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Non-selective lexical access in bilinguals is spontaneous and independent of input monitoring: Evidence from eye tracking

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ABSTRACT

Language non-selective lexical access in bilinguals has been established mainly using tasks requiring explicit language processing. Here, we show that bilinguals activate native language translations even when words presented in their second language are incidentally processed in a nonverbal, visual search task. Chinese–English bilinguals searched for strings of circles or squares presented together with three English words (i.e., distracters) within a 4-item grid. In the experimental trials, all four locations were occupied by English words, including a critical word that phonologically overlapped with the Chinese word for circle or square when translated into Chinese. The eye-tracking results show that, in the experimental trials, bilinguals looked more frequently and longer at critical than control words, a pattern that was absent in English monolingual controls. We conclude that incidental word processing activates lexical representations of both languages of bilinguals, even when the task does not require explicit language processing.

1. Introduction

It is estimated that over half of the world's population speaks multiple languages (Grosjean, 2010). Despite the common intuition that bilingual speakers can function independently in their two languages, research has shown that they cannot completely "turn off" one language while using the other. For example, when Dutch–English bilinguals read in English, words that share form and meaning in the two languages (i.e., cognates such as 'ring') are recognized faster and more accurately as compared to non-cognate words (Duyck, Assche, Drieghe, & Hartsuiker, 2007). This cognate facilitation effect suggests that lexical-semantic information in the non-target language is activated and affects the processing of the target language (Lemhofer & Dijkstra, 2004; Midgley, Holcomb, & Grainger, 2011; Van Assche, Duyck, Hartsuiker, & Diependaele, 2009). However, the origin of the cognate facilitation effect is obscured by the fact that cognates inherently have higher lexical frequency and have overlapping orthographic and phonological features between languages, which all potentially contribute to task performance. Nevertheless, other studies have shown that parallel language activation also characterizes word processing in bilinguals whose native and second languages have radically different lexical forms (e.g., Chinese and English; Moon & Jiang, 2012; Thierry & Wu, 2007; Zhang, van Heuven, & Conklin, 2011). Furthermore, this effect is not restricted to bilingual reading, but has also been found in listening (Lagrou, Hartsuiker, & Duyck, 2011; Spivey & Marian, 1999; Thierry & Wu, 2007; Wu & Thierry, 2010), speaking (Colome, 2001; Guo & Peng, 2006; Hoshino & Thierry, 2011; Kroll, Bobb, Misra, & Guo, 2008), and even sign language (Morford, Wilkinson, Villwock, Pinar, & Kroll, 2010; Shook & Marian, 2012).

The finding that language processing in bilinguals is non-selective (but see FitzPatrick & Indefrey, 2010; Rodriguez-Fornells, Rotte, Heinze, Nosselt, & Munte, 2002 for

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contrasting views) suggests that mental representations of the two languages are integrated (Dijkstra & Van Heuven, 2002; Green, 1998), a view that has been complemented by neuroimaging evidence showing cortical overlap for processing native and second languages (see van Heuven & Dijkstra, 2010, for a review). However, the demonstration of language non-selective lexical access in most previous studies has relied on explicit language tasks such as lexical decision, semantic relatedness judgment, or categorization. Hardly any research has investigated this effect in a non-linguistic context, when words are processed in an involuntary manner. As a result, it is unknown to what extent non-selective lexical access is dependent upon deliberate language processing. To fill this knowledge gap, in a recent study, we used event-related potentials (ERPs) to examine whether bilingual readers activate translations in the native language while they incidentally process words presented in their second language (Wu & Thierry, 2012). ERPs are an averaged brain signal recorded from the surface of the scalp and time-locked to a stimulus (visual, auditory, etc.) or response (button press, speech onset, etc.) of interest. The high temporal resolution (i.e., in the order of one millisecond) of ERPs affords fundamental insights into the chronometry of cognitive functions such as language processing, which is inherently fast. In the study by Wu and Thierry (2012), Chinese–English bilinguals were shown either a visual shape (i.e., a string of circles or squares) or a word of English in separate trials. They were instructed to press a given button when they saw circles, another button when the saw squares, and to withhold their response when they saw a word. In the critical condition, the Chinese translation of the to-be-ignored English word shared a phonological segment with the Chinese word for ‘circle’ or ‘square’. Although this manipulation did not affect behavioral performance, ERPs showed that an index of cognitive inhibition (the N200) was significantly increased in amplitude for critical words as compared to control words, suggesting greater involvement of the executive system. Since the study did not require participants to read the words or to engage in metalinguistic processing, the study demonstrated activation of native language translations elicited by incidental processing of words in the second language.

