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動詞偏態對處理中文關係子句的影響: 事件相關電位研究

The Influence of Verb Bias on On-line Mandarin Relative Clause Processing: an ERP study

鍾柔安

Jou-An Chung

指導教授: 李佳穎博士、李佳霖博士

Advisers: Chia-Ying Lee, Ph.D.; Chia-Lin Lee, Ph.D.

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致謝詞

航行了兩年半，終於找到了那引頸期盼的寶藏。還記得五專時，特別喜歡到圖書館閱讀科學人雜誌中關於大腦的研究，或許也加上自身的經驗，對於腦科學越來越好奇。在大三時，因上了英文系文惠老師所開的「心理語言學」後，我開始對於大腦如何處理語言感興趣。爾後，我便嘗試去聽相關演講，得到了許多張尋寶路線圖。事實上，剛開始得到這些尋寶圖時，我不知道該尋找什麼寶藏，也不清楚需要些什麼才能成功找到。在某一次佳穎老師的演講中，我不僅更加認識神經語言學也更認識到此領域是如何能幫助到其他人。於是，我鼓起勇氣，向佳穎老師詢問，該如何與他們一起尋寶。於是，大四時，每週一次我到實驗室，向船長佳穎老師和其他船員學長姐請教並閱讀寶藏背後各種的故事。

就這樣，越來越清楚自己想要尋的寶藏是什麼。進入研究所後，我開始了兩年半的尋寶航行之旅。能夠成功尋得寶藏，我真的很感謝參與在整段航程的所有人。我非常感謝佳穎船長在我碰到每個關卡時，給予方向、一步步教我，在經歷每個暴風雨時，她穩住不讓船往下沉，給了我往下尋寶的信心。每次和船長的討論，總是非常的開心，我們尋到了更多新的小寶藏。最讓我感動的是船長始終提醒我「莫忘初衷」。此外，在尋寶的最後階段中，我經歷了外公的離世，老師的擁抱和關心皆讓我非常的感動。感謝佳霖老師在課堂上教我們腦波研究的知識，也給予實驗上的提醒。在碰到每個關卡時，我很感謝船上的學長姐，幫助我破關。感謝家如、智婷學姊教我如何設計、執行、與分析實驗。還記得，家如時常陪我到晚上七八點多。她們甚至到了美國，仍關心我的尋寶狀況; 感謝子昀、逸如和我一起想和校對刺激材料; 感謝峻賢學長、彥植，在準備刺激材料上，教我撰寫程式; 感謝培均教我分析腦波資料，不厭其煩的為我解釋每個分析和程式的意義。感謝雅為、欣怡和盈吟一起和我收實驗，讓整個實驗過程能更有效率的完成。在實驗室中，我感受到滿滿的溫暖和不斷的幫助。我真的很感謝和喜歡這個實驗室。感謝舒凱老師和瑜芸學姊在程式分析語料的課中，帶領我認識的計算機語言學的世界。謝謝所有老師的教導，奠定我完成此次尋寶的基礎。謝謝同學們景瑄、柏亨、青芳、俊輝的一起學習和相互加油。謝謝所有受試者耐心的完成實驗。

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整個尋寶航行之旅過程中，在每個挫折裡，我不斷的往前進，更體會到那種「哇！我知道為什麼了！好意想不到啊！」的滿足感。感謝上帝為我預備的每個人和事讓我在這趟旅程中，感到如此的滿足。

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Abstract

This study investigated how verb bias which carries both syntactic and semantic information incrementally modulates RC processing in Mandarin. We first conducted a norming study for the classification of verb bias. Forty-four verbs, chosen from Academia Sinica Balanced Corpus of Modern Chinese, version 4.0 were classified into three types of bias: Direct Object (DO), Sentential Complement (SC), and Equilibrium Balanced (EQ). Two event-related potentials (ERPs) experiments were then conducted to address how verb bias respectively influences the real-time ORC and SRC processing. Experiment 1 examined the verb effect in ORC processing, in which each type of verb bias was followed by a ORC (1stnoun + RC verb + RC marker DE + head noun). ERPs data for four target regions of RC structure were analyzed. The result showed verb bias effect on ORC processing and the difficulty of processing ORCs following DO-bias verbs, as first reflected by larger frontal positivity (617-1000ms) on the RC verb in DO-bias condition than that in SC-bias condition. It indicated the difficulty of processing unexpected but plausible syntactic structure. This effect also lasted on the subsequent RC marker DE and head noun. RC marker DE following DO-bias verb elicited larger N400 than that following SC-bias verb, indicating the difficulty of integrating DE to the expectation of "the concept of event". Furthermore, head noun

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following DO-bias verb elicited frontal negativity, suggesting the need of establishing the referential binding between the DO-bias verb and its correspondent referent.

