

CROSS-LANGUAGE NEGATIVE PRIMING FROM
UNATTENDED NUMBER WORDS: EXTENSION TO
A NON-ALPHABETIC LANGUAGE

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Abstract

In selective attention tasks, the efficiency of processing a target stimulus in a given trial is often influenced by what happens in a previous trial. When a to-be-attended target on a current trial (the probe trial) matches the ignored or inhibited distractor on a previous trial (the prime trial), a response to the target is typically delayed compared with when the two stimuli are not associated with one another. This phenomenon is called the *negative priming* (NP) effect. Although there have been many studies demonstrating the factors that influence the manifestation of the NP effect, most of these experiments used the traditional paradigm, in which the target and distractor are presented simultaneously in both the prime and probe trials. These studies explore how target selection is achieved when the target is presented concurrently with one or multiple distractor stimuli in a display.

The experiments reported in this thesis used a recently developed new paradigm, the NP paradigm under rapid serial visual presentation, or NP under RSVP (Wong, 2012), to explore target selection among temporally separated stimuli. In RSVP presentation, each stimulus is presented very briefly and at the same spatial location. In the present study, each trial couplet consisted of a prime and a probe stream. Each stream included a target, a unique coloured distractor, and several task-irrelevant neutral stimuli. Whereas the neutral stimuli were always letters, in different experiments, the target and distractor could be digits, number words in English, or number words in Chinese. The critical manipulation was the relationship between the probe target and the preceding prime distractor, which could be

unrelated (the Control condition) or matched (the IR condition). When they were matched, they could be in the same language or in different languages.

In four experiments, I explored the factors that might influence the manifestation of the NP effect under RSVP. In Experiment 1, a baseline experiment, the prime distractor was a digit, and it was identical in form to the probe target. A significant NP effect was found. In Experiment 2, the prime distractor was an English number word, but the probe target was a digit. A significant NP effect was found in accuracy, indicating that the NP under RSVP could be found even when the relationship between the prime distractor and probe target was conceptual rather than identical. In Experiment 3, the target and distractor were shown in two different representational forms. In the prime trial, the distractor was a Chinese number word, but the target was a digit. In the probe trial, the distractor was a digit, but the target was a Chinese number word. A significant NP effect was once again found, suggesting that participants could shift quickly from one representational form (digit) to another (Chinese number word) between the prime and probe trials and still show NP.

Experiment 4 was a cross-language NP experiment with Chinese-English bilinguals. In half the trials (the L1-to-L2 trials), the prime distractor was a Chinese number word while the probe target was its English translation equivalent. In the other half of the trials (the L2-to-L1 trials), the prime distractor was an English number word while the probe target was its Chinese translation equivalent. A significant NP effect was found in the L1-to-L2 trials, but not in the L2-to-L1 trials. Taken together, these results extended the finding of previous research under RSVP.

They also provided additional evidence for the revised distractor inhibition account of NP (Tipper, 2001).

Chapter 1 Cross-Language Negative Priming Phenomenon

In the mid-1800s, Hermann von Helmholtz first measured the propagation speed of neural signals, showing a finite velocity (Schmidgen, 2002). This implies that what we see or hear is slightly delayed relative to the presence of external objects. Since then, researchers have sought to determine and interpret the time lag between the onsets of external events and the onset of a response to the task relevant stimulus (i.e., reaction time or response latency). Applying a recently developed rapid serial visual presentation-based negative priming (NP) paradigm (see details below; Wong, 2012), the present thesis uses response latency as an index of processing efficiency to explore the effects of within- and cross-language priming from an ignored or inhibited distractor on a subsequent target.

In the traditional NP paradigm, participants see two sequentially presented displays: a prime display followed by a probe display, each consisting of a target and a distractor. In one condition, the ignored repetition condition (IR), the target in the probe display is the distractor in the prime display. In another condition, the neutral condition (Control), the target in the probe display is a new stimulus that does not appear in the prime display. Responses to the target in the probe display are typically slower and/or more error-prone in the ignored repetition condition than in the neutral condition, demonstrating the NP effect. The NP effect indicates that a successful prime selection involves the processing of the distractor to some extent.

What might Cause Negative Priming?

Dalrymple-Alford & Budayr (1966) were the first to examine the behavioural consequence of ignoring a preceding distractor on a subsequent target. In some conditions, participants were shown a list of Stroop words (Stroop, 1935) whose meaning was inconsistent with the colour of the ink in which the word was written (e.g., the word “RED” written in green ink) and the task was to name the colour of the ink as quickly and as accurately as possible. In one condition, the control condition, the current correct response was not associated with the preceding stimulus. In another condition, the related condition, the current correct response (i.e., the name of the colour) matched the meaning of the preceding word that needed to be suppressed. The participants were slower and made more errors in the related condition than in the control. This result indicates that task irrelevant information was inhibited for colour naming. (See Appendix A for more detail.)

A decade later, Neill (1977) extended Dalrymple-Alford & Budayr (1966) research on selective inhibition. Instead of seeing a list of Stroop stimuli all at once, the participants in Neill’s study saw one Stroop word at a time. Neill confirmed the original finding of in the 1960s when the response was vocal naming (i.e., the same as that used in Dalrymple-Alford & Budayr), but not when the response was manual key-pressing. This prompted him to conclude that the manifestation of the inhibitory aspect of selective attention depends on the experimental context.

The term “negative priming” was coined by Tipper (1985), who introduced a new paradigm by using separate target and distractor objects instead of Stroop colour words. Importantly, he manipulated both the identity and the categorical relationship

between the distractor in a preceding trial (i.e., the prime distractor) and the target in a subsequent trial (i.e., the probe target). In one experiment (Experiment 2), participants saw two superimposed line drawings of different colours on each trial. The prime and probe trials were either unrelated to one another (i.e., the control condition) or were associated. When they were associated, the prime and probe trials could have the same target object (the attended repetition condition), different target objects in the same category (the attended semantic condition), the probe target identical to the prime distractor (the ignored repetition condition), or the probe target in the same category but physically different from the prime distractor (the ignored semantic condition). Both positive and NP effects were found.

Compared to the control condition, RT was faster in the attended repetition and the attended semantic conditions and slower in the ignored repetition and the ignored semantic conditions. Moreover, there was no difference in the magnitude of the NP effect between the latter two conditions. Based on this and subsequent experiments (e.g., Tipper & Driver, 1988), Tipper proposed that the internal representation of the distractor is processed at a representational level beyond specific physical features and that the NP effect results from the delayed processing of the activated post-categorical representation. In addition, the delay is caused by a de-coupling process separating the unwanted representation of a distractor from generating its overt response. This variant of the selective inhibition account has been shown to be consistent with the results of a number of studies (Driver & Tipper, 1989; Neill, Lissner, & Beck, 1990; Yee, 1991).

In two 1992 papers, Neill and colleagues (Neill & Valdes, 1992; Neill, Valdes, Terry, & Gorfein, 1992) proposed an alternative episodic retrieval account of NP based on their observation that NP decays over time, and that the pattern of decay is consistent with the decaying curves of memory trace. For example, in one experiment, the participants in Neill & Valdes (1992) were shown a string of letters, with two of them being the task relevant letters, and the task was to determine whether the two letters were the same or different. On some trials, one or both target letters (the probe target) were the same as the flanking distractor letter in the previous trial (the prime distractor). On other trials, the probe target was not associated with the prime distractor. The critical manipulation was the response-to-stimulus interval (RSI) between the prime and probe trials, which varied from 500 msec to 8000 msec. Significant NP effects were found only when the RSI was less or equal to 2000 msec showing that memories decay, a result consistent with the episodic memory retrieval account.

More recently, Tipper (2001) expanded his original selective inhibition account of NP to incorporate the results of long-term NP effects. In the original proposal, NP was thought to be caused by the response de-coupling process separating task irrelevant representational activation from accessing the response generation mechanism. Although this account can explain short-term NP effects, it has difficulty to explain long-term NP effects such as those reported by DeSchepper & Treisman (1996), who showed their participants nonsense shapes and found NP effect for probe stimuli those corresponding prime stimuli were shown one month earlier. In the new account, the viewing of a probe target can trigger the retrieval of

the inhibitory status associated with the prime distractor when the two stimuli match, and this in turn causes the delay in responding to the probe target.

Although there is still debate about the underlying mechanisms that give rise to the NP effect, the selective inhibition and episodic retrieval accounts are not necessarily exclusive to one another. Which mechanism is used can depend on the specific interference control demand, and NP can be caused by one or both mechanisms within the same paradigm, such as in a location or an identity NP task. (See Appendix B for a common notation system of these tasks.)

In a location-based NP task, the selective inhibition or the episodic retrieval mechanism may be needed to control the interference being generated from attending multiple stimulus locations of a prime and probe trial. Both trials often display a target position that requires a locating response, and at least one nontarget position that is task irrelevant. When a probe location is the same as the one that was task irrelevant on the prime trial, the locating response to this position is often slowed, manifesting spatial NP.

The same mechanisms may also be deployed to control the interference being created from attending the identities of multiple objects. In such identity NP task, both trials display a target object that requires identification, and at least one nontarget that does not. When the presentation of a probe target in trial n is the same as a distractor in trial $n-1$, responses to the probe target are often slowed regardless of its position, showing identity NP.

Moreover, the selective inhibition or the episodic retrieval mechanism is also needed to control the interference being driven by processing semantically associated

stimuli, such as in recognising the word “cat” after identifying “dog” or their pictures. In such semantic relatedness-based NP task, both trials display different objects that require to be ignored or identified. A person must identify the word “desk” and ignore the word “cat” on a prime trial. When its subsequent probe target to be identified is a physically different but categorically same stimulus (e.g., the picture of a dog) as the one that was ignored (i.e., the word “cat”), its identification is often slowed as well, resulting in semantic NP. Understanding the semantic NP relies on appreciating the underlying visual-linguistic interference control mechanisms. Two NP studies provided preliminary evidence of this kind.

Initial Support for Cross-Language Negative Priming

Cross-language NP studies began with (Fox, 1996), who used English-French and French-English bilinguals to examine cross-language NP from ignored distractors. In one experiment (Experiment 2), the participants performed a digit categorization task (odd or even) in the prime trial followed by a lexical decision task in the probe trial. The prime display consisted of a single digit at fixation flanked by two identical words, one above and the other below the digit. The probe display consisted of either a word or a nonword at fixation. When the probe target was a word, it was either unrelated or related to the flankers in the prime trial. Significant cross-language NP was found when the prime distractor was the translation equivalent of the probe target.

Furthermore, the magnitude of the NP effect was larger when the prime distractor was in L1 and the probe target in L2 than the other way round. These

results are important, because they not only provide evidence supporting the view that the lexical knowledge of bilinguals is represented in a common, language-independent memory system (Kroll & Sholl, 1992; Kroll & Stewart, 1994), but also provide evidence for the revised selective inhibition account of the NP effect (Tipper, 2001).

Additional evidence for cross-language priming was shown by Neumann et al. (1999) with English-Spanish bilinguals. In Experiment 2 of their study, the participants saw two English words in the prime trial, one being the target and the other the distractor, and the task was to name the target word verbally. In the probe trial, the target was either a Spanish word or a nonword while the distractor was an English word, and the task was lexical decision. When the probe target was a word, it could be the Spanish translation equivalent of the prime target (the attended repetition condition), the Spanish translation equivalent of the prime distractor (the IR condition), or a new word unrelated to the prime distractor (the Control condition). The results showed a significant NP effect, indicating cross-language NP. Interestingly, no positive priming effect was found in the attended repetition condition compared with the control condition.

The finding of the NP effect in the absence of a positive priming effect is interesting. This pattern of data indicates that cross-language NP is perhaps a more sensitive diagnostic measure of bilinguals' inter-language interference control relative to the cross-language positive priming. It provides support for a global and local inhibitory account of NP and for the view that bilinguals store their language representations in a shared representational system.

NP under Rapid Serial Visual Presentation

So far, the aforementioned NP effects have been demonstrated primarily in a paradigm where targets and distractors are presented simultaneously within the same trial. More recently, Wong (2012) combined the traditional NP paradigm with rapid serial visual presentation (RSVP) typically used in studies that explore the temporal limitation of attentional selection (Dux & Marois, 2009; Raymond, Shapiro, & Arnell, 1992). In a typical experiment with RSVP, each stimulus is presented very briefly at the same spatial location in rapid succession, usually at a rate from 6 to 20 items per second. There are two targets in each trial. The task is to identify the first targets (T1) and to indicate the presence or absence of the second target (T2), and the interval between the targets is varied across trials. It has been shown that when T2 is presented within 150 msec to 500 msec after T1, participants often miss the presentation of T2. This phenomenon is called Attentional Blink (AB). AB underscores the temporal constraint of attentional allocation. It indicates that when attention is engaged in the processing of a stimulus and when the processing is still underway, attention cannot be reliably reallocated to another stimulus that requires processing.

To understand how target selection is accomplished when the target and distractor overlap spatially but are separated temporally, Wong (2012) developed a new NP paradigm, in which the prime and probe trial each consisted of a stream of stimuli presented sequentially in rapid succession at the same spatial location. He termed this paradigm the NP under RSVP.

Two experiments were reported in Wong (2012). In Experiment 1, participants saw two streams of stimuli, each with a symbol to indicate the beginning and the end of the stream. Within each stream, five alphanumeric stimuli were presented. Three of them were digits, and they were the nontargets. The other two were letters, one being the target and the other the distractor. Whereas the distractor had a unique colour, the rest of the stimuli all had the same colour. The temporal location of the target was unpredictable, and it could appear either before or after the distractor, with one nontarget in between. The probe target was either identical or unrelated to the prime distractor, and the participant's task was to make a speeded response to the identity of the target letter. A robust NP effect was found regardless of whether the distractor appeared before or after the target, and the magnitude of the NP effect was similar between the two types of trials.

In Experiment 2, the colour of the target and the distractor was switched such that the target had a unique colour while the distractor had the same colour as the other stimuli in the stream. Significant NP effects were again found in both the distractor-before-target and target-before-distractor trials, although the magnitude of the NP effects was substantially reduced from that of Experiment 1. These results are largely similar to what one would expect to find in studies that use the traditional NP paradigm, suggesting that the underlying mechanisms may be similar in the two paradigms with respect to interference control.

Overview of the Present Experiments

Wong (2012) extended the scope of NP research, and his new paradigm allows researchers to investigate temporal attentional selection when the distractor is presented closely in time with the target. However, because the probe target was identical to the probe distractor in his study, the locus of selective inhibition is unclear. It could be at a physical level, at a conceptual level, or both.

The experiments presented in this thesis investigated temporal attentional selection under several situations. The design of the experiment was modelled after Wong (2012). However, instead of using letters for the target and the distractor and using digits for the nontargets, I used letters for the nontargets and digits or number words for the target and/or the distractor in different experiments (see Appendix C for more detail). This change is necessary because in addition to explore NP between identical stimuli, I also investigated NP at the conceptual level and over language boundaries (English-to-Chinese and Chinese-to-English). As in Experiment 1 of Wong's study, the distractor was red while the target and the other stimuli were black. The distractor could appear before or after the target, and the relationship between the probe target and the prime distractor was systematically manipulated. The participant's task was to identify the target as quickly and as accurately as possible.

Experiment 1 was a baseline experiment. The goal was to examine whether Wong's results could be generalized to a different set of stimuli. As in Wong's study, the probe target was either identical or unrelated to the prime distractor. Based on Wong's results, a significant NP effect was predicted.

Experiment 2 investigated NP when the probe target differed from the prime distractor in physical form but not in meaning. As in Experiment 1, the target and distractor were both digits in the probe trial, but they were both English number words in the prime trial. If NP is observed again, this would indicate either that the prime distractor was inhibited at a conceptual level, or that the “do-not-respond” tag occurred at a semantic level.