One practical limitation of ERPs is that eye movements generate artifacts that interfere with the measurement of relevant brain activity. To control such artifacts, in Wu's (2012) study, all stimuli were presented at the center of the screen. Thus, in the incidental word presentation trials, participants had to fixate the stimulus for a period of 500 ms, a process which may have triggered in-depth word processing despite the fact that it was to be ignored. In the present study, we overcome this limitation by using eye-tracking in an adaptation of the previous paradigm. Eye-tracking offers the full flexibility of measuring ocular responses in the context of visual displays in which task-irrelevant words can be presented amongst distracters. Here, each trial involved the presentation of a 4-item stimulus grid, scattered far enough from one another as to require eye movements during visual search. In filler trials, three of the stimuli were English words and the fourth was a target, made of circles or squares (i.e., a nonverbal visual target, Fig. 1). In the test trials, all four stimuli were words of English, one of which featured a phonological overlap with the Chinese word for ‘circle’ or ‘square’ when

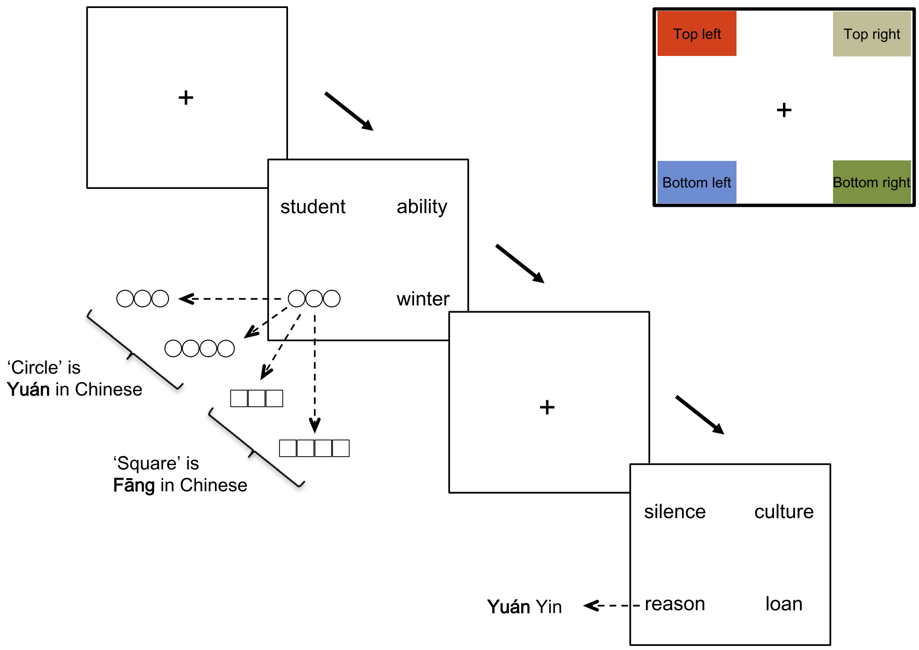

Fig. 1. Experiment structure and examples of stimuli used in filler (second screen) and experimental (fourth screen) trials. The Chinese translation for ‘Circle’ is ‘Yuán’ and that for ‘Square’ is ‘Fāng’. One of the four English words in this sample experimental trial (e.g., ‘Reason’) overlaps phonologically with either Yuán or Fāng when translated into Chinese (e.g., ‘Yuán Yin’). On the right-hand upper corner is an illustration of the ROIs.

translated in Chinese (i.e., a target-related word). Participants were instructed to press one of two keys, depending on the shape, to terminate filler trials, and to press a third key to terminate test trials where no shape was present. Since participants had control over trial termination, they were expected to look at an English word only for the time necessary to distinguish it from target shapes when scanning through the grid. The task, therefore, encompassed nothing but a simple, unbiased visual search process. Assuming that language non-selective lexical access is independent of explicit language processing effort, access to the Chinese translation of English words would interfere with the nonverbal task when translations are connected to the visual shape targets (e.g., causing longer fixation duration and more fixations; Spivey & Marian, 1999). The absence of a difference between critical and control words, together with previous literature, would suggest that language non-selective processing in bilinguals may be contingent upon explicit linguistic processing and/or individual input monitoring.

