the word identification system. This explains why the LPC was prominent in both the D-ND and ND-D conditions.

In sum, due to the relative frequency of the dominant and non-dominant languages in daily use, a less frequent D-ND switch was more likely to create unexpectedness of the perceived sound (as reflected by the PMN during 250-300 ms), to fail to gain benefit for lexical access (as indicated by the N400 effect), and to recruit extra resources for cognitive control (as indexed by the frontal negativity possibly starting from the 250-300 ms latency window), on top of the difficulty of
integration in switching per se (as reflected by the LPC in both switching directions). Our findings were generally in line with the predictions of the BIA+ model (Dijkstra, & van Heuven, 2002), which suggested that sentence context and resting-level of activation of the target language could both affect the word identification system and that cross-linguistic influence from the dominant language to the less dominant one was larger. Although the BIA+ model did not explicitly specify the activation level of pre-activated language node/representations in the dominant vs. the non-dominant languages, our results clearly revealed that sentence context in the dominant language provides a better/stronger prediction for the upcoming word. Also, the proclaimed modularity of the word identification system in the BIA+ model precludes discussion of the possibility of its being directly influenced by the task/decision system, whose activity was suggested to be associated with the frontal negativity in our study. Future research is needed to clarify the relationship between the two systems, especially in the inhibition of non-target representations and selection of target representations in sentence comprehension.

5. Conclusion

Our results add to the language switching literature and show that switching between languages requires more efforts than not switching at all (as shown by the LPC), and that switching from the dominant to the non-dominant direction taxes more cognitive resources than the other way around (as indicated by the PMN, stronger N400 and frontal negativity on top of the LPC), suggesting that the dominant language can provide better prediction of the phonological and semantic features of the upcoming word for bilinguals listeners.
Table 1: Example stimuli of the eight conditions. The Mandarin materials are presented in Pinyin while the Taiwanese ones are presented with the Taiwanese Romanization System. Symbols in square brackets under Mandarin and Taiwanese materials are International Phonetic Alphabet (IPA) symbols.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Cloze Probability</th>
<th>Switching</th>
<th>Context Frame Language</th>
<th>Target Frame Language</th>
<th>Example Context Frame</th>
<th>Example Target Frame</th>
</tr>
</thead>
<tbody>
<tr>
<td>H-MM</td>
<td>High</td>
<td>NonSwitched</td>
<td>Mandarin</td>
<td>Mandarin</td>
<td>Ni nuer hai nianqing, buyao gei ta taiduo</td>
<td>yali pressure [ia li]</td>
</tr>
<tr>
<td>H-MT</td>
<td>High</td>
<td>Switched</td>
<td>Mandarin</td>
<td>Taiwanese</td>
<td>[ni ny ɐ̃ hai nien tuŋ pu jao ket tʰa tʰa tʰa]</td>
<td>ap-lik pressure [ap li]</td>
</tr>
<tr>
<td>L-MM</td>
<td>Low</td>
<td>NonSwitched</td>
<td>Mandarin</td>
<td>Mandarin</td>
<td>xianjin money [ciɛn ʨin]</td>
<td></td>
</tr>
<tr>
<td>L-MT</td>
<td>Low</td>
<td>Switched</td>
<td>Mandarin</td>
<td>Taiwanese</td>
<td>hiān-kim money [hien ʨin]</td>
<td></td>
</tr>
<tr>
<td>H-TT</td>
<td>High</td>
<td>NonSwitched</td>
<td>Taiwanese</td>
<td>Taiwanese</td>
<td>ap-lik pressure [ap li]</td>
<td></td>
</tr>
<tr>
<td>H-TM</td>
<td>High</td>
<td>Switched</td>
<td>Taiwanese</td>
<td>Mandarin</td>
<td>yali pressure [ia li]</td>
<td></td>
</tr>
<tr>
<td>L-TT</td>
<td>Low</td>
<td>NonSwitched</td>
<td>Taiwanese</td>
<td>Taiwanese</td>
<td>hiān-kim money [hien ʨin]</td>
<td></td>
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<tr>
<td>L-TM</td>
<td>Low</td>
<td>Switched</td>
<td>Taiwanese</td>
<td>Mandarin</td>
<td>xianjin money [ciɛn ʨin]</td>
<td></td>
</tr>
</tbody>
</table>

“Your daughter is too young; don’t give her too much pressure (high)/money (low).”
**Table 2:** Summary of the degrees of freedom and F values of repeated measures ANOVAs for different time windows.