In Experiments 1 and 2, the target and distractor within each trial were either two digits or two number words. In Experiment 3, this was changed. The target and distractor were shown in two different representational forms. In the prime trial, the distractor was a Chinese number word, but the target was a digit. In the probe trial, the distractor was a digit, but the target was a Chinese number word. This would require participants to shift between two different representational forms (i.e., digit, and logographic Chinese number form) within each trial. If NP was found, this would provide initial evidence showing the NP under RSVP with logographic symbols.

Experiment 4 was a cross-language NP experiment with Chinese-English bilinguals. A new factor was introduced. In half the trials (the L1-to-L2 trials), the prime distractor was a Chinese number word while the probe target was its English translation equivalent. In the other half of the trials (the L2-to-L1 trials), the prime distractor was an English number word while the probe target was its Chinese translation equivalent. Regardless of the pattern of data found, this experiment will have important implications for NP theories (i.e., the selective inhibition account vs.

the episodic retrieval account) and for bilinguals' visual-linguistic interference control mechanisms.

Chapter 2 Experiment 1

Experiment 1 was designed to model after Wong's Experiment 1 (2012). The main difference between Wong's experiment and the present one was the stimuli. The digits were task-relevant in this experiment rather than task-irrelevant as those in Wong's. This change was necessary because if NP could be found, the result of this experiment would serve as a baseline for subsequent experiments, including the cross-language one presenting the same digits in the Chinese and English characters for Chinese-English bilinguals.

Method

Participants. Forty-three volunteers, aged from 18 to 40, were recruited. Some of them ($n = 20$) were native Chinese speakers who could speak English, and their participation was compensated with either a \$15.00 ($n = 8$) or a \$10.00 ($n = 12$) voucher depending on whether or not they submitted their IELTS scores and participated in a language background survey¹. The rest of them were undergraduate students (the majority being non-Chinese) recruited from the participant pool of the University of Canterbury Psychology Department. They took part in the experiment

¹ IELTS stands for International English Language Testing System, which is an international standardised English language proficiency examination. The IELTS data were collected for another series of experiments that are not reported here.

for course credits. All the participants were naïve to the purpose of this experiment, and they reported to have normal or corrected to normal vision.

Apparatus and stimuli. A 19-in Philips LCD monitor, driven by a Linux laptop computer (Torvalds, 1997), presented all the stimuli at the refresh rate of 60 Hz. Psychopy (Peirce, 2007), an open source software package, synchronised the stimuli generation and data collection. Responses were registered through a mechanical gaming keyboard.

Stimuli were presented in an RSVP paradigm. In each RSVP stream, participants saw three uppercase letters intermixed with two Arabic digits presented rapidly in the centre of the LCD screen on a grey background. The stream began with the symbol “@”, followed by the five items described above (i.e., three letters and two digits), and ended with the symbol “#” (see Figure 1). Of the five alphanumeric stimuli, the two numbers always appeared in the 3rd and 5th position, and they were equally likely to be “3”, “4”, “6”, or “7”. The other three letter stimuli were randomly selected from the set “A, B, E, F, G, H, J, K, M, N, P, R, S, W, X, Y, and Z”. They were equally likely to appear in the other three positions (i.e., the 1st, 2nd, and 4th position). All the alphanumeric stimuli were shown in the Arial font. At a viewing distance of approximately 60cm, each stimulus subtended a visual angle of 0.96° x 0.57°.

All these stimuli were black except for one of the two numbers, which was red. This red number was the critical distractor. It was equally likely to appear in either the 3rd or the 5th position in both the prime and probe trials. The other number was

always black. This was the target, and it always appeared in the other position that was not occupied by the red distractor. Participants were instructed to respond to the target as quickly and as accurately as possible. In the rest of this thesis, I will refer to the red stimulus as the distractor, the black number or number word as the target, and the letters as the neutral stimuli.

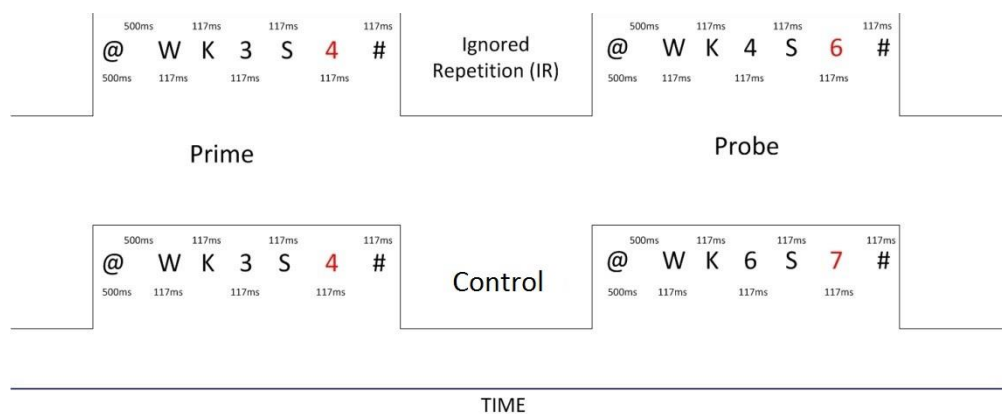


Figure 1. Examples of the RSVP streams used in Experiment 1, with the ignored repetition condition (IR) on the top showing the prime distractor “4” became the probe target. The control condition is illustrated at the bottom without such relation.

Design. The experiment used a within-participants design. This was to minimise the impact of inter-participant variability across the different experimental conditions. There were three factors: (a) the position of the prime distractor in the prime trial (the prime at 3rd or 5th location, or Prime D1 vs Prime D2); and (b) the position of the probe distractor in the probe trial (the probe distractor at the 3rd or 5th location, or Probe D1 vs Probe D2), and (c) the prime-probe relationship (the prime distractor and the probe target were identical or different, or IR vs Control). The

three factors were independently manipulated. There were as many Prime D1 and D2 trials. The same was true for the Probe D1 and D2, and IR and Control trials.

Procedure. After signing off the consent form, the participants were informed about the general procedure of the experiment. The instruction was in both verbal and written forms. After the introduction, they completed three brief practice sessions while the experimenter was on site. The practice sessions were different from the experimental session in feedback and item presentation rate.

For the first two practice sessions, there was immediate feedback after each response. The word “Correct” followed a correct response while the phrase “Oops, that was incorrect” was shown when the response was incorrect. The item presentation rate increased by decreasing the unit presentation time for each item across these sessions, starting from 160 msec/item in the first session to 140 msec/item in the second one. In the last session, the rate was set the same as that in the experimental session (i.e., 117 msec/item). No feedback was provided in the last practice session, simulating what was to occur in the real experiment.

Before the real experimental session started, the experimenter left the room after answering the participant’s inquiries if there was any. Each participant initiated the experiment by pressing a key on the keyboard. Each trial began with a warning fixation “@” for 500 msec, followed by a blank interval of 500 msec. The distractors and targets were then presented one at a time for 117 msec at the same location in the centre of the screen. Each stream ended with a post-mask “#” of 117 msec.

The participants were instructed to respond to the black number while ignoring all the other stimuli. Because the colour black was associated with the target and the neutral stimuli (i.e., letters), the participants could not use colour alone to identify the target. Instead, they would have to use both colour and form for target identification. They were also instructed to respond as quickly and as accurately as they could by pressing one of four labelled keys: “e”, “r”, “i” and “o” for responses “3”, “4”, “6”, and “7” respectively. The responses were made by the left middle and index fingers for responses “3” and “4”, and by the right middle and index fingers for responses “6” and “7”.

The experiment consisted of 384 pairs of prime-probe trials. After every 96 pairs of trials, the participants had a chance to take a break. The experiment resumed when they pressed any key after the break. Altogether, there were three breaks during the entire experimental session. At the end of it, the experimenter came back for debriefing. The whole experiment (practice plus experimental trials) took about 45 minutes to complete.

Results

Figure 2 shows the mean correct RTs for the probe trials of Experiment 1, and Table 1 shows the error rates. The mean RTs were the response latencies of the correct probe trials given that the corresponding prime trials were also correct. Thus, the RT analyses were limited to those probe trials in which the participants correctly identified both the prime and probe targets. Moreover, the correct RTs were constrained by a latency range between 200 msec and 2,000 msec. In this

experiment, 98.9% of the correct RTs were within this range. The data of seven participants with over 30% error rates were not included in further analyses. The alpha level was set at .05.

Table 1

Mean error rates (% error) for the Ignored Repetition and Control Condition in Experiment 1. Between-participants standard errors are in the parentheses.

	Prime D1		Prime D2	
	Probe D1	Probe D2	Probe D1	Probe D2
IR	15.2 (1.7)	12.5 (1.3)	17.0 (2.0)	12.4 (1.4)
Control	14.6 (1.8)	11.4 (1.3)	15.6 (1.5)	10.6 (1.4)

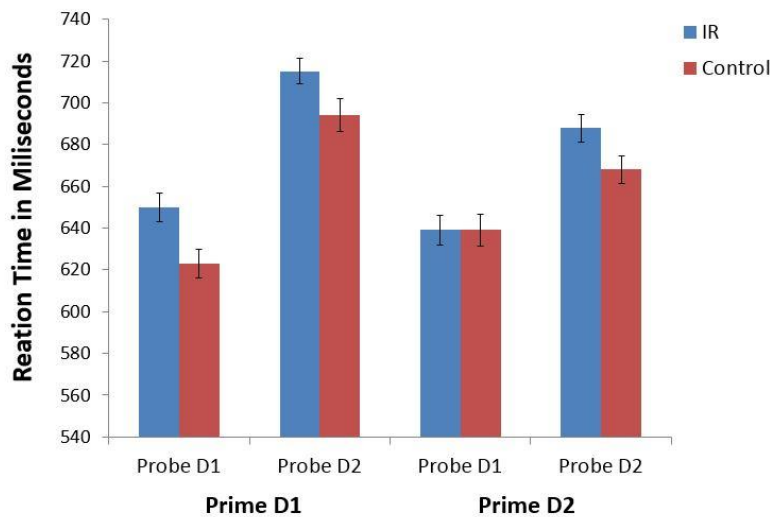


Figure 2. Reaction times as a function of the positions of the distractor in the prime and probe trials. Error bars represent the within-participants standard errors.

The mean RT data were submitted to a 2 x 2 x 2 repeated-measure ANOVA with the prime distractor position, the probe distractor position, and the prime-probe relationship as the three factors. The main effect of prime distractor position was significant, $F(1, 35) = 12.99, p < .001, \eta_p^2 = .27$, indicating slower responses when the prime distractor was at D1 position ($M = 671$ msec) rather than when it was at D2 position ($M = 658$ msec). In addition, there was a significant main effect of probe distractor position, $F(1, 35) = 37.86, p < .001, \eta_p^2 = .52$, indicating slower responses when the probe target preceded the probe distractor ($M = 691$ msec) rather than after it ($M = 638$ msec). More importantly, there was also a significant NP effect, $F(1, 35) = 11.15, p < .01, \eta_p^2 = .24$, indicating slower responses in the IR condition ($M = 673$ msec) than in the Control condition ($M = 656$ msec). The interaction between the stimulus positions in the prime and probe trials was also significant, ($F(1, 35) = 6.28, p < .05, \eta_p^2 = .15$). This result indicates that the difference in RT between the trials when the probe target was presented before the probe distractor was larger in the Prime D1 condition (68 msec) than in the Prime D2 condition (39 msec).

As in RTs, a similar 2 x 2 x 2 repeated-measures ANOVA was conducted on the accuracy data. The main effect of probe distractor position was significant, $F(1, 35) = 9.34, p < .01, \eta_p^2 = .21$. Interestingly, the direction was opposite to that found in the RTs. Whereas the participants were slower when the probe target was at D2 than at D1 position, they made *fewer* errors in the former condition ($M = 11.7$ % error) than in the later condition ($M = 15.6$ % error). The main effect of priming was marginally significant, $F(1, 35) = 3.49, p = .07, \eta_p^2 = .09$. Consistent with the RTs, the error rate was higher in the IR condition ($M = 14.3$ % error) than in the Control

condition ($M = 13.1$ % error). No other main or interactive effects reached significance.

Discussion

Several aspects of the data are worth noting. First, there was a robust NP effect. As in Wong's (2012) study, the participants in the present experiment showed significant NP in RT. In addition, they also showed a marginally significant NP effect in accuracy. These results generalized Wong's result, and provided converging evidence for the manifestation of NP in RSVP streams.

Second, responses to the probe target were slower when the prime distractor was at D1 position compared with when it was at D2 position. This result was likely caused by the shorter interval between the responses to the prime and probe targets when the prime distractor was at D1 position (i.e., prime target at the 5th position in the RSVP stream) rather than when it was at D2 position (i.e., prime target at the 3rd position in the RSVP stream). With the prime target at the 5th position in the D1 condition, the participants had less time to replenish the depleted resources used in responding to the prime target, and this in turn resulted in longer response latencies to the probe target.

Third, responses to the probe target were slower when it was before rather than after the probe distractor. There may be two reasons for this. One is related to the reason stated above, i.e., participants had shorter interval between the prime and probe responses when the probe target preceded the probe distractor. The other is the

uncertainty of the stimulus when the target was shown before the distractor. In this condition, there was no way to know whether the stimulus at the 3rd position would be a target or a distractor. So, participants had to wait until the stimulus appeared before they could decide whether it was a stimulus to be responded to. Once the stimulus was presented, they then had to determine, based on its identity, which response key they should press.

In contrast, participants did not need to wait for the appearance of the probe target when it was shown after the probe distractor, because they knew that it would be a target stimulus. This is because the probe distractor had always appeared before the onset of the probe target. The knowledge that the target would occur next could help participants engage in motor preparation, allowing them to respond quickly as soon as the stimulus appeared. This may also explain the speed accuracy trade-off found in the main effect of probe target position (also see, Wong, 2002). While the preknowledge of the target in the Probe D1 condition allowed participants to respond quickly, it also caused them to make more errors, for they were less likely to spend time to identify the stimulus before they pressed the response key. I will discuss this issue more in the general discussion section.

Finally, it is worth noting that there was no interaction between NP and the position of the target/distractor in either the prime or probe trials. This result indicates that the distractor presented before or after the target may be processed to the same degree. This is likely due to the fact that the distractor in the present study

was a color singleton presented at the center of the screen, and that its salience made it difficult to ignore regardless of its temporal position in the RSVP stream.

As introduced before, Experiment 1 was modelled after Wong's study (2012). However, the NP effect was much larger in Wong's experiment (66 msec) than in the present one (17 msec). This difference may be caused by different methodologies used in the two studies. In Wong's study, the target could occur at any one of the five positions. In contrast, for Experiment 1 reported here, the target could only appear at either the 3rd and 5th position. The greater position uncertainty in Wong's study could induce participants to apply stronger selective inhibition, resulting in a larger NP effect. Furthermore, participants processed digits as targets in this experiment whereas the single letters were the targets of Wong's study. In addition, the data preparation was different. For this experiment, the RTs consisted of the correct responses within a range of 200 msec to 2,000 msec whereas in Wong's (2012) study the incorrect prime trials were excluded. All these differences may affect the magnitudes of the NP effects.

Another difference between the experiment of Wong (2012) and the present experiment was the finding of a significant main effect of prime distractor position in Experiment 1, but not in Wong's study. In Experiment 1, the probe response latencies were longer in D1 than in D2 condition. In other words, when the prime targets were the last stimuli, the subsequent probe responses were slower. As mentioned before, this result may indicate attentional limitations. It is also in line with previous research on attentional dwell time (Duncan, Ward, & Shapiro, 1994).

The lack of such a position-related significant effect in Wong's experiment could be due to his adoption of a flexible target presentation format, as evidenced by the much longer RTs in his experiment (i.e., over 1000 msec) than in Experiment 1 (i.e., between 600 msec to 700 msec).