2. Method

2.1. Participants

Twenty Chinese–English bilinguals (13 females; mean age = 22, SD = 1.9) and twenty native speakers of English (11 females; mean age = 21, SD = 2.4) gave written consent to take part in the experiment approved by the ethics committee of Bangor University. Participants were right-handed undergraduate or Masters students, and had normal or corrected-to-normal vision. All bilingual participants spoke mandarin Chinese as their native language and English was their only foreign language. They began to learn English in the classroom at around 12, and at the time of testing they had spent between 42 and 48 months (mean = 45, SD = 2.0) in the UK. Bilingual participants' English proficiency was measured by the International English Language Testing System (www.ielts.org/test_takers_information/what_is_ielts.aspx) which covers four fundamental language skills (i.e., reading, listening, writing, and speaking). The current participants all had a score of 7 on a scale of 1–9, with a minimum of 6.5 on each of the four components.

2.2. Stimuli

There were a total number of 200 trials. Forty of them were experimental trials in which only English words were presented. The remaining were filler trials in which three English words and a nonverbal target (25% made of three adjacent circles, 25% made of four adjacent circles, 25% made of three adjacent squares, and 25% made of four adjacent squares). The stimulus sequence was fully randomized. English words in both the critical and filler trials were presented in 11-point Arial font, the size of which was matched to that of the target (i.e., 8 pixels, .31°). To avoid explicit interference with target shapes, none of the words were related to the English words 'circle' or 'square' either lexically (i.e., homophones or orthographic neighbors) or semantically (e.g., 'Ring' or 'Checkerboard'). In the critical trials, one of the four English words overlapped phonologically with the Chinese word for 'circle' or 'square' through Chinese translations (i.e., the experimental word; see Table 1). The other three words were control words featuring no such overlap. Experimental and control words were matched for lexical frequency, concreteness, and word length (see Table 1) as these factors might influence lexical selections in bilingual word processing (Baten, Hofman, & Loeys, 2010; Hauk, Davis, Ford, Pulvermuller, & Marslen-Wilson, 2006; Hauk & Pulvermuller, 2004; Sunderman & Kroll, 2006; Thierry & Wu, 2007). Chinese translations were verified in previous studies (Thierry & Wu, 2007; Wu & Thierry, 2010, 2012) using the "first translation" method (Tokowicz & Kroll, 2007) in which participants provide the first translation that comes to mind, cannot change their responses and skip words of which they ignore the translation. In all conditions, participants generated >90% correct translations, and there were no significant differences between conditions. The targets and experimental words appeared in all 4 screen locations with equal probability. No word was repeated.

Table 1
Stimulus characteristics and matching test results.

	Critical words	Control words	*p* values
Frequency	2469	2614	.841
Concreteness	384	374	.672
Word length	6.775	6.667	.770

2.3. Procedure

Participants were seated in a dark room at a viewing distance of 57 cm. The experiment was presented on a 21-inch calibrated CRT monitor (Mitsubishi™ DP 2060u). The visual size of the monitor was 40 × 30 degrees set at the resolution of 1024 × 768 pixels. Eye gaze was tracked monocularly using a tower mounted EyeLink 1000 eye-tracker (SR Research™). Saccades and fixations were extracted using the default system settings of the eye-tracker. After a nine point calibration, participants pressed the spacebar to start the experiment. Each trial began with a drift correction where participants had to look at a fixation cross presented at the centre of the screen and press the spacebar. Following a 500-ms blank screen, four stimuli were presented simultaneously within a 4-item grid display (see Fig. 1). The eccentricity between the central fixation point and the centre of the word was 20.5°. With their right hand, participants needed to press "1" if they saw squares, "2" if they saw circles, and "3" if they saw only words. The stimuli were left on the screen until participants made a response, and inter-stimulus-interval was one second.

3. Results

Behavioral data were analyzed using repeated measures ANOVA with trial type (experimental *versus* filler) as the within-subject factor and group (English controls *versus* Chinese–English bilinguals) as the between-subject factor.