Experiment 2 assessed the verb effect on SRC processing, in which each type of verb bias was followed by a SRC (RC verb + 1stnoun + RC marker DE + head noun). Distinct processing difficulty between conditions suggested the influence of both verb bias and word order on SRC processing. The difficulty of processing SRCs following DO-bias verb was first supported by the late frontal positivity elicited by RC verb following DO-bias verb than that following SC-bias verb. However, the difficulty of processing SRCs following SC-bias verb was demonstrated by larger N400 responses on RC verb than that in DO-bias condition. It implied that the variability of syntactic structure following the SC-bias verb did not provide an advantage for processing ongoing syntactic structure. The role of word order has to be considered since it competed with the characteristics of SC-bias verb in terms of the role in sentence processing. Moreover, this difficulty also lasted on the subsequent RC marker DE and head noun, such as the need of additional memory resources due to the thematic-role ambiguity in parsing head noun following SC-bias verb.

The processing of EQ-bias verbs following ORCs was different from that

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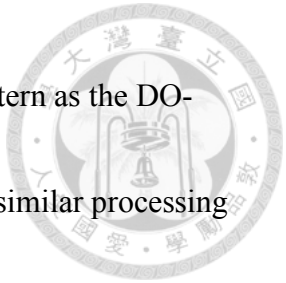

following SRCs. EQ-bias verbs following ORCs exhibit a similar pattern as the DO-bias verbs did. However, when following SRCs, they did not exhibit similar processing pattern with either DO-bias verbs or SC-bias verbs.

In sum, this study not only provided ERP evidence that verb bias incrementally influences Mandarin RC processing but also revealed the crucial role of word order in RC processing.

key words: verb bias (effect), relative clause processing, syntactic processing, incremental process

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摘要

本篇研究探討動詞偏態如何漸進地影響中文關係子句的處理。首先，我們將動詞進行分類。從中研院平衡語料庫 4.0 版本中，挑選出 44 個動詞，分類出三種動詞偏態: 傾向接上受詞(Direct Object ,DO)、子句(Sentential Complement, SC),以及接上受詞和子句比例相當的動詞(Equilibrium Balanced ,EQ)。接下來，本研究使用事件相關電位(Event-Related Potential, ERP) 技術探討動詞偏態如何分別影響受詞關係子句(Objective Relative Clause, ORC) 與主詞關係子句(Subjective Relative Clause, SRC) 的處理。

實驗一研究動詞偏態對受詞關係子句的影響。上述的三種動詞類型分別接上受詞關係子句。此實驗的四個主要觀察位置，依序為 RC noun 、 RC verb 、 RC marker DE 、 head noun。實驗結果發現動詞偏態漸進地影響受詞關係子句的處理。此影響首先展現在處理傾向接受詞的動詞的情況時，其接上的RC verb 比傾向接子句的動詞引發較正的frontal positivity。此外，此影響也延續到接下來的 RC marker DE 與 head noun。相較於傾向接子句的動詞，於傾向接受詞的動詞之情況下，RC marker DE 引發較負的N400，以及head noun 引發較負的frontal negativity。實驗一呈現出傾向接受詞的動詞接上受詞關係子句比傾向接子句的動詞狀況更容易處理。

實驗二研究動詞偏態對主詞關係子句的影響。實驗二和實驗一最大的不同在於語序。實驗一中的受詞關係子句符合中文的語序(主詞＋動詞＋受詞)而實驗二的主詞關係子句卻不符合。因此，語序的不同或許會在實驗二中扮演重要的角色。實驗二的四個主要觀察位置，依序為RC verb 、 RC noun 、 RC marker DE 、 head noun。實驗結果發現動詞偏態漸進地影響主詞關係子句且凸顯出中文語序的重要性。處理傾向接受詞的動詞的情況時，相較於於傾向接子句的動詞，其接上的RC verb 引發更正的late frontal positivity。然而，處理傾向接子句的動詞時，相較於於傾向接受詞的動詞，其接上的RC verb 引發更負的N400。這顯示於第一個實驗中，傾向接子句的動詞所佔的優勢並未在處理主詞關係子句中出現。兩個實驗最大的不同在於語序。因此，語序的不同使得不論處理傾向接受詞的動詞或是子句的動詞上，皆產生不同的困難。此困難也延續至其後的RC marker DE與head noun。

此外，接受詞或子句比例相當的動詞在接上受詞關係子句或是主詞關係子句上，有不同的效果。當此類動詞接上受詞關係子句時，其展現類似於傾向接上受詞的動詞的效果;而接上主詞關係子句時。此類動詞並沒有展現與任何類型相似的效果。

綜觀兩個實驗的結果，此研究不僅展現動詞偏態漸進地影響中文關係子句的處理外，也凸顯出語序在中文關係子句的處理中扮演重要的角色。

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關鍵詞：動詞偏態（效果）、關係子句、語法處理、漸進式處理