Chapter 3 Experiment 2

In Experiment 1, the target and distractor were identical in the prime and probe trials. They were both digits. In Experiment 2, the target and distractor in the probe trial remained to be digits. However, they were changed to English number words in the prime trial (e.g., “THREE” instead of “3”). The goal of the experiment was to investigate whether NP would still be found in an RSVP paradigm when the critical stimuli in the prime and probe were the same in meaning but different in form.

Previous research that used the traditional NP paradigm has reported inconsistent results regarding NP across symbolic domains. On the one hand, Tipper & Driver (1988) provided evidence showing that the NP effect can be observed between pictures and words. Yee (1991) also reported NP between semantically related words when the prime display consisted of stimuli selected from word association norms, such as priming “dog” and testing its aftereffect with the word “cat”. Moreover, cross-language NP effects have been found in a number of studies (Fox, 1996; Neumann et al., 1999). These results demonstrate that inhibition, which gives rise to the NP effect, occurs at a semantic level rather than at a physical level (for reviews, see Fox, 1995; May, Kane, & Hasher, 1995).

On the other hand, there is also evidence showing that NP does not occur across different domains. For example, MacLeod, Chiappe, and Fox (2002) found no evidence of NP for semantically related words. No NP effects were observed by Lammertyn and Fias (2005; 2005) for numbers, either. These and other studies (e.g., Duscherer & Holender, 2002; Koelewijn, Van der Burg, Bronkhorst, & Theeuwes,

2008) suggest that although NP can be obtained reliably when the prime distractor and probe target were identical; when they are different, there are boundary conditions under which NP effects do not occur. The goal of Experiment 2 was to explore whether the NP effect observed in Experiment 1 could be generalized to Experiment 2, in which the prime distractor and probe target differed in form but not in meaning.

Method

Twenty-one undergraduates were recruited for this experiment. Most of them came from the psychology department's participant pool. Four of them were recruited through other means (i.e., sign-up websites or flyers). They received either course credits or a \$10 voucher for their participation. All were naïve to the purpose of the experiment and reported to have normal or corrected to normal vision.

The same set of apparatuses was used for presenting stimuli and collecting responses. Except for the four number words (i.e. "THREE", "FOUR", "SIX", and "SEVEN") that replaced the digits in the prime trials, the stimuli were the same as those used in Experiment 1(See Figure 3). Once again, all the stimuli were presented in the Arial font. At a viewing distance of approximately 60cm, the number words subtended a visual angle ranging from $0.96^\circ \times 1.71^\circ$ to $0.96^\circ \times 2.85^\circ$. All the other aspects of the experiment were identical to those in Experiment 1.

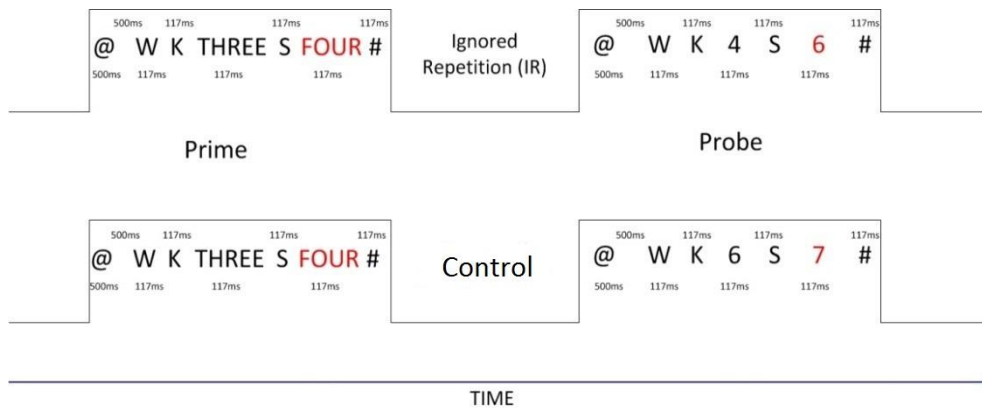


Figure 3. Examples of the RSVP streams used in Experiment 2.

Results

Figure 4 and Table 2 show the mean correct RTs and the error rates of the probe trials, respectively. The data were treated in the same way as in Experiment 1. Six participants' data were excluded from further analyses because each showed an error rate of over 30%. Once again, only correct RTs ranging from 200 msec to 2,000 msec were analysed. Over 96% of the RTs were within this range.

Table 2

Mean error rates (% error) for the Ignored Repetition and Control Condition in Experiment 2. Between-participants standard errors are in the parentheses.

	Prime D1		Prime D2	
	Probe D1	Probe D2	Probe D1	Probe D2
IR	15.3 (2.4)	13.8 (1.5)	15.4(1.9)	13.0 (1.7)
Control	12.1 (2.1)	12.5 (1.7)	12.9 (2.0)	11.7 (1.6)

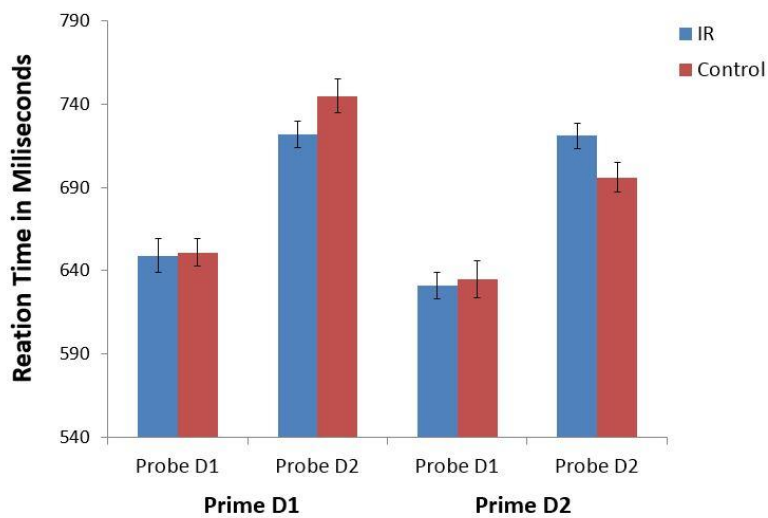


Figure 4. Reaction times as a function of the positions of the distractor in the prime and probe trials. Error bars represent the within-participants standard errors.

As in Experiment 1, the mean RT data were submitted to a 2 x 2 x 2 repeated-measure ANOVA. The main effect of prime distractor position was significant, $F(1,$

14) = 16.07, $p < .01$, $\eta_p^2 = .53$, indicating slower responses when the prime distractor was at D1 position ($M = 692$ msec) than at D2 position ($M = 671$ msec). Moreover, there was a significant main effect of probe distractor position, $F(1, 14) = 41.44$, $p < .001$, $\eta_p^2 = .75$, indicating slower responses when the probe target was shown before the probe distractor ($M = 721$ msec) rather than after it ($M = 641$ msec). These results, which were also found in Experiment 1, showed that the participant took longer to respond to the probe target when the prime and probe targets were closer in time than when they were further apart, and that the preknowledge of the presentation of the target in those trials when it appeared after the distractor reduced the response time to the target.

In addition to these main effects, NP interacted with prime distractor position, ($F(1, 14) = 5.89$, $p < .05$, $\eta_p^2 = .29$). Whereas the participants showed some degree of NP (IR-Control = 11 msec) when the prime distractor was at the D2 position, they showed positive priming (IR – Control = -12 msec) when the prime distractor was at the D1 position. However, subsequent Tukey's HSD tests showed that neither effect was significant ($p > .2$ in both cases).

A 2 x 2 x 2 repeated-measures ANOVA was also conducted on the error rates. The main effect of NP was significant, $F(1, 14) = 5.55$, $p < .05$, $\eta_p^2 = .28$, indicating more errors on the IR trials ($M = 14$ % error) than the Control trials ($M = 12$ % error). No other main or interactive effects were significant.

Discussion

In Experiment 2, the participants responded to a number word in the prime trial but to an Arabic digit in the probe trial. Although the prime and probe shared little physical resemblance, a significant main effect of NP was found in accuracy, although the effect was absent in RTs. The difference in manifestation between the RT and accuracy data is consistent with previous research showing that accuracy and speed may tap different cognitive operations (Pashler, 1989; Wong, 2002). The finding of the significant NP effect in accuracy is also consistent with previous studies that observed NP across different representational forms (Tipper & Driver, 1988; Yee, 1991). It also extended the results of Experiment 1 and Wong's (2012) study by providing evidence that NP could occur at a semantic level in an RSVP paradigm.

It is likely that the salience of the prime played an important role in the manifestation of NP in Experiment 2. Unlike the traditional NP paradigm in which the prime distractor is typically shown concurrently with the target and often at a peripheral location, in the present study, the prime was displayed alone at the center of attentional focus. Being a color singleton also ensured that the prime would attract attention and evoke strong reactive inhibition (Wyatt & Machado, 2013a, 2013b), resulting in the NP effect.

The selective inhibition account can explain the NP effect found in Experiment 2 quite readily so long as we assume that inhibition can occur at a semantic level, which has been shown by many previous studies using the traditional paradigm (Fox,

1996; Tipper & Driver, 1988; Yee, 1991). The result can also be explained by the episodic retrieval account. According to this account, NP is caused by the conflicting response tags in the prime and probe trials. Because the task was digit identification, it was likely that the participants used verbal coding. This means that the processing of the stimuli was probably at a conceptual level. If the processing was at a conceptual level, the “do-not-respond” tag could be at the same level. Thus, even though the prime and probe differed in form in Experiment 2, the result can be explained by both the selective inhibition account and the episodic retrieval account.

Experiment 3

Experiment 3 investigated whether Chinese-English bilingual participants could shift quickly from one representational form (digit) to another (Chinese number word) between the prime and probe trials and still show NP effects. In Experiments 1 and 2, the target and distractor were shown in the same representational form within each trial (i.e., both were digits or English number words). In Experiment 3, they were from two different representational forms. In the prime trial, the distractor was a Chinese number word, but the target was a digit. In the probe trial, the distractor was a digit, but the target was a Chinese number word (See Figure 5). Thus, although the prime distractor and the probe target were identical in form (i.e., both were Chinese number words), from a participant's perspective, to respond to the target in the prime and probe trials, they would have to shift between two different representational forms.

Because shifting between different representational forms of numbers could be challenging, participants could choose to keep both representational forms active throughout the experiment instead of inhibiting one representational form in the prime trial and the other one in the probe trial. Adopting this response strategy would lead to positive priming instead of NP. Alternatively, they could still choose to inhibit the distractor within each trial, and this would result in NP. Thus, a NP effect would indicate that the participants inhibited the distractor or tagged a “do-not-respond” to it in the prime trial and that such preceding events still influenced their

probe responses even in the case where the logographic Chinese number words were presented for identification.

Method

Twenty-two volunteers were recruited for this experiment. Most of them were native Chinese speakers who enrolled in the University of Canterbury as international students whereas others were recruited through advertisements. All of them were Chinese-English bilinguals. Each of them received a \$10.00 voucher for their participation. As before, all were naïve to the purpose of the experiment and reported to have normal or corrected to normal vision.

The same set of apparatuses as in the previous experiments was used for presenting stimuli and collecting responses. Unlike Experiment 1, in which the target and distractor were shown in the same representation form within each trial, in Experiment 3, they were shown in two different representation forms: a digit and a Chinese number word (i.e., “三”, “四”, “六”, and “七”, which correspond to “3”, “4”, “6”, and “7”, respectively). Specifically, in the prime trial, the target was always a digit and the distractor a Chinese number word; in the probe trial, the target was always a Chinese number word and the distractor a digit. Once again, all the stimuli were presented in the Arial font. At a viewing distance of approximately 60cm, the number words subtended a visual angle ranging from $0.96^\circ \times 0.57^\circ$. All the other aspects of the experiment were identical to those in Experiment 1.

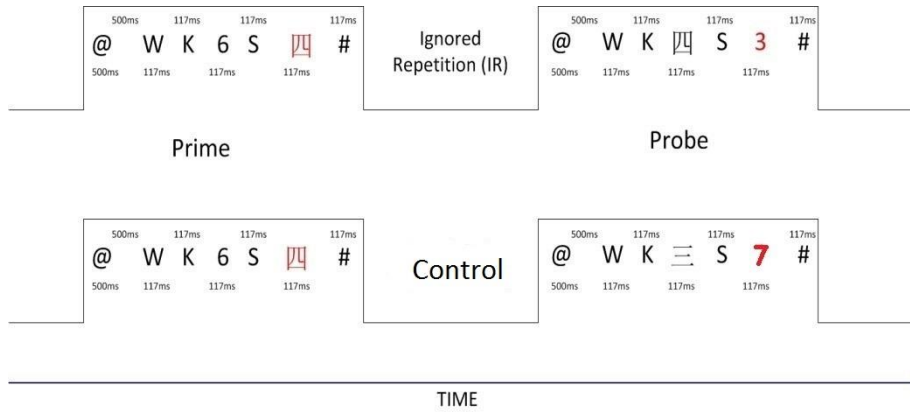


Figure 5. Examples of the RSVP streams used in Experiment 3.

Results

Figure 6 and Table 3 show the mean correct RTs and the error rates of the probe trials, respectively. The data were treated in the same way as before. Five participants' data were excluded from further analyses because each showed an overall error rate of over 30%. For the rest of the participants, 99% of their correct RTs were within the range between 200 msec and 2,000 msec.

Table 3

Mean error rates (% error) for the Ignored Repetition and Control Condition in Experiment 3. Between-participants standard errors are in the parentheses.

	Prime D1		Prime D2	
	Probe D1	Probe D2	Probe D1	Probe D2
IR	5.9 (.9)	5.4 (1.0)	8.8 (1.2)	4.8 (1.0)
Control	4.9 (.6)	5.5 (1.2)	7.9 (0.9)	3.9 (.9)

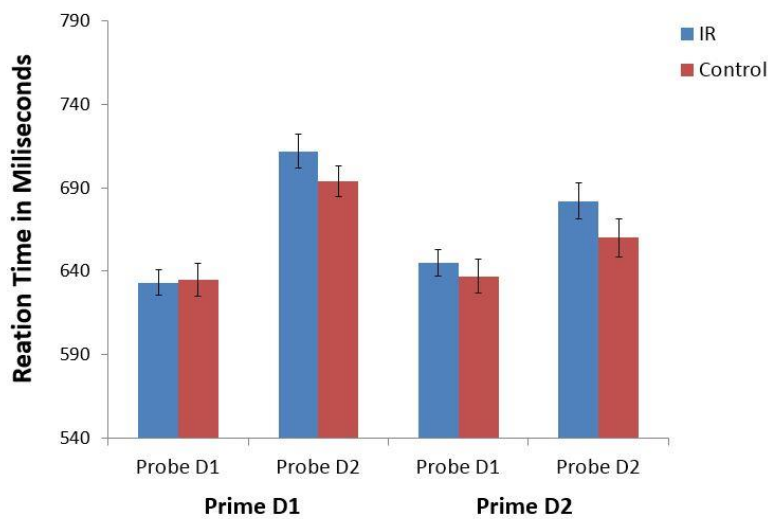


Figure 6. Reaction times as a function of the positions of the distractor in the prime and probe trials. Error bars represent the within-participants standard errors.

As before, the mean RT data were submitted to a 2 x 2 x 2 repeated-measure ANOVA. There was a significant NP effect, $F(1, 16) = 5.56, p < .05, \eta_p^2 = .26$,

indicating slower responses in the IR trials ($M = 668$ msec) than in the Control trials ($M = 656$ msec). Once again, the main effect of prime distractor position was significant, $F(1, 16) = 4.63, p < .05, \eta_p^2 = .23$, indicating slower responses when the prime distractor was at D1 position ($M = 669$ msec) rather than at D2 position ($M = 656$ msec). The main effect of probe distractor position was also significant, $F(1, 16) = 11.42, p < .005, \eta_p^2 = .42$, indicating slower responses when the probe target was presented before ($M = 687$ msec) rather than after ($M = 637$ msec) the probe distractor.