We found a significant main effect of trial type on reaction time, $F(1, 38) = 36.389$, $p < .001$. No effect of group, $F(1, 38) = .873$, $p = .356$, or interaction, $F(1, 38) = 2.952$, $p = .094$, was found. Follow-up analysis showed that both English, $t(19) = 8.701$, $p < .001$ and bilingual participants, $t(19) = 4.000$, $p < .001$ took longer to respond to experimental than filler trials. There was a near significant difference between English ($M = 1516$; SE = 68) and bilingual ($M = 1722$; SE = 140) participants in the experimental trials, $t(19) = -1.325$, $p = .059$. The two groups of participants had similar reaction times in filler trials (English participants: $M = 1233$; SE = 47; bilingual participants: $M = 1213$; SE = 46), $t(19) = .310$, $p = .758$. Analysis of error rates showed the same pattern as that found for reaction times: A significant main effect of trial type $F(1, 38) = 26.898$, $p < .001$, no effect of group $F(1, 38) = .372$, $p = .546$, and no interaction $F(1, 38) = 1.342$, $p = .254$. Follow-up analysis showed that both English, $t(19) = 3.563$, $p = .002$, and bilingual participants, $t(19) = 4.425$, $p = .001$, made less errors in experimental than filler trials. Between group comparisons showed similar performance in experimental (English participants: $M = 0.99$; SE = 0.01; bilingual participants: $M = 0.98$; SE = 0.01, $t(19) = .375$, $p = .710$) and filler (English participants: $M = 0.95$; SE = 0.01; bilingual participants: $M = 0.96$; SE = 0.01, $t(19) = -1.020$, $p = .314$) trials. Response accuracy in both experimental and filler trials was over 90% in both groups, indicating that participants successfully performed the task. Reaction times and eye movement data were based on correct trials only and all participants were included in the analysis.

Eye movement data were analyzed by examining mean gaze duration and fixation frequency per trial per Region Of Interest (ROI). We used 4 equally sized ROIs (160 by 300 pixels) centered on each word (see Fig. 1). The eye movement analysis was performed for experimental trials only (40 trials), in which the three control ROIs were averaged together and values are reported per trial. Mean gaze duration (sum of fixation dwell times per trial) was analyzed using a repeated-measures ANOVA with word status (critical *versus* control) as the within-subject factor and group (English control *versus* Chinese–English bilinguals) as the between-subject factor. We found a significant main effect of word status, $F(1, 38) = 9.310$, $p = .004$, no significant effect of group, $F(1, 38) = 3.034$, $p = .09$, and a significant interaction between word status and group, $F(1, 38) = 9.036$, $p = .005$. Pair-wise comparisons further showed that bilingual participants spent more time look-