<table>
<thead>
<tr>
<th></th>
<th>df</th>
<th>250-350 ms</th>
<th>350-550 ms</th>
<th>600-900 ms</th>
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<td><strong>Main effect</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Cloze</td>
<td>1,21</td>
<td>11.892**</td>
<td>19.331***</td>
<td>8.631**</td>
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<tr>
<td>Context language</td>
<td>1,21</td>
<td>6.879*</td>
<td>4.381*</td>
<td>14.382***</td>
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<tr>
<td>Switching</td>
<td>1,21</td>
<td>11.507**</td>
<td>7.663*</td>
<td>1.256</td>
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<tr>
<td>Region</td>
<td>5,105</td>
<td>13.288***</td>
<td>1.813</td>
<td>2.357*</td>
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<tr>
<td><strong>2-way interaction</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cloze x Context language</td>
<td>1,21</td>
<td>3.017</td>
<td>1.136</td>
<td>1.727</td>
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<tr>
<td>Cloze x Switching</td>
<td>1,21</td>
<td>6.898*</td>
<td>2.864</td>
<td>1.655</td>
</tr>
<tr>
<td>Cloze x Region</td>
<td>5,105</td>
<td>3.472**</td>
<td>9.476***</td>
<td>10.260***</td>
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<tr>
<td>Context language x Switching</td>
<td>1,21</td>
<td>20.738***</td>
<td>24.684***</td>
<td>21.494***</td>
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<td>1.589</td>
<td>1.731</td>
<td>3.064*</td>
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<tr>
<td>Switching x Region</td>
<td>5,105</td>
<td>1.302</td>
<td>.573</td>
<td>3.458*</td>
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<td><strong>3-way interaction</strong></td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>Cloze x Context language x Switching</td>
<td>1,21</td>
<td>.610</td>
<td>1.100</td>
<td>.157</td>
</tr>
<tr>
<td>Cloze x Context language x Region</td>
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<td>.577</td>
<td>1.204</td>
<td>.488</td>
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<tr>
<td>Cloze x Switching x Region</td>
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<td>.898</td>
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<tr>
<td>Context language x Switching x Region</td>
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<td>1.242</td>
<td>.739</td>
<td>.754</td>
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<td><strong>4-way interaction</strong></td>
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<tr>
<td>Cloze x Context language x Switching x Region</td>
<td>5,105</td>
<td>1.305</td>
<td>1.326</td>
<td>1.859</td>
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</tbody>
</table>

* p < .05, ** p < .01, *** p < .005
Figure 1: Presentation of stimuli. An audio signal was presented with a fixation point on the center of a black screen to signal the beginning of a trial. Each sentence stimulus was composed of a context frame and a target frame. Electroencephalography (EEG) data were time-locked to the onset of the target frame. Twenty percent of the sentences were followed by an audio probe word, and the participants had to judge whether the probe word had occurred in the sentence by button-pressing. Once the self-paced response was made, an 1800 ms inter-trial interval would appear and the next trial began.
**Figure 2:** Grand average ERPs from 22 subjects in response to targets in the Switched and Non-switched conditions with the Mandarin and Taiwanese context, collapsed across Cloze probability: D-D (Dominant-Dominant/Mandarin-Mandarin), black; D-ND (Dominant-NonDominant/Mandarin-Taiwanese), red; ND-ND (Non-Dominant-NonDominant/Taiwanese-Taiwanese), blue; ND-D (Non-Dominant-Dominant/Taiwanese-Mandarin), green. Negativity is plotted upward.
Figure 3: Topographic maps of the switching effect (Switched – Non-switched) in different switching directions (250-950 ms, 100 ms interval). Top: D-ND (Mandarin-Taiwanese) minus D-D (Mandarin-Mandarin). Bottom: ND-D (Taiwanese-Mandarin) minus ND-ND (Taiwanese-Taiwanese). Positivity is painted in red and negativity in blue.
Figure 4: Grand average ERPs from 22 subjects in response to targets with High- and Low-cloze probability in the Switched and Non-switched context, collapsed across Context language: High-NonSwitched, black; Low-NonSwitched, red, High-Switched, blue; Low-Switched, green. Negativity is plotted upward.
**Figure 5:** Topographic maps of the cloze probability effect (Low-cloze – High-cloze) in the Non-switched and Switched contexts (250-950 ms, 100 ms interval). Top: Cloze in NonSwitched context (Low-NonSwitched minus High-NonSwitched). Bottom: Cloze in Switched context (Low-Switched minus High-Switched). Positivity is painted in red and negativity in blue.
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