In addition, the interaction between the stimulus positions in the prime and probe trials was significant, $F(1, 16) = 17.04, p < .005, \eta_p^2 = .52$. As in Experiment 1, the participants took longer to respond to the probe target when it appeared before rather than after the probe distractor, but this difference was larger when the prime distractor was at D1 position (a difference of 69 msec) rather than when it was at D2 position (a difference of 30 msec). No other main effects or interaction effects were significant.

A $2 \times 2 \times 2$ repeated-measures ANOVA was also conducted on the accuracy data. The results showed a main effect of probe target position, $F(1, 16) = 6.08, p < .05, \eta_p^2 = .27$. The participants made more errors when the probe target followed the probe distractor ($M = 6.9\%$ error) rather than preceded it ($M = 4.9\%$ error). As in Experiment 1, this result was in the opposite direction to the result in RT, which showed faster responses in the former condition than in the latter condition. Finally, the interaction between the stimulus positions in the prime and probe trials was

significant ($F(1, 16) = 10.41, p < .01, \eta_p^2 = .39$). Whereas the error rates were comparable regardless of probe target position when the prime distractor was at D1 position, the error rate was 4% larger when the probe target appeared after the probe distractor when the prime distractor was at D2 position. Once again, this result was contrary to the RT data. In RT, the difference between the T1 and T2 conditions was larger when the prime distractor was at the D1 position than when the prime distractor was at the D2 position.

Discussion

The most important finding of Experiment 3 is the significant NP under RSVP effect with logographic Chinese number words. Thus, the number identification-based NP effects have been demonstrated in three experiments with three visual forms: digits, English number words, and logographic Chinese number words. Collectively, they seem to suggest a post-perceptual locus of the NP under RSVP effect. The suggestion agrees with Tipper's (1985) concept of semantic NP. Furthermore, the result is also in agreement with another study that reported a traditional Chinese Stroop Colour word-based NP effect (Chao, 2011).

Tipper's (1985) semantic NP, Chao's (2011) Stroop task-based NP and the observed NP under RSVP effects converge to suggest that the underlying interference control process may be associated with some common brain mechanisms, especially for vision. The suggestion is not surprising because the light contrast patterns of objects or words were known to be projected to the retina since the era of Hermann von Helmholtz (Wade & Finger, 2001). In the 19th century,

Helmholtz popularized the idea of seeing the eyes as the optical instrument for transducing light. However, the understanding of the functional roles of the visual information processing pathways after the retinal transduction came much later (Cohen et al., 2000; N. Kanwisher, McDermott, & Chun, 1997; Mishkin, Ungerleider, & Macko, 1983). Its implications for visual interference control with respect to NP have been mentioned before (Fox, 1995), but still have not been discussed at its appropriate level for the NP under RSVP.

As indicated by Fox (1995), the ventral visual pathway of our visual system is largely responsible for the identity and semantic NP whereas the dorsal pathway for the spatial NP. As the neuroanatomical evidence shows that along the ventral pathway the activation of the occipital visual word form cortical area (VWFA) forward feeds the inferior temporal cortical area (TE) that is largely responsible for categorising and integrating complex visual forms (See Appendix D for detail). These cortical areas are also connected with other anterior and posterior cortical areas by feedback links for associative elaboration.

Roughly speaking, the ventral pathway is more sensitive to nonspatial information given that the VWFA is largely tuned by the stroke patterns (Cohen et al., 2000) whereas the TE is the final stage of the occipital-temporal processing that is suitable for representing complex categorical patterns (Grill-Spector & Malach, 2004). Thus, such common brain mechanisms may give rise to the identity or semantic NP effect. Because the ventral pathway is a memory-supported system, the

need of shifting attention between two types of online representations (i.e., visual memories) also becomes understandable.

However, this initial finding was only produced with the identical Chinese number words, the interference control could be implemented early at the visual perceptual level or late at their semantic associative level. Without new data, it would be hard to tell these possibilities apart. To this end, numbers' cross-language translation equivalents readily provide a new testing vehicle.

In comparison with non-linguistic bars or dots, the visual stimuli of translation equivalents have a common meaning component; and its interpretation can be associated with different character stroke contours or edges. To illustrate, a Spanish word *estrella* can be paired with the English word *star*. The construction of these single letters determines the words' visual forms that produce their retinal images. In turn, the retinal images drive the ventral visual pathway for word perception and associative elaboration.

Moreover, the same English word *star* can also be paired with a logographic Chinese word “星”. Thus, the same meaning (i.e., one of the perceived light dot seen in the night sky originated from an astronomical object) can be spelled or written in different character stroke patterns. Their construction determines another structurally different retinal image relative to the aforementioned retinal images of the English or Spanish word. Whether the NP under RSVP can still be observed with these translation equivalents is still unknown. Given initial cross-language NP evidence and the common representational basis for word perception, cross-language

NP under RSVP was expected. As in Experiment 1, there was speed-accuracy trade-off with regard to the target probe position, which is discussed later.

Chapter 4 Experiment 4

Experiment 3 established that Chinese bilingual participants could shift quickly from responding to a digit in the prime trial to responding to a Chinese number word in the probe trial and showed NP when the prime distractor and probe target were identical Chinese number words. In Experiment 4, participants still responded to a digit in the prime trial and to a number word in the probe trial. However, the prime distractor differed from the probe target. In half the trials, the prime distractor was a Chinese number word (e.g., “三”) and the probe target was the corresponding word written in English (e.g., “THREE”). In the rest of the trials, the two stimuli switched their roles.

The goal of Experiment 4 was to test the cross-language NP. Specifically, it investigated whether Chinese bilingual participants would show NP effects when the prime distractor and probe target were in different languages, and whether the magnitude of the NP effects would be different depending on whether the prime distractor was written in the participants' dominant language (i.e., Chinese, or L1) or in a non-dominant language (i.e., English, or L2). Based on previous research (Fox, 1996; Neumann et al., 1999), it was hypothesized that the bilingual participants would show a significant NP effect when the prime distractor was in Chinese. However, when it was in English, the effect would reduce or disappear.

Method

Twenty-two Chinese-English bilinguals were recruited. Most of them were native Chinese speakers who enrolled in the University of Canterbury as international students. The others were local bilinguals recruited through advertisements. Each of them received a \$10.00 gift voucher for their participation. They were naïve to the purpose of this experiment and reported to have normal or corrected to normal vision.

The apparatus and stimuli were identical to those in the previous experiments. The experiment used a 2 x 2 x 2 x 2 within-subjects design. In addition to the three factors used in the previous experiments (i.e., prime distractor position, probe distractor position, and prime-probe relationship), a new factor was introduced (see Figure 7). The new factor was the languages used in the prime and probe trials (i.e., from prime distractor in Chinese to probe target in English vs. from prime distractor in English to probe target in Chinese, or L1-to-L2 vs L2-to-L1). This was to see whether there was any asymmetry in the magnitude of NP between L1-to-L2 and L2-to-L1, as shown by Fox (1996). There were as many L1-to-L2 trials as there were L2-to-L1 trials, and the two types of trials were presented randomly within a block. As before, all the factors were manipulated independently. The entire experiment lasted for about 45 minutes.

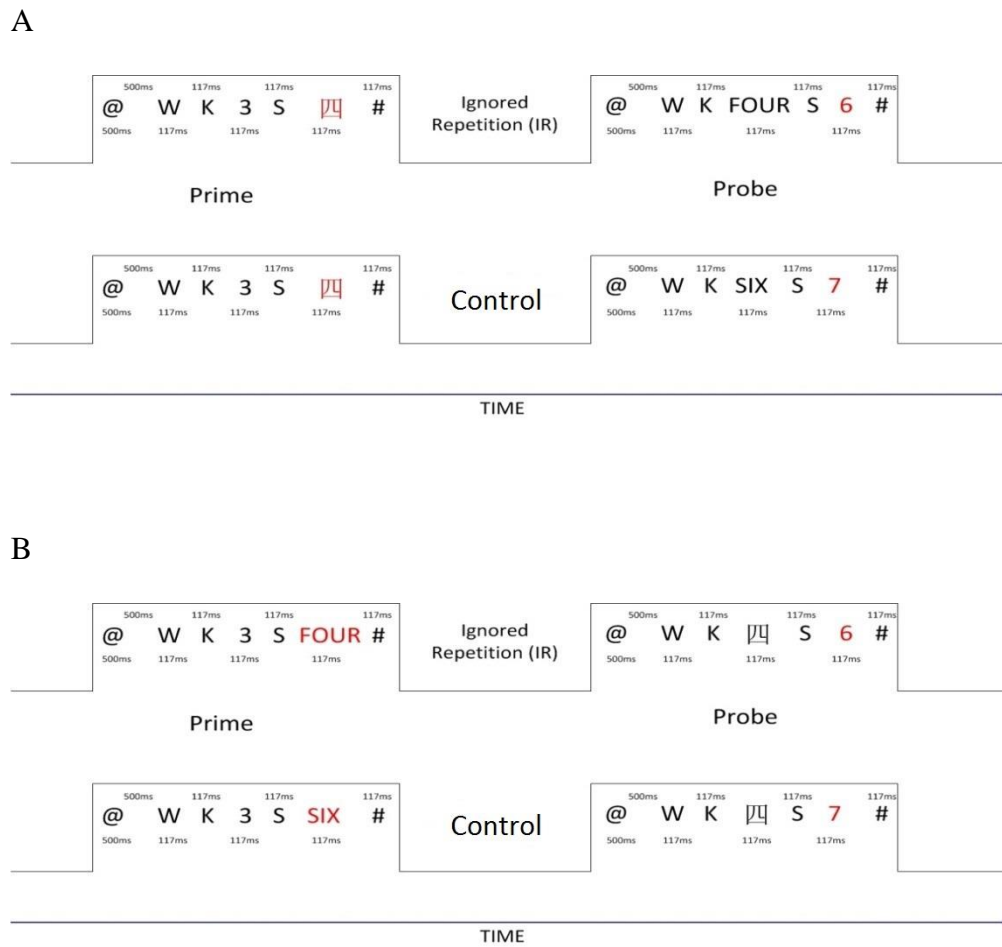


Figure 7. Examples of 2 pairs of the cross-language prime-to-probe trials used in Experiment 4. All stimuli were black except for the critical distractor, which was red. A. Examples of L1-to-L2 trials. In these trials, the prime distractor was in the participants' dominant language (i.e., Chinese) and the probe target in the non-dominant language (i.e., English). B. Examples of L2-to-L1 trials. In these trials, the prime distractor was in the participants' non-dominant language (i.e., English) and the probe target in the dominant language (i.e., Chinese).

Results

The data were treated in the same way as in the previous experiments. Seven participants' data were excluded due to high error rates, which exceeded 30 % in one or more conditions. Table 4A and Figure 8A show the error rates and the mean correct RTs of the L1-to-L2 trials. Table 4B and Figure 8B show the error rates and the mean correct RTs of the L2-to-L1 trials.

A 2 x 2 x 2 x 2 repeated-measures ANOVA with language, prime distractor position, probe distractor position, and prime-probe relationship was conducted on the mean RTs. The main effect of prime distractor position was significant, $F(1, 14) = 10.12, p < .01, \eta_p^2 = .42$, indicating slower responses when the distractor was at D1 position ($M = 657$ msec) rather than at D2 position ($M = 642$ msec). In addition, there was a significant main effect of probe distractor position, $F(1, 14) = 4.6, p < .05, \eta_p^2 = .25$, indicating slower responses when the probe target was shown before the probe distractor ($M = 659$ msec) rather than the other way around ($M = 640$ msec). The NP effect was marginally significant, $F(1, 14) = 4.19, p = .06, \eta_p^2 = .23$, indicating slower responses in the IR condition ($M = 653$ msec) than in the Control condition ($M = 645$ msec).

The interaction between stimulus positions in the prime and probe trials was also significant, $F(1, 14) = 13.12, p < .01, \eta_p^2 = .48$. This result indicates that whereas there was no difference in RTs regardless of the probe target position when the prime distractor was at D1 position, when the prime distractor was at D2 position, probe RT was longer when the probe target preceded the probe distractor

rather than after it (a difference of 31 msec). Furthermore, the three way interaction among the prime distractor position, the probe distractor position, and the prime-probe relationship was also significant, $F(1, 14) = 8.01, p = .01, \eta_p^2 = .36$, indicating that the magnitude of the NP effect was a function of the stimulus position in the prime and probe trials. No other effects were significant.

Table 4A

Mean error rates (% error) for the Ignored Repetition and Control Condition on the L1-to-L2 Trials in Experiment 4. Between-participants standard errors are in the parentheses.

	Prime D1		Prime D2	
	Probe D1	Probe D2	Probe D1	Probe D2
IR	6.8 (1.8)	2.7 (1.2)	5.0 (1.1)	3.2 (1.1)
Control	4.8 (1.8)	3.1 (.9)	5.5 (1.5)	2.7 (1.0)

Table 4B

Mean error rates (% error) for the Ignored Repetition and Control Condition on the L2-to-L1 Trials in Experiment 4. Between-participants standard errors are in the parentheses.

	Prime D1		Prime D2	
	Probe D1	Probe D2	Probe D1	Probe D2
IR	9.7 (2.3)	3.9 (0.8)	7.6 (1.8)	5.0 (1.4)
Control	9.3 (1.9)	6.4 (1.5)	8.9 (1.7)	4.2 (0.9)

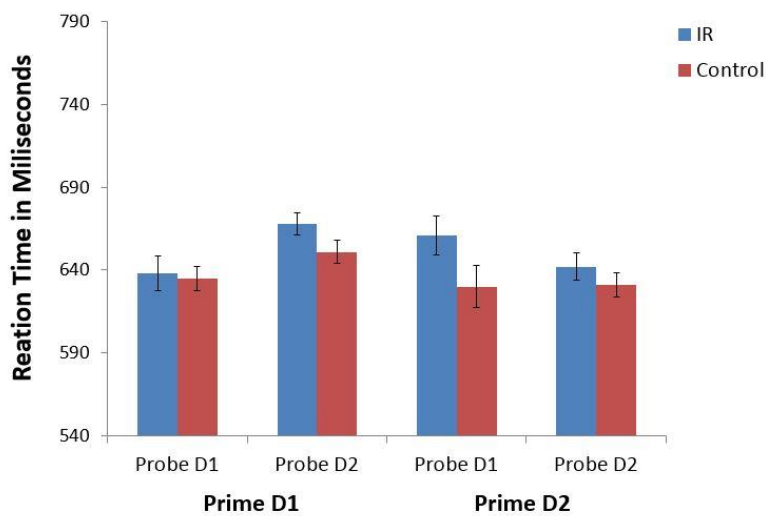


Figure 8A. Reaction times as a function of the positions of the distractor in the prime and probe trials. The graph depicts the data from the L1-to-L2 trials. Error bars represent the within-participants standard errors.

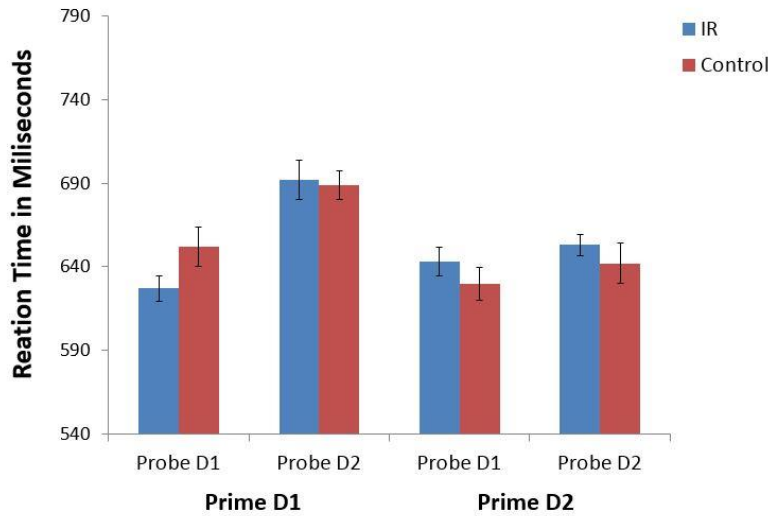


Figure 8B. Reaction times as a function of the positions of the distractor in the prime and probe trials. The graph depicts the data from the L2-to-L1 trials. Error bars represent the within-participants standard errors.