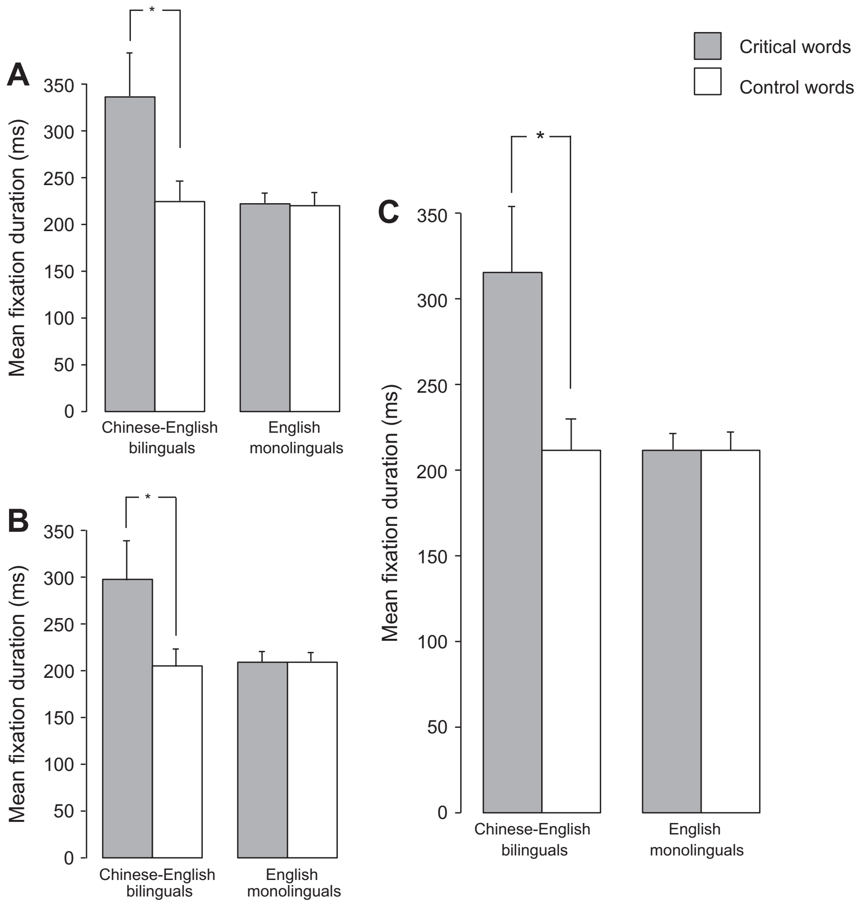

Fig. 2. Total gaze duration in the first half (A), second half (B), and over the entire experiment (C) for the Chinese–English bilingual and the native English monolingual groups. Bars represent mean fixation duration and error bars represent standard error. An asterisk indicates a significant difference ($p < .05$).

ing at critical than control words, t (19) = 3.046, $p < .007$, whilst English participants showed comparable mean gaze duration in the two conditions, t (19) = 0.211, $p = .835$ (see Fig. 2). Analysis of mean fixation frequency (average number of fixations per trial) showed the same pattern of results as the mean gaze duration: A significant effect of word status (see Fig. 3), F (1, 38) = 6.678, $p = .014$, no effect of group, F (1, 38) = .564, $p = .457$, and a significant interaction between the two factors, F (1, 38) = 4.431, $p = .042$. Follow-up analysis showed that, while bilingual participants looked more frequently at critical than control words, t (19) = 2.361, $p = .029$, the two conditions did not differ significantly in English controls, t (19) = 2.004, $p = .06$.

To determine whether the above effects developed over the course of the experiment, we conducted a time-bin analysis comparing the first and second half of the experiment. Paired-sample t-test performed on the data from bilingual participants revealed an increase in mean gaze duration when comparing critical with control words in both the first, t (19) = 3.277, $p = .004$, and the second period, t (19) = 2.125, $p = .047$. No significant difference between conditions was found in either of the two epochs in the English group ($ps > 0.1$). However, analysis of the fixation frequency showed a significant difference only in the first epoch t (19) = 2.689, $p = .015$, but not the second t (19) = 1.824, $p = .084$, in the bilingual participants. No effect on fixation frequency was found in either epoch in the English controls ($ps > 0.1$).

A repeated-measures ANOVA was also performed on first fixation durations (average of first fixation duration within the ROI) with word status (critical *versus* control) as the within-subject factor and group (English control *versus* Chinese–English bilinguals) as the between-subject factor. We found a nearly significant effect of word type F (1, 38) = 3.966, $p = .054$, a significant group effect F (1, 38) = 4.631, $p = .038$, and a significant interaction between the two factors F (1, 38) = 9.369, $p = .004$. Follow-up analysis showed a significant difference between critical and control words in bilingual participants (mean for critical words = 205; SE = 10; mean for control words = 187; SE = 5), t (19) = 2.637, $p = .016$. The same