Although the interaction between language and NP was not significant, $F(1, 14) = 2.78, p = .12, \eta_p^2 = .17$, from a theoretical perspective, it is important to examine the NP effect in the L1-to-L2 condition and the L2-to-L1 condition separately. Consequently, two separate $2 \times 2 \times 2$ repeated-measures analyses were conducted, one on the RTs of the L1-to-L2 trials, and the other on the RTs of the L2-to-L1 trials. For the L1-to-L2 trials, the main effect of NP was significant, $F(1, 14) = 5.70, p < .05, \eta_p^2 = .29$, indicating slower responses on the IR trials ($M = 653$ msec) relative to the Control trials ($M = 637$ msec). There was also a significant interaction between the stimulus positions in the prime and probe trials, $F(1, 14) = 15.40, p = .001, \eta_p^2 = .52$. This result shows that the difference between the probe target at the 3rd and 5th position was larger when the prime distractor was at D1 position (a

difference of 23 msec) than when it was at D2 position (a difference of -9 msec). No other effects reached significance.

For the L2-to-L1 trials, the main effect of prime distractor position was significant, $F(1, 14) = 9.81, p < .01, \eta_p^2 = .41$, indicating slower responses when the prime distractor was at D1 position ($M = 665$ msec) rather than at D2 position ($M = 642$ msec). In addition, the main effect of probe distractor position was also significant, $F(1, 14) = 10.0, p < .01, \eta_p^2 = .42$, indicating slower responses when the probe target appeared before the probe distractor ($M = 669$ msec) rather than the other way around ($M = 638$ msec). Once again, the interaction between the stimulus positions in the prime and probe trials was significant, $F(1, 14) = 4.60, p < .05, \eta_p^2 = .25$, and the pattern of result was similar to that found in the L1-to-L2 trials. The difference between the probe target at the 3rd and 5th position was larger when the prime distractor was at D1 position (a difference of 51 msec) than when the prime distractor was at D2 position (a difference of 11 msec). Importantly, there was no evidence of a NP effect, $F(1, 14) < 1, ns$. No other results were significant, either.

A 2 x 2 x 2 x 2 repeated-measures ANOVA was also conducted on the accuracy data. The main effect of language was significant, $F(1, 14) = 11.88, p < .01, \eta_p^2 = .46$, indicating higher errors in the L2-to-L1 trials ($M = 6.8\%$ error) than in the L1-to-L2 trials ($M = 4.2\%$ error). The main effect of the probe distractor position was also significant, $F(1, 14) = 44.24, p < .001, \eta_p^2 = .76$, indicating more errors when the probe target was after the probe distractor ($M = 7.2\%$ error) rather than before the latter ($M = 3.9\%$ error). No other effects reached significance. As

there was no indication of any interaction involving language, no further analyses were conducted on the accuracy data.

Discussion

The most important finding is the observation of the cross-language NP effect. The current finding has extended what Neumann et al. (1999) found with their English-Spanish bilinguals. In addition, the result also agrees with the cross-language NP effects reported by Fox (1996) with her English-French and French-English bilinguals. Table 5 summarizes extant cross-language NP effects.

Table 5

Summary of Extant Cross-Language NP Effects

Experiment	Participant	Experimental Specification		Priming Effect
		Global	Structural and categorical features of TEs	
Fox (1996)	English-French & French-English	Parafoveal (2.4° above or below)presentation of prime distractor; single probe letter string; probe selection cue not needed	Alphabetic-to-Alphabetic TEs of associative words & direct TEs	NP (33 msec*)
Neumann (1999)	English-Spanish	Foveal (fixated at a letter string 0.4° x 1.0°-2.4°) presentation of prime distractor; double probe letter strings; probe selection based on lettercase	Alphabetic-to-Alphabetic direct TEs	NP (49 msec**)

Note. TE = Translation equivalent; NP = NP; PP = Positive priming.

* $p < .01$; ** $p < .05$.

What has been found in this experiment is different from all of them with respect to the following aspects: (a) participants' characteristics, (b) the stimulus presentation format, (c) the structural and categorical features of the translation equivalents, and (d) the magnitude of the cross-language NP effect. This is the first experiment testing Chinese-English participants on the NP under RSVP trials; and the translation equivalent-based cross-language NP effect has been observed with logographic symbols. Furthermore, the effect was observed under the RSVP format, which ensured that each stimulus was presented in its own presentation duration without concurrent spatial overlap and thus controlled undesired deployment of attentional resources. Moreover, the magnitude of what has been found in this experiment is smaller relative to other cross-language effects. The current effect has a magnitude that is below 20 msec whereas others are larger. In addition, the prime and probe target position effects have suggested some unexpected effects of applying temporally separated stimuli. Given these differences, the current findings substantially extend current cross-language NP literature.

Consistent with previous cross-language NP research that used the traditional NP paradigm (Fox, 1996; Neumann et al., 1999), the participants in Experiment 4 has showed an asymmetrical NP effects between the L1-to-L2 and L2-to-L1 trials. Whereas a significant NP effect was found when the prime distractor was in L1 and the probe target in L2, no evidence of NP was observed when the prime distractor was in L2 and the probe target in L1. It is likely that this pattern of data reflects the

visual linguistic interference control over different activation levels derived from representing and processing the L1 or L2 prime distractors.

Because the Chinese-English participants have more experience in processing their native language both at the single number word level and at the whole language level than that of L2, the internal representation of a stimulus in L1 is likely to be stronger than that of L2. Thus, when the prime distractor was in L1, strong inhibition was required to prevent it from interfering with the current task relevant selection. Consequently, a robust cross-language NP effect was manifested.

The current result found in the L1-to-L2 trials has provided additional support for the revised selective inhibition account of NP (Tipper, 2001), suggesting that the prime distractor is inhibited at least to its post-categorical level. As for the bilinguals' semantic memory structure, the current finding has confirmed that the lexical representations of these two languages share a common meaning store (Kroll & Sholl, 1992). Because the prime distractor and probe target were the translation equivalents of the two different languages, the observed cross-language NP effect would be difficult to be accommodated by the original formulation of the episodic memory retrieval account, which would predict a similar pattern of data between the T1-to-T2 trials and the T2-to-T1 trials. However, this does not mean that the contribution of memory-related processes to the cross-language NP effect is negligible. This point will be elaborated in general discussion. Once again, the participants in Experiment 4 showed the speed accuracy trade-off with regard to probe target position.

Chapter 6 General Discussion

The goal of the research presented in this thesis was to investigate the mechanisms of attentional selection among temporally separated stimuli in a new NP under RSVP paradigm with respect to the visual linguistic interference control (Wong, 2012). Experiment 1 used identical stimuli for the probe target and the prime distractor. Consistent with previous research (Koelewijn et al., 2008; Wong, 2012), a significant NP effect was found in both RT and error rates. Experiment 2 explored semantic NP between the prime distractor and the probe target. NP was observed in accuracy but not in RT, suggesting that the effect of NP was somewhat weakened.

Experiment 3 required the participants to shift from one representational form to another between the prime and probe trials. Although the participants responded to a digit while having to ignore a Chinese number word in the prime trial and responded to a Chinese number word while having to ignore a digit in the probe trial, the magnitude of the NP effect did not appear to decrease much compared with that in Experiment 1. Experiment 4 investigated the Chinese-English cross-language NP. A significant NP effect was found in the L1-to-L2 trials, in which the prime distractor was in the participants' L1 and the probe target in their L2. No effect was found in the L2-to-L1 trials. An overall data analysis of the 4 experiments was also conducted with regard to the median RTs of the probe responses (see the Appendix E). The magnitudes of these results are similar to previous findings using the traditional NP paradigm, in which the target and distractor are presented

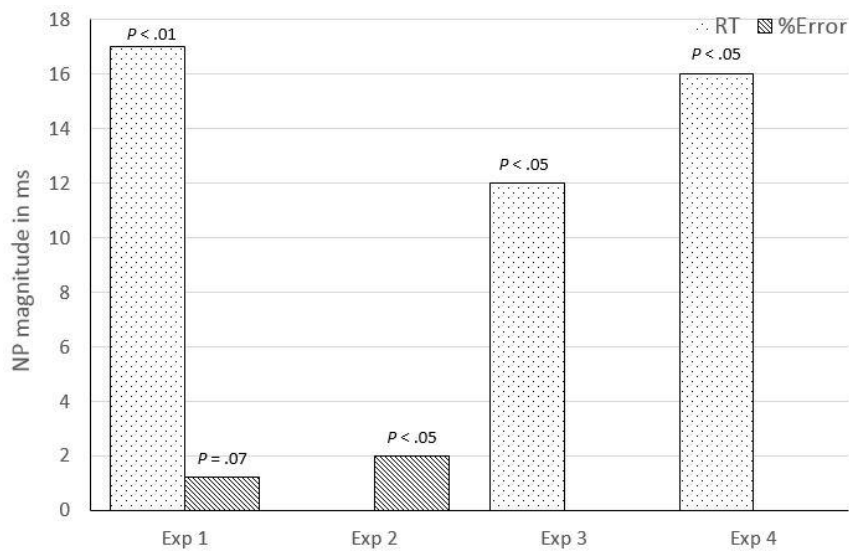
simultaneously in both the prime and probe trials; but the NP under RSVP effects suggest temporal interference control-related NP mechanisms, which need further investigation. Table 6 and Figure 9 show the significant NP results in each experiment.

Table 6

Summary of NP under RSVP

Experiment/	RT / % error
Sample size	
Exp1 / 43	17ms* / 1.2%***
Exp2 / 21	n.s. / 2%**
Exp3 / 22	12ms** / n.s.
Exp4 / 22	16ms** / n.s.

* $p < .01$; ** $p < .05$; *** $p = .07$

Figure 9. *Summary of NP under RSVP*

Implications for the Episodic Retrieval Account and the Distractor Inhibition Account

As described earlier, Neill and his colleagues (Neill et al., 1992) proposed that it is the memory retrieval triggered by the probe target that gives rise to NP. According to this account, when a probe target is encountered, it automatically triggers the retrieval of the memory trace of the previously encountered same stimulus along with any response code associated with the stimulus. However, because the probe target requires response, this creates a conflict with the “do-not-respond” tag associated with the memory trace of the prime distractor. Resolving the conflict requires time, resulting in the delay in responding to the probe target in the IR condition compared with the control condition.

The episodic retrieval account can explain the results of Experiments 1 through 3. In Experiments 1 and 3, the prime distractor and probe targets were identical. In Experiment 2, they were matched at the semantic level. Because the stimuli used in the experiments are highly familiar to the participants, it is likely that verbal codes were used during the experiments in addition to the visual orthographic codes. Consequently, the “do-not-respond” tag could be applied either to the physical appearance of the prime distractor or to its meaning. Hence, the longer RTs and/or more errors were observed in the IR conditions than in the Control conditions in these experiments.

However, the episodic retrieval account is difficult to explain the results of Experiment 4, because the pattern of data differed between the L1-to-L2 and the L2-to-L1 trials. In Experiment 4, the prime distractor and the probe target differed in both form and language. Even if we assume that the “do-not-respond” tag could be applied at a semantic level across different languages, the episodic retrieval account would still predict similar degree of NP in both types of trials. The asymmetry in NP between the two types of trials is inconsistent with the episodic retrieval account.

In contrast, the results found in Experiments 1 to 4 are consistent with the revised selective inhibition account proposed by Tipper and colleagues (Tipper, 1985; 2001). According to this account, when the prime distractor is encountered, inhibition is applied at least to its internal representation. This transient inhibition can still be present during the processing of the probe target when the interval between the probe target and prime distractor is short, resulting in delayed responses to the probe target. When the interval between the two stimuli is long, the probe target can trigger the retrieval of the inhibitory processes associated with the prime distractor, causing a delay in responding to the probe target.

This account can easily explain the results of Experiments 1 to 3. Inhibition was applied to the distractor when it was encountered in the RSVP stream. Even though the distractor was presented alone, as the only other stimulus in the same category as the target (i.e., a digit or a number word), it is important for its representation to be inhibited so that the target could be responded to correctly. Because the probe target and the probe distractor were either the same in physical

appearance (in Experiments 1 and 3) or shared the same meaning (in Experiment 2), inhibition could be applied at the physical or semantic level or both. NP could arise because the residual inhibition to the internal presentation of the distractor was still present when the probe target appeared, or it could arise because the probe target triggered the retrieval of the inhibitory processes associated with the prime distractor.

The revised selective inhibition account can also explain the asymmetry between the L1-to-L2 trials and the L2-to-L1 trials in Experiment 4. The participants are more familiar with L1 than L2, and the activation of L1 stimuli should be greater than the activation of L2 stimuli. Previous research has shown that a stimulus with greater activation is more strongly inhibited than a stimulus with weaker activation, and that NP is larger when the prime distractor is the former than the latter (Wong, 2012). Given that the activation to stimuli in L1 is stronger than to stimuli in L2, greater inhibition would be applied to the prime distractor in L1-to-L2 trials than in L2-to-L1 trials. As a result, a larger NP was found in the L1-to-L2 trials than in the L2-to-L1 trials.

Implications for Lexical Organization in Bilinguals

How are the two languages in bilinguals represented in memory? According to the hierarchical bilingual semantic memory model proposed by Kroll & Sholl (1992), there are two types of links in the long-term memory of bilinguals. The first is the lexical link between L1 and L2. However, the strength of the association from L1 to L2 is different from the strength of the association from L2 to L1, with the latter being stronger than the former. This asymmetry exists because most second

language learners begin to learn L2 when they are already fluent in L1, and they learn L2 by translating the lexicon in L2 to the lexicon in L1. As a result, the strength of the connection from L2 to L1 exceeds that from L1 to L2.

The second link is the conceptual link, both between the L1 lexicon and its underlying concept, and the L2 lexicon and its underlying concept. As bilinguals are typically more fluent in L1 than in L2, the strength of the conceptual link is stronger in L1 than in L2. Applying such a model to the bilinguals' number representation, it would imply that digits, English number words, and logographic number words might share a common meaning system. However, the connections among these notations have various strengths, thus affecting their meaning activation patterns and times.

The pattern of the data in Experiment 4 is consistent with the hierarchical bilingual memory model of (Kroll et al., 1992; Kroll & Stewart, 1994). In the L1-to-L2 trials, the prime distractor was in L1, which has a strong conceptual link to the conceptual memory. The appearance of the prime distractor should therefore evoke the underlying concept quickly, making its internal representation highly activated. This should trigger strong inhibition (Wong, 2012), resulting in a significant NP effect.

In contrast, in the L2-to-L1 trials, the prime distractor was in L2, which has a relatively weak link to the conceptual memory. When the underlying concept was only weakly activated, it is unlikely that strong inhibition was applied at a conceptual level. Consequently, no NP effect was found. One might wonder why there was no

NP effect if L2 could be translated to L1 by the lexical link, which in turn could activate the underlying concept in memory. This was probably due to time constraint in Experiment 4. Because the stimuli were presented in RSVP, the participants might not have sufficient time to engage in translation.

One of the current findings for bilingual processing is the advantages observed from bilinguals' performance on selective attention tasks. According to Bialystok (2011), bilinguals' prolonged experience with two languages shape their executive control mechanisms so that they are better at interference control relative to monolinguals. However, the current results provided so evidence for this.

The Speed Accuracy Trade-Off in the Probe Target Position

Effect

In Experiments 1, 3 and 4, the probe RTs when the probe target appeared before the probe distractor (T1) were slower than when the probe target appeared after the probe distractor (T2). At the same time, the slower T1 responses were more accurate whereas the faster T2 were more error prone, suggesting speed accuracy trade-offs. As discussed before, the speed accuracy trade-off may reflect the preknowledge of the stimulus status when a stimulus occurred at T1 or T2. In the case of a stimulus at T1 position, participants had no way of knowing whether the stimulus was going to be a target or distractor. Thus, they would have to be more conservative in preparing a response. They would have to determine first whether it was a distractor or not. They probably did that based on feature. If it was red, they withheld any responses. If it were black, they would then determine which of the

four response keys they should press. The time needed to engage in these processes led to relatively long response latencies. At the same time, because of the delay in response, participants would have more time to identify the target stimulus, and this would lead to fewer errors.

In contrast, this is not the case in those trials where a distractor had been presented at T1. The appearance of the distractor would serve as a cue for the upcoming target, indicating to the participants that the upcoming digit would be a target. By the time the target appeared, participants might have already made the necessary motor preparation to respond. This would lead to relatively fast response time. However, the fast response can also lead to more motor error and/or more perceptual error, because participants would have less time to identify the stimulus. As a result, speed accuracy trade-off was found.

It is also possible that the high error rate in the T2 trials was caused, at least in part, by the capture of attention of the probe distractor. In these trials, the probe distractor was a colour singleton, and colour singletons are known to capture attention (Yantis, 1993). When an attentional capturing stimulus was presented before the target, it could induce some kind of attentional blink (Raymond et al., 1992). Attentional blink typically occurs when T1 and T2 appear within 500 msec. The interval between the distractor and the target in the probe trial was within this range.

Unlike most studies on attentional blink, in which T1 and T2 are stimuli from the same category and in the same representational form (e.g., both are letters), the

prime and probe in the present study were in the same representational form in Experiment 1 (i.e., both were digits), but in two different representational forms in Experiments 3 and 4 (i.e., a digit and a Chinese or English number word). If the higher error rate in the T2 trials was indeed related to attentional blink, the results from the present experiments suggest that the “blink” is not limited to stimuli in the same representational form.

In prior research on attentional blink, when T1 does not require identification, there is no attentional blink on T2 (Raymond et al., 1992). Attentional blink occurs only when T1 requires attentional resources to process. In the present study, the distractor did not require identification to the level of meaning (i.e., participants could reject the distractor on the basis of colour). However, unlike attentional blink experiments, in which the task related to T2 is to detect the presence or absence of a target stimulus, the present study required participants to discriminate among four stimuli, with each stimulus mapped to a different response. It is possible that the more demanding task in the present study requires more attentional resources. As a result, performance is more easily disrupted by a preceding stimulus, even though that stimulus does not require semantic processing.

Limitation of the Present Study

One major goal of the study was to investigate the cross-language NP effect under RSVP. The participants in Experiment 4 were Chinese-English bilinguals of different language proficiency. However, due to the difficulty in participant recruitment, I was unable to recruit sufficient number of bilingual participants so that

the effect of language proficiency could be investigated. For those people who started to learn L2 from a very young age, it would be reasonable to expect them to achieve the same level of proficiency in L2 as in L1, and this should lead to a similar level of distractor activation and its subsequent inhibition regardless of whether the prime distractor is in L1 or in L2. As a result, there should be no asymmetry in NP between the L1-to-L2 and L2-to-L1 trials. Further studies should include language proficiency as a factor. It will be informative to find out whether the degree of NP would increase in L2-to-L1 trials when the proficiency of L2 increases.

Another limitation of the present study is the predictability of the temporal positions of the target and distractor. Although the actual position of the target was unpredictable, because it could only appear at position 3 or 5, participants could ignore all the stimuli that occurred before the stimulus at position 3, effectively reducing the RSVP stream to a list of 3 items. A longer list that contains a dozen or more stimuli will make the temporal location of the target and distractor more unpredictable. It will also allow the manipulation of the lag between the distractor and the target, and this in turn may affect the speed accuracy trade-off found in the present study. If speed accuracy trade-off is found when the lag between the probe distractor and the probe target is short but not when it is long, this will indicate that the speed accuracy trade-off observed in the present study was indeed related to attentional blink. Future experiments should explore this possibility.

Chapter 7 Conclusion

In four experiments, participants' temporal interference control was measured in the NP under RSVP procedure by varying the presence of a red prime distractor and its probe target repetition. To my knowledge, this is the first study that has demonstrated how to measure it, and the first study that has given an initial estimate of its magnitude. In addition, NP was found on the top of independent background activities of RSVP. The results confirmed that participants' number recognition can be slowed by the presence of a red prime distracting stimulus, either physically or categorically identical with its probe repetition. In contrast to the identical stimuli-based NP, the cross-language NP under RSVP has showed some unique characteristics: a) being only observed on the L1-to-L2 trials; b) being largely contributed from the temporal inhibition implemented after the post-lag 1 sparing period. They have also indicated that NP effects, at least in the present paradigm, are better explained by the revised selective inhibition theory than by the episodic retrieval theory. Although it is still far away from gaining a full understanding of the NP phenomenon (Fox, 1995; Frings, Schneider, & Fox, 2015), this study has provided a suitable reference point for further investigation into the relationship between controlling temporal interference and NP.

References

- Adrian, E. D., & Bronk, D. W. (1929). The discharge of impulses in motor nerve fibres. *The Journal of Physiology*, *67*(2), 9–151.
- Baylis, G. C., Rolls, E. T., & Leonard, C. (1987). Functional subdivisions of the temporal lobe neocortex. *The Journal of Neuroscience*, *7*(2), 330–342.
- Bennett, M. R. (2000). The concept of transmitter receptors: 100 years on. *Neuropharmacology*, *39*(4), 523–546.
- Bialystok, E. (2011). Reshaping the Mind: The Benefits of Bilingualism. *Canadian Journal of Experimental Psychology-Revue Canadienne De Psychologie Experimentale*, *65*(4), 229–235. <http://doi.org/10.1037/a0025406>
- Changizi, M. A., Zhang, Q., Ye, H., & Shimojo, S. (2006). The structures of letters and symbols throughout human history are selected to match those found in objects in natural scenes. *American Naturalist*, *167*(5), E117–E139. <http://doi.org/10.1086/502806>
- Chao, H. F. (2011). Active Inhibition of a Distractor Word: The Distractor Precue Benefit in the Stroop Color-Naming Task. *Journal of Experimental Psychology-Human Perception and Performance*, *37*(3), 799–812. <http://doi.org/10.1037/a0022191>
- Chen, L. (1982). Topological Structure in Visual Perception. *Science*, *218*(4573), 699–700. <http://doi.org/10.1126/science.7134969>
- Chen, L. (1985). Topological structure in the perception of apparent motion. *Perception*, *14*(2), 197–208.

- Chen, L. (2005). The topological approach to perceptual organization. *Visual Cognition*, 12(4), 553–637.
- Chen, L., Zhang, S., & Srinivasan, M. V. (2003). Global perception in small brains: Topological pattern recognition in honey bees. *Proceedings of the National Academy of Sciences*, 100(11), 6884–6889.
- Cohen, L., Dehaene, S., Naccache, L., Lehericy, S., Dehaene-Lambertz, G., Henaff, M. A., & Michel, F. (2000). The visual word form area - Spatial and temporal characterization of an initial stage of reading in normal subjects and posterior split-brain patients. *Brain*, 123, 291–307.
<http://doi.org/10.1093/brain/123.2.291>
- Cohen, L., Lehericy, S., Chochon, F., Lemer, C., Rivaud, S., & Dehaene, S. (2002). Language-specific tuning of visual cortex functional properties of the Visual Word Form Area. *Brain*, 125, 1054–1069.
<http://doi.org/10.1093/brain/awf094>
- Dalrymple-Alford, & Budayr. (1966). Examination of Some Aspects of Stroop Color-Word Test. *Perceptual and Motor Skills*, 23(3P2), 1211–&.
- Dehaene, S., & Cohen, L. (2007). Cultural recycling of cortical maps. *Neuron*, 56(2), 384–398. <http://doi.org/10.1016/j.neuron.2007.10.004>
- DeSchepper, & Treisman, A. (1996). Visual memory for novel shapes: implicit coding without attention. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 22(1), 27.

- Driver, J., & Tipper, S. P. (1989). On the nonselectivity of “selective” seeing: Contrasts between interference and priming in selective attention. *Journal of Experimental Psychology: Human Perception and Performance*, *15*(2), 304.
- Duncan, J., Ward, R., & Shapiro, K. (1994). Direct measurement of attentional dwell time in human vision. *Nature*, *369*(6478), 313–315.
- Duscherer, K., & Holender, D. (2002). No negative semantic priming from unconscious flanker words in sight. *Journal of Experimental Psychology: Human Perception and Performance*, *28*(4), 839.
- Dux, & Marois, R. (2009). The attentional blink: A review of data and theory. *Attention, Perception, & Psychophysics*, *71*(8), 1683–1700.
- Fields, R. D., Araque, A., Johansen-Berg, H., Lim, S.-S., Lynch, G., Nave, K.-A., ... Wake, H. (2013). Glial biology in learning and cognition. *The Neuroscientist*, 1073858413504465.
- Folk, C. L., Remington, R. W., & Johnston, J. C. (1992). Involuntary covert orienting is contingent on attentional control settings. *Journal of Experimental Psychology: Human Perception and Performance*, *18*(4), 1030.
- Fox, E. (1995). Negative Priming from Ignored Distractors in Visual Selection - A Review. *Psychonomic Bulletin & Review*, *2*(2), 145–173.
<http://doi.org/10.3758/bf03210958>
- Fox, E. (1996). Cross-language priming from ignored words: Evidence for a common representational system in bilinguals. *Journal of Memory and Language*, *35*(3), 353–370. <http://doi.org/10.1006/jmla.1996.0020>

- Frings, C., Schneider, K., & Fox, E. (2015). The negative priming paradigm: An update and implications for selective attention. *Psychonomic Bulletin & Review*, 1–21. <http://doi.org/10.3758/s13423-015-0841-4>
- Goodale, M. A., & Milner, A. D. (1992). Separate visual pathways for perception and action. *Trends in Neurosciences*, 15(1), 20–25.
- Grill-Spector, K., & Malach, R. (2004). The human visual cortex. *Annu. Rev. Neurosci.*, 27, 649–677.
- Haines, D. E. (2007). Santiago Ramon y Cajal at Clark University, 1899; his only visit to the United States. *Brain Research Reviews*, 55(2), 463–480.
- Hodgkin, A., Huxley, A., & Eccles, S. (1963). Ionic mechanics involved in nerve cell activity. *The Nobel Prize for Physiology or Medicine*.
- Houghton, G., & Tipper, S. P. (1994). A model of inhibitory mechanisms in selective attention.
- Kanwisher, N. G. (1987). Repetition blindness: Type recognition without token individuation. *Cognition*, 27(2), 117–143.
- Kanwisher, N., McDermott, J., & Chun, M. M. (1997). The fusiform face area: a module in human extrastriate cortex specialized for face perception. *The Journal of Neuroscience*, 17(11), 4302–4311.
- Koelewijn, T., Van der Burg, E., Bronkhorst, A., & Theeuwes, J. (2008). Priming T2 in a visual and auditory attentional blink task. *Perception & Psychophysics*, 70(4), 658–666.

- Kroll, J., Sholl, A., Altarriba, J., Luppino, C., Moynihan, L., & Sanders, C. (1992). Cross-language semantic priming - evidence for independent lexical and conceptual contributions. *Bulletin of the Psychonomic Society*, 30(6), 443.
- Kroll, & Sholl, A. (1992). Lexical and conceptual memory in fluent and nonfluent bilinguals. *Advances in Psychology*, 83, 191–204.
- Kroll, & Stewart, E. (1994). Category interference in translation and picture naming: Evidence for asymmetric connections between bilingual memory representations. *Journal of Memory and Language*, 33(2), 149–174.
- Lammertyn, J., & Fias, W. (2005). Negative priming with numbers: No evidence for a semantic locus. *Quarterly Journal of Experimental Psychology Section a-Human Experimental Psychology*, 58(7), 1153–1172.
<http://doi.org/10.1080/02724980443000520>
- MacLeod, Chiappe, & Fox. (2002). The crucial roles of stimulus matching and stimulus identity in negative priming. *Psychonomic Bulletin & Review*, 9(3), 521–528. <http://doi.org/10.3758/bf03196308>
- May, Kane, & Hasher. (1995). Determinants of Negative Priming. *Psychological Bulletin*, 118(1), 35–54. <http://doi.org/10.1037//0033-2909.118.1.35>
- Mesulam, M. (1998). From sensation to cognition. *BRAIN*, 121(6), 1013–1052.
<http://doi.org/10.1093/brain/121.6.1013>
- Mishkin, M., Ungerleider, L. G., & Macko, K. A. (1983). Object vision and spatial vision: two cortical pathways. *Trends in Neurosciences*, 6, 414–417.

- Neill. (1977). Inhibitory and Facilitatory Processes in Selective Attention. *Journal of Experimental Psychology-Human Perception and Performance*, 3(3), 444–450. <http://doi.org/10.1037//0096-1523.3.3.444>
- Neill, & Valdes. (1992). Persistence of Negative Priming - Steady-State or Decay. *Journal of Experimental Psychology-Learning Memory and Cognition*, 18(3), 565–576. <http://doi.org/10.1037//0278-7393.18.3.565>
- Neill, Valdes, L. A., Terry, K. M., & Gorfein, D. S. (1992). Persistence of Negative Priming .2. Evidence for Episodic Trace Retrieval. *Journal of Experimental Psychology-Learning Memory and Cognition*, 18(5), 993–1000. <http://doi.org/10.1037/0278-7393.18.5.993>
- Neill, W. T., Lissner, L. S., & Beck, J. L. (1990). Negative Priming in Same-Different Matching - Further Evidence for a Central Locus of Inhibition. *Perception & Psychophysics*, 48(4), 398–400. <http://doi.org/10.3758/bf03206694>
- Neumann, McCloskey, M. S., & Felio, A. C. (1999). Cross-language positive priming disappears, negative priming does not: Evidence for two sources of selective inhibition. *Memory & Cognition*, 27(6), 1051–1063. <http://doi.org/10.3758/bf03201234>
- Pakkenberg, B., & Gundersen, H. J. G. (1997). Neocortical neuron number in humans: effect of sex and age. *Journal of Comparative Neurology*, 384(2), 312–320.