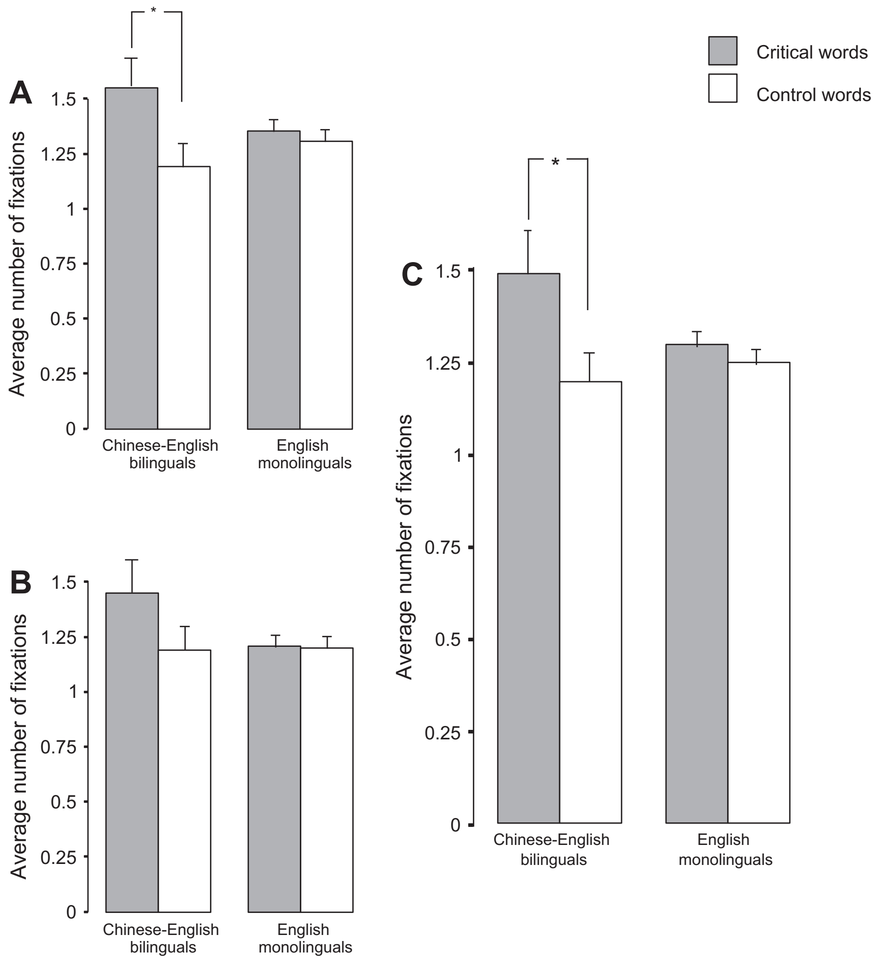

Fig. 3. Mean fixation frequency in the first half (A), second half (B), and over the entire experiment (C) for the Chinese–English bilingual and the native English monolingual groups. Bars represent mean fixation frequency and error bars represent standard error. An asterisk indicates a significant difference ($p < .05$).

comparison in the English participants failed to yield a significant difference (mean for critical words = 175; SE = 5; mean for control words = 179; SE = 5), t (19) = −1.864, p = .078.

An F2 analysis (average over items) was also carried out on the mean gaze duration and fixation frequency. A repeated-measures ANOVA with word status (critical *versus* control) as the between-subject factor and group (English control *versus* Chinese–English bilinguals) as the within-subject factor showed a significant main effect of group, F (1, 158) = 71.3, $p < .001$, and word status, F (1, 158) = 28.109, $p < .001$, on mean gaze duration and a significant interaction between the two variables, F (1, 158) = 60.288, $p < .001$. Independent sample t-tests showed that bilingual participants had longer mean gaze duration on critical (M = 313; SE = 8) than control words (M = 222; SE = 7), t (158) = 6.931, $p < .001$. In English participants, mean gaze duration was comparable between critical (M = 221; SE = 8) and control words (M = 218; SE = 4), t (158) = .487, p = .627. Analysis of fixation frequency showed the same pattern: a significant main effect of group, F (1, 158) = 12.418, $p < .001$, a main effect of word status, F (1, 158) = 20.144, $p < .001$, and a significant interaction between the two factors, F (1, 158) = 24.142, $p < .001$. Fixation frequency was higher on critical (M = 1.48; SE = .04) than control words (M = 1.20; SE = .03) for the bilingual participants, t (158) = 5.235, $p < .001$. No significant variation in fixation frequency was found in English participants (mean for critical words = 1.28; SE = .03; mean for control words = 1.23; SE = .02), t (158) = 1.502, p = .135.

4. Discussion

The present study used eye-tracking to examine automatic cross-language activation in bilinguals engaged in a non-linguistic, visual perceptual task. The experimental manipulation failed to elicit significant behavioral differences between groups, as was the case in several previous studies involving the same subtle cross-language manipulation (e.g., Thierry & Wu, 2007; Wu & Thierry, 2010). There was also no between-subject difference in the filler trials, suggesting that the two groups did not adopt different experimental strategies. Analysis of eye movement data (i.e., total gaze duration, first gaze duration, and fixation frequency), however, showed that bilingual participants looked more frequently[1] and longer at critical words as compared to control ones, whereas the two conditions yielded no significant difference in the control group of English monolinguals (see Figs. 2 and 3). Importantly, in the experimental trials, participants had to check every English word presented because no visual shape target was present. We contend that the interference effect observed in the bilingual group can only be explained by implicit activations of Chinese translations. One important aspect of this experiment is that filler trials (involving a nonverbal target) were four times as frequent as experimental trials (only words). This design led the participants to believe that they were taking part in an experiment on visual perception rather than language processing as they did not need to read or process the words more than is needed to distinguish them from a string of circles or squares.