- Pashler, H. (1989). Dissociations and dependencies between speed and accuracy: Evidence for a two-component theory of divided attention in simple tasks. *Cognitive Psychology*, *21*(4), 469–514.
- Peirce, J. W. (2007). PsychoPy - Psychophysics software in Python. *Journal of Neuroscience Methods*, *162*(1-2), 8–13.
<http://doi.org/10.1016/j.jneumeth.2006.11.017>
- Pomerantz, J. R. (2003). Wholes, holes, and basic features in vision. *Trends in Cognitive Sciences*, *7*(11), 471–473.
- Raymond, J. E., Shapiro, K. L., & Arnell, K. M. (1992). Temporary suppression of visual processing in an RSVP task: An attentional blink? *Journal of Experimental Psychology: Human Perception and Performance*, *18*(3), 849.
- Schmidgen, H. (2002). Of frogs and men: the origins of psychophysiological time experiments, 1850–1865. *Endeavour*, *26*(4), 142–148.
[http://doi.org/http://dx.doi.org/10.1016/S0160-9327\(02\)01466-7](http://doi.org/http://dx.doi.org/10.1016/S0160-9327(02)01466-7)
- Stadler, M. A., & Hogan, M. E. (1996). Varieties of positive and negative priming. *Psychonomic Bulletin & Review*, *3*(1), 87–90.
- Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology*, *18*, 643–662. <http://doi.org/10.1037/0096-3445.121.1.15>
- Szwed, M., Cohen, L., Qiao, E., & Dehaene, S. (2009). The role of invariant line junctions in object and visual word recognition. *Vision Research*, *49*(7), 718–725. <http://doi.org/10.1016/j.visres.2009.01.003>

- Tipper. (1985). The Negative Priming Effect - Inhibitory Priming by Ignored Objects. *Quarterly Journal of Experimental Psychology Section a-Human Experimental Psychology*, 37(4), 571–590.
<http://doi.org/10.1080/14640748508400920>
- Tipper. (2001). Does negative priming reflect inhibitory mechanisms? A review and integration of conflicting views. *Quarterly Journal of Experimental Psychology Section a-Human Experimental Psychology*, 54(2), 321–343.
<http://doi.org/10.1080/02724980042000183>
- Tipper, S. P., & Driver, J. (1988). Negative Priming between Pictures and Words in a Selective Attention Task - Evidence for Semantic Processing of Ignored Stimuli. *Memory & Cognition*, 16(1), 64–70.
<http://doi.org/10.3758/bf03197746>
- Torvalds, L. (1997). *Linux: a Portable Operating System* (Thesis).
- Wade, N. J. (2007). Image, eye, and retina (invited review). *Journal of the Optical Society of America a-Optics Image Science and Vision*, 24(5), 1229–1249.
<http://doi.org/10.1364/josaa.24.001229>
- Wade, N. J., & Finger, S. (2001). The eye as an optical instrument: from camera obscura to Helmholtz's perspective. *Perception*, 30(10), 1157–1177.
<http://doi.org/10.1068/p3210>
- Wong. (2002). The relationship between attentional blink and psychological refractory period. *Journal of Experimental Psychology: Human Perception and Performance*, 28(1), 54.

- Wong. (2012). Negative Priming Under Rapid Serial Visual Presentation. *Plos One*, 7(5). <http://doi.org/10.1371/journal.pone.0037023>
- Wyatt, N., & Machado, L. (2013a). Distractor inhibition: Principles of operation during selective attention. *Journal of Experimental Psychology: Human Perception and Performance*, 39(1), 245.
- Wyatt, N., & Machado, L. (2013b). Evidence inhibition responds reactively to the salience of distracting information during focused attention. *PLoS One*, 8(4), e62809.
- Yantis, S. (1993). Stimulus-driven attentional capture. *Current Directions in Psychological Science*, 156–161.
- Yee, P. L. (1991). Semantic Inhibition of Ignored Words During a Figure Classification Task. *Quarterly Journal of Experimental Psychology Section a-Human Experimental Psychology*, 43(1), 127–153.
<http://doi.org/10.1080/14640749108401002>
- Zucker, S. W. (2012). Local field potentials and border ownership: a conjecture about computation in visual cortex. *Journal of Physiology-Paris*, 106(5), 297–315.

Appendix A

Summary of Classic NP Studies

Author (year)	Condition							
Dalrymple-Alford & Budayr (1966)	RB	RC	CC	S	SX	XS	HS	
Neill (1977)	Related		Unrelated					
Lowe (1979)	IDENT	REV	SUP-SUP	SAY-SUP	CONT	SAY-SAY	SUP-SAY	
Tipper (1985)	Control		Ignored Repetition					
Tipper (1985)	Control		Ignored Repetition			Ignored prime		
Neumann & DeSchepper (1991)	TTDD	TT	DD	C	DT	TD	TDDT	
Stadler & Hogan (1996)	AA/II	II	AA	Control	IA	AI	IA/AI	

Note. Only NP sequence-related conditions are elaborated below. References contain explanations for all other conditions. **XS:** the naming condition in which the correct response is the same as the previous interfering word. **Related:** the naming condition in which the current response is the same as the distracting word in the preceding item. **REV:** the leading target colour swaps to the trailing distractor while the leading distractor swaps to the trailing target; **SUP-SAY:** the leading distractor swaps to the trailing target while the leading target is unrelated to a trailing distractor. **Ignored Repetition:** the leading distracting prime was turned into the trailing target. **DT:** a leading distractor turns into a trailing target; **TDDT:** a leading target turns into a trailing distractor while a leading distractor turns into a trailing target. **AA/II:** the leading distractors and target repeating themselves in its trailing event; **II:** only the leading distractors being repeated in its trailing event; **AA:** only the leading target being repeated in its trailing event; **Control:** no leading distractors or the target being repeated in its trailing event; **IA:** the leading distractors being interchanged as the target in its trailing event; **AI:** the leading target being interchanged as the distractor in its trailing event; **IA/AI:** the leading distractors and target being interchanged as the target and distractors in its trailing event at the same time.

Appendix B

A small set of notations, such as using S for representing a stimulus and R for a response can be introduced to describing a NP task. For a typical NP trial with two displays, the prime display can be further specified as s_0 whereas the probe display as s_1 . Moreover, these two symbols can be further dichotomised, with s_0^t and s_0^d referring to the target and distractor in the prime trial, and s_1^t and s_1^d to the target and distractor in the probe trial. With the aid of these notations, an identity NP task can be simplified as determining what has been presented in s_1^t over a visual s_0^d -to- s_1^t repetition. These notations can be used for stimuli and responses to stimuli beyond the visual modality, in particular for summarising cross-domain NP experiments

Appendix C

The RSVP-based NP Procedure

More detail of the experimental design is provided in this appendix. For studying the cross language NP effect, I combined Wong's (2012) RSVP procedure with Neumann et al.'s (1999) cross-language NP paradigm. The new paradigm consisted of a prime stream of stimuli, followed by a probe stream of stimuli. Each stream included a black target stimulus, a red distractor stimulus, and several black neutral distractors. The probe target could be either a new stimulus or the distractor in the prime stream. Across different experiments, the two stimuli were written in either the same language or different languages.

Experiment 1 was a baseline experiment, in which a red digit of each stream was instructed to be ignored so that a black target number can be identified as required. Besides the red distracting digit, three single letters also served as task irrelevant items, reversing Wong's (2012) stimuli assignment. Figure 9 illustrates the general structure of the stimulus arrangement adopted in this series of experiments.

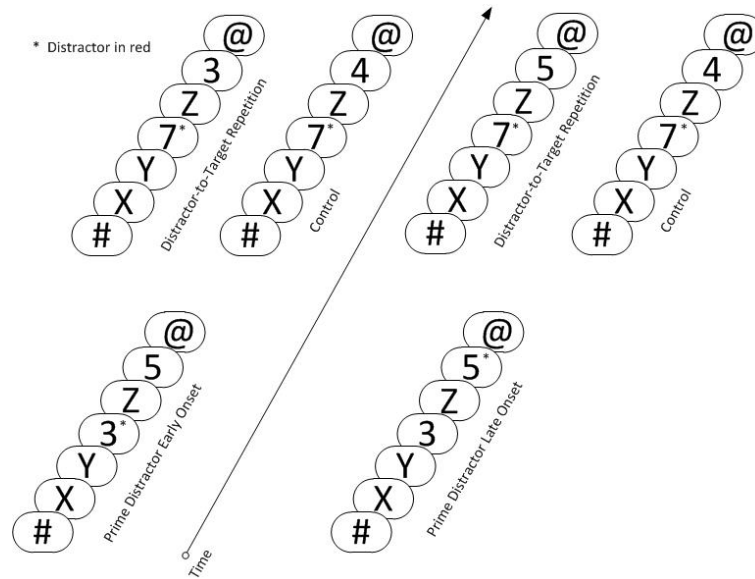


Figure 10. An illustration of the NP (NP) trials presented in this study with respect to a distractor's temporal position (i.e., the prime distractor early versus late onset). Following these prime trials, the prime distractor is either repeated in some trials (i.e., the distractor-to-target repetition condition) or is unrelated to a new probe target (i.e., the control). On these trials, the asterisk indicates a red distractor numeral. From the perspective of a participant, each trial starts with “#” and ends with “@”. On each single trial, they need to identify a black numeral regardless of its visual forms. To accomplish this, they have to ignore distracting information (i.e., uppercase single letters and a red number presented before or after the black numeral). All these stimuli are presented briefly in rapid serial visual presentation (RSVP) streams.

To be more specific, a sequential number distractor (i.e., 3* or 5* of prime displays) would be presented at either the third or the fifth position of each RSVP stream. On the other position that was not occupied by this distractor, a number target would be presented. The distractor and the target would be separated by a letter distractor. In doing so, a sequential distractor-based NP condition can be established as either the distractor early onset or late onset condition. For example, the distractor early onset condition can be established by presenting s_0^d before s_0^t whereas the late onset condition can be established by presenting s_0^d after s_0^t . On these distractor early onset or late onset trials, these single sequential stimuli were presented each for 117 ms.

Thus, the RSVP procedure would make a unique retinal image available for participants' visual information processing. A schematic illustration of such retinal image is shown in Figure 10, with its left side showing a partial stimulus arrangement and with the right side illustrating their temporal superimposing effects. On actual experimental trials, the visibility of either digit "4" or "6" would be further reduced by neighbouring single distracting letters and by the ending symbol "@", which is not shown here.

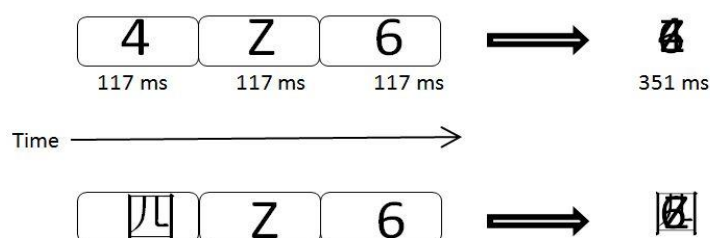


Figure 11. An illustration of the visual effects created by presenting three temporally superimposed stimuli (i.e., a leading distractor, a neutral distractor, and its trailing target) at a fixated position. One of the numbers would be presented as red but is shown here as black because the superimposing effect is to be illustrated. The top panel displays the effect at the baseline NP (NP) condition whereas the bottom panel shows it at one of the cross-language conditions. In either case, the left sides represent the actual rapid serial visual display (RSVP) events. The right sides show the undifferentiated impression of the three stimuli being superimposed together within less than half a second (i.e., 351 ms). To identify a black numeral, the undifferentiated raw impression must be processed in a task relevant manner (i.e., ignoring a red numeral while identifying the black numeral target as soon as possible with fewer errors).

The illustration of the retinal image made available by the translation equivalent-based procedure has been shown in the lower panel. In this illustration, the logographic language number word “四” and the digit “6” would mask the visibility of each other in the translation equivalent-based NP condition. Although the contour of the logographic language number word may provide extra information,

its influence on identification should be equally distributed in the Control and IR condition.

Besides these intra trial features, two experiment-wise design features were also adopted for the translation equivalent-based NP procedure implemented via RSVP: (a) the within-participants design; (b) a baseline condition. First, the within-participants design was adopted because many extraneous variables would influence participants' number identification. Such influences might be distributed more evenly between the Control and IR condition by adopting such a design. Thus, conclusions can be drawn more confidently based on such a design.

Second, a baseline level of participants' number identification was first established. At the baseline level, monolinguals and bilingual participants all responded to the same stimulus set (i.e., ignoring a digit first and then processing its target repetition). If observable, the sequential distractor-based NP effects can be compared with such a baseline response when the cross-language variations were introduced later. Thus, a cross-experiment comparison can be carried out meaningfully. Taken together, aiming at extending the cross-language NP phenomenon, I constructed a translation equivalent-based NP procedure implemented via a rapid serial visual presentation (RSVP) task. On the translation equivalent-based NP trials, monolingual and bilinguals' probe number identification was contrasted to show the cross-language NP effect, which did not depend on the repetition of visual form identical stimuli.

Appendix D

The Neurophysiological Basis of Representing Visual Word Forms

The appendix is organised into three parts: (a) the neurophysiological basis of representing visual information in a synaptic hierarchy; (b) representing topological features of written number words, (c) a task relevancy-based interrupt system. The idea of the single “neuron”, or the basic cellular structure of the human brain as we now know it, was developed 100 years ago. The independent cellular structure of a neuron was first demonstrated by (Haines, 2007). By stimulating single isolated sensory nerve fibres or motor nerve fibres, Adrian & Bronk (1929) linked the spiking patterns with common axonal and dendritical mechanisms. The mechanisms as demonstrated as the ionic excitatory and inhibitory processes inside and outside neurons’ membranes were discovered by Hodgkin, Huxley, & Eccles (1963).

These single neuron-based mechanisms form one aspect of electrical neural impulses generated in the brain. The other equally important aspects include at least: (a) the glial cells-based mechanism (Fields et al., 2013), (b) the synaptic chemical information transmission (Bennett, 2000). At the cellular level, the white matter can be categorized as the glial cells (i.e., microglia, astrocytes, oligodendrocytes and oligodendrocytes progenitor cells) that sustains the myelinated axonal fibres and the unmyelinated fibres. According to Fields et al., (2013), the glial cell-based mechanisms are still largely absent from thinking about representing and processing information because the glial cells do not generate electrical impulses. However, they form important cell-cell interaction that shapes the cellular mechanisms of

learning and cognition, in particular in coupling neurons into functional units for the short-term and long-term information storage and learning.

As for the chemical agent-based cell-to-cell communication, the specialised structure at the axon terminal is called a synapse, the gap for neurotransmitter molecules in diffusion. The diffusion process starts from releasing these molecules from pre-synaptic neurons' membranes into the synaptic gap. Over the gap, the ionic channels of post-synaptic neurons would enable a membrane fusing process, binding these molecules in a lock-and-key manner, opening and closing these membrane channels. The opening and closing would enable the cell-to-cell information transmission, relaying neural information forward. Taken together, the single neuron, the glial cells and the synaptic structure form the neuronal basis for neural information transmission in the central and peripheral nerve system.

For attentional, memory and language-related functions, billions of neocortical neurons form large-scale neuronal networks to support their implementation. For example, the human neocortical areas of the cerebral cortex has been estimated to contain 19 to 23 billion neurons (Pakkenberg & Gundersen, 1997). If divided by the cortical functions, the largest crude number would be associated with the frontal cortex, which centres around 7 billion, followed by the 5 billion parietal neurons. Moreover, there are roughly 4.6 billion neurons belonging to the temporal cortex whereas for the occipital cortex the number goes below 4 billion. In addition, a much larger number (i.e., 10^{15}) may be needed to describe their synaptic connections.

To characterise this incredibly complex synaptic connection-based structure, Mesulam (1998) introduced a neuronal network hierarchy based on six degrees of synaptic separations to capture the essence of the functional zones of neocortical neurons (i.e., its primary sensory-motor function, unimodal associative representing function, the heteromodal associative representing function and the paralimbic and limbic representing function).

The primary sensory-motor function serves to interface the obligatory processing of “raw” sensory inputs and the generation of behaviourally significant responses. The unimodal associative function serves to maintain the fidelity of the “raw” sensory inputs. The heteromodal associative function serves to provide cross-sensory-modality representation of the input data. The paralimbic and limbic function provides reciprocal access to the hypothalamus. The neural information processes between the obligatory processing of “raw” sensory inputs and the generation of behaviourally significant responses are cognitive processing, manifesting various aspects of contextual effects, memory guidance or task-bound constraints.

Vision, one of the main interfaces of representing an external environment, is such a cognitive process that is heavily influenced by contextual factors, past experience and task-bound constraints. Its primary sensory-motor function initiates from the information processing occurred in a small multilayer-structured network of cells (i.e., the cone-shaped or rod-shaped electromagnetic wave sensitive receptor cells) at the back “screen” of our eyes (Wade, 2007). The word *retina* itself also

derives from its Latin root *rēte*, meaning a small network. The activation within such retinal network projects to the lateral geniculate nucleus (LGN) for representing the retinotopic features of visual fields. The magnocellular and parvocellular layers of the LGN are the obligatory neuronal routes for packaging the retinotopic information into the cortical circuitry.