To further confirm that the observed effect was not due to a covert manipulation of awareness or a response strategy developed over the course of the experiment, we compared eye-tracking results in the first and second half of the experiment. A significant interference underpinned by Chinese translation in the critical word condition was found in both periods. Indeed, during the debriefing procedure at the end of the experiment, bilingual participants were asked if they had noticed any relatedness between the words and the shapes or among the words themselves. No participant was able to report the relatedness in the Chinese translations. Then the participants were shown the verbal stimuli used in the experiment with their Chinese translations. They again confirmed that they were not aware of this manipulation during the experiment.

The finding that bilinguals activated translations in the native language when they incidentally read words in their second language supports psycholinguistic models assuming language non-selective access (Dijkstra & Van Heuven, 2002; Green, 1998). It also helps explain two phenomena that are less well understood. The first is that sentence context does not fully inhibit activation of the non-target language (Duyck et al., 2007; Schwartz & Kroll, 2006; Van Assche et al., 2009). According to the BIA model (Dijkstra & Van Heuven, 1998), contextual factors, such as that provided by a sentence, constrain lexical access in a top-down fashion and enable bilinguals to operate in a language-selective mode. We argue that non-selective lexical access depends fundamentally on bottom-up activation. Since this effect survives in a non-linguistic processing context, semantic or (linguistic) contextual manipulations may only modulate, but not entirely eliminate, this effect. However, it is worth noticing that the BIA + model (Dijkstra & Van Heuven, 2002), a refined version of the BIA model, posits that word identification in bilinguals is not fully influenced by the task/decision system. Although both models are based on explicit language processing contexts (e.g., reading), assumptions of the BIA + model are more compatible with the current findings as it highlights the bottom-up nature of bilingual word processing.

The second phenomenon is the finding of non-selective lexical access in bilingual toddlers. In a recent study, Von Holzen and Mani (2012) examined German–English bilingual toddlers, aged between 1.5 and 3.5 years old, using a passive word recognition task, in which auditory English words and visual words of German were presented one after the other in three conditions: phonologically related, phonologically related through translations, and unrelated. Results showed that, as compared to the control condition, explicit phonological relatedness facilitated recognition but phonological relatedness through translations impeded it, both effects being taken as evidence of

[1] English control participants displayed a trend of increased fixation frequency for the critical as compared to control words, while gaze duration was highly comparable for the two conditions. Since the performance of English monolinguals could not possibly be influenced by Chinese translations, this difference must have been caused by irrelevant factors, which may have also contributed to the performance of the bilingual group. Therefore, gaze duration, rather than fixation frequency, might be a more reliable dependent variable for the experimental manipulation.

cross-language activation. However, the critical difference between adults and toddlers is that the latter do not actively perceive words as linguistic inputs, because they cannot be instructed to do so. In Von Holzen and Mani (2012)'s study, visual word recognition of toddlers was measured by monitoring their spontaneous eye movements on a screen where German words were displayed following the auditory presentation of English words. Therefore, the findings can only be fully accounted for by assuming non-selective lexical access (1) at the beginning of bilingual development and (2) independent of an explicit language task.

5. Conclusion

We examined incidental language processing in bilinguals using a visual perception task. Eye-tracking data shows that bilinguals activated translation equivalents in the native language, which were not presented in the experiment. Such implicit effect, found when the participant is fully in control of filtering the input, shows that language non-selective access in not conditional upon lexical information being actively processed for meaning (e.g., during a semantic task) but even when only superficial scanning is required, i.e., when in-depth processing of the input is not necessary. This evidence establishes non-selective lexical access as a very robust effect in bilinguals. Future studies will explore the neural mechanism that regulates this effect.

Table 1 shows mean values for frequency (Brysbaert & New, 2009), concreteness (Coltheart, 1981), and word length. The *p* values are results of independent sample *t*-tests, which have been used to compare critical and control words for each of the three variables.

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