According to Mesulam (1998), the neuronal router packages topographically well organised neural information and sends them to the primary visual cortex V1, forming a neocortical representational basis for cognitive processes separated by various levels of neuronal synaptic separations (e.g., V2, hV4, and hMT+ which are separated only by one degree of the synaptic separation from V1). Although all of them are recipients of the V1's inputs, their contributions to the downstream ventral and dorsal pathways are different, with V2 splitting its contribution between the ventral and dorsal pathways.

Based on the inferred human homologue degrees of the synaptic separation, the fidelity of “raw” visual information is largely reserved within these monosynaptic separated neocortical areas. Further transfer of the raw information is driven either towards the parietal cortex for encoding spatial aspects of visual fields or towards the temporal lobe for processing invariant identity-level information of words or objects. The associative treatment would “enable identical stimuli to trigger different responses depending on the situational context, past experience, present needs and contemplated consequences” (p. 1015).

At the fourth level of the synaptic separation neocortical neurons distributed along the ventral pathway are tuned to represent categorical level information of visual objects (i.e., tools, words or faces). After such multiple levels of the synaptic separation, the tuned neocortical neurons would enable fast recognition of significant visual patterns even before identifying a single componential part. The cognitive mechanism has been proposed as processing the invariant topological feature of visual stimuli (Changizi, Zhang, Ye, & Shimojo, 2006; Chen, 1982, 1985, 2005; Chen, Zhang, & Srinivasan, 2003; Pomerantz, 2003).

The topological feature-based perception is different from the serial compiling componential forms, colours and motion characteristics derived from the information processing only given the first three synaptic separation levels. Although the monosynaptic separated visual information processing centres may provide enough visual information for identifying two visual form identical words or objects, “but could not lead from word to meaning, from physiognomy to recognition, or from sensory events to coherent experiences” (Mesulam, 1998, p. 1023).

In this sense, the neocortical neurons clustered at the bi-lateral mid-fusiform gyrus seem to be able to encode these visual stimuli at the categorical level even before adding more detailed componential information. For the neurons at its left side processing they may be well tuned for representing topological features of written words for most right-handed readers (Changizi et al., 2006; Cohen et al., 2000). The topological information provides a fast coarse approximation of the classes of objects (Baylis, Rolls, & Leonard, 1987). If a detailed intra-category

differentiation is required, the constituent neocortical neurons within a cell cluster of the visual word form areas may add their contribution. Together, “identification can thus start by matching the coarse (or generic) features and then focusing on finer (subordinate) detail” (Mesulam, 1998, p. 1021).

There are various ways to describe the interaction between the topological level information processing and the individual level information processing. In the context of encoding two close repetitions of the same word, the encoding has been described as activating a generic type node that is at its topological level (N. G. Kanwisher, 1987) and activating its token level features that are at its individual level featuring when and how a specific instance of the type node has been treated. Collectively, the type-token interaction helps forming a fast seemingly “effortless” approximation of the initial retinal image of a visual object. Further transfer of the resultant information through the heteromodal associative treatment and the paralimbic and limbic processing would facilitate visual learning and memory or add emotional tones, collectively known as transmodal treatment.

In summary, representing visual information can be described in a synaptic separation hierarchy, in which the information flow streamed along the two visual information processing pathways can be illustrated in a functional manner. Thus, the fidelity of visual inputs is still preserved within the first three synaptic separations with respect to representing external stimuli whereas the further synaptic separations would enable cross-modality associative treatment. In the middle of such a synaptic separation hierarchy, the topological features of visual objects or words are

represented at the fourth level, which is only one synaptic degree away from the Wernicke's area at the fifth level. The superior temporal gyrus (BA 22) is another synaptic degree away from the heteromodal posterior parietal cortex.

With respect to the representing spatial or identity-based information of an object, the V1-hMT+-Posterior Parietal Cortex pathway is largely responsible for encoding spatial information of visual objects whereas the V1-hV4-Inferior temporal cortex for encoding the invariant identity-based information of the objects. The further heteromodal associative treatment of these aspects of visual objects adds more extensive transmodal associative treatment. Such a general synaptic separation hierarchy allows reciprocal connections being established from one functional separation to another, enabling bi-directional feedback cascaded through such neocortical circuitry.

In the context of NP, Houghton & Tipper (1994) described such a functional hierarchy with a few neuroanatomical additions. They took the posterior cerebral cortex as the localizable neuroanatomical substrate for the object field, the prefrontal cortex the target field, the frontal cortex (i.e., the premotor and supplementary motor areas) the motor schemas. In addition, they highlighted the gating function of the prefrontal cortex with respect to the refferent loop from the sensory cortex through the limbic system back to the cortex. Thus, the activation in the nonmatching streams would lead to suppression of their sensory registers.

The refferent loop indicates the synergistic interaction among these functional areas. In this sense, it should be noted that the ventral and dorsal visual pathways co-

measure different aspects of the same object for complementary functions (Goodale & Milner, 1992). The measurement represented along the ventral pathway seems to be carried out in an object-centred reference frame (i.e., exocentric) for identification whereas the measurement represented along the dorsal pathway in an observer-centred reference frame (i.e, egocentric) for visual information guided manipulation. For normal people these two visual pathways perform their constructive functions in a cooperative manner. Under such cooperative construction most people identify objects, faces or words, linking general visual perception abilities with word recognition (Changizi et al., 2006; Cohen et al., 2002; Szwed, Cohen, Qiao, & Dehaene, 2009).

Given “the extremely recent emergence of written languages in human phylogeny and its relatively late acquisition in ontogeny, the organisation of the word-form area is almost certainly not genetically or epigenetically programmed. A more likely possibility is that it represents an experiential modification of neuronal subgroups within population tuned to the encoding of faces and objects” (Mesulam, 1998, p. 1021). A similar suggestion describes such visual perception-word recognition linkage as a neural circuitry recycling process (Dehaene & Cohen, 2007). The validity of the neural circuitry recycling process depends on two premises: (a) the visual system can be tuned to extract invariant character stroke patterns; (b) symbolic systems (written words or printed numbers) in their development manifest some topological features.

Reading abilities of most literates have demonstrated the plasticity of the neocortical neuron network and the effectiveness of modern educational systems. In addition, Chen (1982) provided evidence showing the topological feature-based visual perception. However, the topological commonality of symbolic systems is less obvious. In this aspect, Changizi et al., (2006) provided new evidence, showing the common topological structure of written symbols. According to them, some of these symbols seemed to evolve towards accommodating visual recognition (e.g., visual signs, trademark symbols), rather than towards programming a motor response.

They hypothesised that the shapes of visual signs correlate with boundary patterns of natural objects, thus linking pre-existing visual recognition abilities with visual sign identification. To reflect the essential topological structures of these patterns, they used 36 different configuration types (e.g., “X”, “T” or “L”) to define classes of type-identical configurations. These found strong correlations existed between configuration type distributions of visual signs and those of natural scenes, suggesting these signs’ being configured for visual identification at the cost of motor.

Assuming its universality, such a neural circuitry recycling mechanism may also underlie the organisation of two or more languages within bilinguals’ minds. Language learners may have to rely on their general visual perceptual abilities to decode and encode the configuration types of written symbols of a second language. Such visual experience over time may lead to the development of a special bilingual associative memory system, such as is the Revised Hierarchical Model (RHM: Kroll & Stewart, 1994). The model differentiates two types of language representations:

lexical word forms and their conceptual representation. At the word form level, lexical forms of a native language and subsequently acquired forms of a second language are differentiated; at the lexical meaning level, no division has been suggested between the L1 and L2-related meanings, in particular when numbers are involved in visual word processing.

Using Mesulam's (1998) synaptic separation degrees, the primary sensory-motor function is differentiated for decoding or producing two different configuration types of two languages. One synaptic separation degree away, their unimodal associative representations may largely reserve the fidelity of sensory inputs decoded from a specific language system. However, their heteromodal associative integration must be shared. Take number words for instance, the meanings of two different written number words are shared by both languages in an integrated semantic system whereas L1 and L2 lexicon are separated from each other, reflecting a separated primary sensory-motor function and unimodal association coordinated by a common heteromodal associative integration.

Although any translation equivalent of a number word goes through the unimodal association treatment and the heteromodal elaboration, the L1 word form accesses the shared conceptual component more easily given a stronger associative connection than that of its L2 counterpart. Thus, the order of presenting a specific translation equivalent derived from a written number word may affect how fast its heteromodal association can be elaborated and which competing lexical item would be activated or is inhibited. After such meaning access, the task irrelevant motor

function must be inhibited for the expression of a goal-oriented selective response. In such a process, the identification activities carried out in the visual ventral pathway must coordinate its influence with respect to the action generation programmed in the visual dorsal pathway. Collectively, a timely task relevant number identification response can be initiated. Thus, in Kanwisher's (1987) terms, the type-token interaction with respect to representing cross-language written words influences such number identification.

In the case of processing an ambiguous retinal image or two discrete items presented closely, the involvement of the lateral prefrontal cortex is more pronounced with respect to inference control, a special type of attentional modulation mechanism. By establishing a goal-oriented template, the contents of the on-line storage of visual information (i.e., an object or event file) can be compared with respect to current task relevancy. In particular for two items displayed closely in time, the candidate interference control mechanisms may involve only allowing the first item accessing the unimodal and heteromodal associative treatment, but not for the second one. Even all of them might have gained access to the unimodal association, the interference created in working memory may still bias the inter-item competition so that only the representation of the first item can access next heteromodal association, but not for that of the second one.

Similarly, if all of them might have been fully associatively elaborated, the response competition may still be biased against the second item's responding code expression. Thus, the multi-functional levels distributed on the synaptic separation

degrees can work together for interpreting an ambiguous retinal image or for separating a target relevant target from sequential distractors presented too closely in time. In the context of attentional orientation, one way to realise such a multi-level coordination is by implementing an attentional interrupt system (Folk, Remington, & Johnston, 1992), a rough analogy drawn between orienting attentional resource and calling a software level interrupt when running a computer program.

Unlike any genetically coded interrupt systems, the attentional level interrupt system of the brain can be set by task instruction or varying expectation. In this sense, an attentional interrupt system functions to implement current behavioural goals through the six-degree separated neuronal network hierarchy. Thus, such a small world-like synaptic separation (Mesulam, 1998) can be associated with a contingency-based control structure for explaining the observed patterns of human selective responses. To interpret the results like NP, it might be informative to consider the primary sensory-motor function and the multilevel associative treatment at the same time.

Thus, once a task-based orienting attentional interrupt setting has been set, multiple levels of unimodal and heteromodal associative treatment are subject to such contingency-based interrupt control. If the visual form identical stimuli are repeated over a nearest s_0^d -to- s_1^f sequence, reversing the unimodal inhibitory associative treatment may be the shortest route needed for initiating a probe response. However, when the visual form non-identical stimuli are repeated, a reversal of the

heteromodal associative elaboration is an obligatory process, still complying with the shortest route neural computation principle.

To sum up, visual stimuli projected onto the retina may not always provide sufficient and enough information for triggering an attentional interrupt call. Only after sufficient unimodal and heteromodal associative treatment have been elaborated on both task relevant and irrelevant aspects of the same retinal image, the required task relevancy can thus be established, leading to interrupt the information processing of the task irrelevant aspects of the retinal image and to initiate a goal-oriented response. Moreover, when time is tightly constrained and the need for speed is obligatory, a full range detailed associative treatment may not always provide an optimal solution (Zucker, 2012).

One possible solution to address the visual perceptual challenge may come from considering the topological features of complex visual stimuli. In this sense, the componential border membership cannot be fully determined only by relying on an initial retinal image due to spatial or temporal overlapping. Large scale global-, intermediate- and local-scale visual analyses have to be coordinated simultaneously so that the figure-ground separation would be stable with respect to current task relevancy. Once the componential border membership can be stably separated, the goal-oriented action can be implemented as required. Thus, the tested distractor-to-target repetition sequence can be seen as implementing a time-based attentional interrupt system in the domain of processing topological visual features separated by the six synaptic degrees.

The neural interrupt system for vision, once set, has directed the dorsal pathway for registering rapid changes reflected in RSVP streams. In addition, it has also organised a quick construction of the topological features of most presented numbers with the aid of the ventral pathway based activities. Once the colour cue and a topological feature-based identity have been combined, their synergetic cooperation help establish a multilevel association-based task relevancy. Their further joint efforts would be expressed as implementing an interrupt call, inhibiting the information processing of the task irrelevant aspects of the retinal image and facilitating a goal-oriented response. Over a s_0^d -to- s_1^t repetition, reapplying the same attentional interrupt to release its prior inhibition to the same topological-feature cluster has been demonstrated to be slowed, suggesting a functional synaptic separation-related delay.

The delay may be associated with the cytoarchitectonic and laminar characteristics of the functional synaptic separation. The primary sensory and motor cortices represents the most specialised groupings of neocortical neurons. The unimodal and heteromodal associative cortices are all featured a six-layered neuronal arrangement, with more columnarization and laminar differentiation for the unimodal associative neurons than that for the heteromodal ones. The paralimbic functional zone provides a gradual transition from the isocortex to the allocortex structures such as the least differentiated limbic system.

Given the columnarization and laminar differentiation of the unimodal and heteromodal associative treatment, modulating two visual form identical objects over

a nearest s_0^d -to- s_1^t repetition may only involve coordinating information processing over the first three synaptic separation degrees. The results of Experiment 1 and 3 can be interpreted in this manner. However, for the NP effects observed with repeating non-identical visual forms in the NP paradigm, more extensive transmodal associative treatment is needed. The additional heteromodal associative treatment enables convergent inputs being modulated by current task relevancy in spite of the border membership of contour segments cannot be fully determined only by an initial retinal image.

Appendix E

As for the additional data analysis, the experiment-wise data analysis was conducted using other RT central tendency indicator: the median probe RTs. The median RTs were chosen because: (a) the addition of new central tendency information, (b) the distributional characteristics of the mean RTs. If the median RT data are in agreement with the mean RT results with respect to reflecting NP, a more confident conclusion can be drawn.

The dataset of the median probe RTs was submitted to a mixed $2 \times 2 \times 2 \times 2$ ANOVA with prime distractor position, probe target position, and prime-probe relationship as the within-participant factors and experiment as the between-participant factor. Only the L1-to-L2 trials of experiment 4 were included. As expected, a very similar pattern was identified from such median probe RT analysis. The main effect of prime distractor position was significant, $F(1, 79) = 45.45, p < .001, \eta_p^2 = .37$, indicating an overall slower response when the distractor was at D1 position ($M = 628$ msec) rather than at D2 position ($M = 610$ msec). In addition, there was a significant main effect of probe target position, $F(1, 79) = 57.66, p < .001, \eta_p^2 = .42$, indicating an overall slower response when the probe target was at T1 position ($M = 641$ msec) rather than at T2 position ($M = 598$ msec). Importantly, the main effect of the prime-probe relationship was significant, $F(1, 79) = 11.92, p = .001, \eta_p^2 = .13$, indicating an overall slower response in the IR condition ($M = 624$ msec) than in the Control condition ($M = 614$ msec).

The interaction between prime distractor position and probe target position was significant, $F(1, 79) = 6.49, p < .05, \eta_p^2 = .07$. This result indicates that the difference between the T1 and T2 trials was larger when the prime distractor was at D1 position (T1-T2 = 24 msec) rather than at D2 position (T1-T2 = 9 msec). Furthermore, the interaction between probe target position and experiment was significant, $F(3, 79) = 3.77, p < .05, \eta_p^2 = .13$. This result indicates that the experiment-wise probe RTs' difference was larger when the probe targets were presented at D1 position rather than at D2 position. No other effects were significant. To sum up, the median RT-based analysis has further corroborated what has been found from the mean RT-based analyses.