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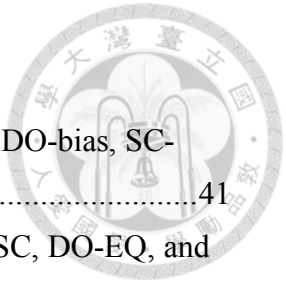

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Chapter 1. Introduction

Sentence comprehension proceeds incrementally (Tanenhaus et al., 1995; Traxler, Bybee, & Pickering, 1997). Each incoming word or phrase is constantly integrated with our stored knowledge and the information constructed by the previous words we read to form the sentence interpretation. During the process of sentence comprehension, the initial interpretation the parsers assign sometimes turns out wrong; therefore, the parsers have to re-read the previous information to re-analyze the sentence. Such a process is so-called the “garden path”. Relative clauses (RCs) complicated in their syntactic structures often elicit the garden-path effect, leading to the fact that the processing of RCs was intensively studied to build better understanding on sentence processing. Many studies have investigated Mandarin relative clause processing. The preference of processing either types of RCs —subjective (SRC) or objective relative clause (ORC) —has been extensively discussed; however, inconsistencies are found across theories (Bever,1970; Gibson, 2000; Jäger, et al. 2015; Lin,2006 ; MacWhinney, 1977) and psycholinguistic experiments (Chen,2008, Hsiao& Gibson, 2003; Lin & Bever 2006; Packard, 2010; Sung, 2016; Yang, 2010) . The experimental designs delving into the issue of SRC or ORC preference varied

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across studies. Relative clauses (RCs) were embedded as subjects (Hsiao& Gibson, 2003; Chen, 2008; Lin & Bever, 2006; Sung, 2016) in some studies, but as objects in other studies (Lin & Bever, 2006; Yang, 2010; Packard, 2010). Therefore, discussions over the preference of SRCs or ORCs processing were incomparable. Moreover, most of the theories and related experiments on this issue focus on RC structure itself without taking the notion of "incremental processing" into account. During the real-time sentence processing, other factors such as the probability of the main verb that would be followed by direct objects or sentence complement structures, the so-called "verb bias", might also influence the processing of the RC structure. This study aimed to investigate how verb bias which carries both semantic and syntactic information incrementally modulates the RC processing. This chapter reviews relevant background about the "Processing of relative clause" and "The role of verb bias effect in sentence processing".

1.1 Processing of relative clause (RC)

Two types of RCs in Mandarin, SRC (1) and ORC (2) are listed as follows:

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(2) Subjective Relative Clause (SRC)

[_____ 聘請 家教 的 經理] 很聰明。

GAP RC verb 1st RC noun RC marker FILLER / head noun

"The manager who hired the tutor is very smart."

(1) Objective Relative Clause (ORC)

[經理 聘請 _____ 的 家教] 很聰明。

1st RC noun RC verb GAP RC marker FILLER / head noun

"The tutor whom the manager hired is very smart."

Many theories and processing models have been proposed to discuss the Mandarin RC processing and preferences, namely structure-based, memory-based, experienced-based account, and perspective shifting theory. The former two accounts focus on the RC structure itself, the third account takes the frequency of the RCs into account, and the last one considers the relation between RC and the main clause. Nevertheless, each of them suggested different standpoints on the processing preferences and none of these accounts take "the preceding context" into consideration.

1.1.1 Structure-based account

Structure-based account emphasizes the significance of syntactic structure and

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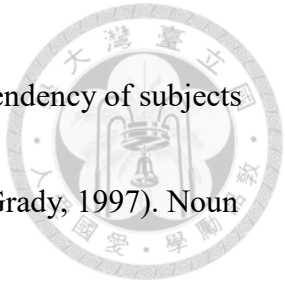

syntactic position in sentence comprehension, such as the universal tendency of subjects being easily assessed (Hawkins, 2004; Keenan & Comrie, 1977; O' Grady, 1997). Noun Phrase Accessibility Hierarchy (NPAH, Keenan & Comrie, 1977) argues that there is a universal tendency that certain syntactic positions are more easily accessed or relativized than others. It ranks the accessibility to relativization of Noun Phrase positions in a simple sentence. The ranking of NPAH is as follows: Subject > Direct Object > Indirect Object > Oblique Object > Genitive > Object of comparison. Since the subject position is positioned higher than the direct object position, NPAH would favor SRCs over ORCs in sentence processing. Other structural- based theories such as O'Grady (1997) and Hawkins (2004) have also proposed that NPs at the subject positions are easier to be relativized and extracted in all languages.

Incremental Minimalist Parser (Lin, 2006; Lin & Bever, 2006) combines the basic mechanism in the Minimalist Program (Chomsky 1995, 2000) with the incrementality hypothesis of Philips (1996, 2003) and proposes the parsers build syntactic structure incrementally from left to right and bind constituent downwards in a syntactic tree. It argues the gap located in a higher hierarchical position is easier to be assessed than that located in a lower position. Since the gap (the extracted subject) in

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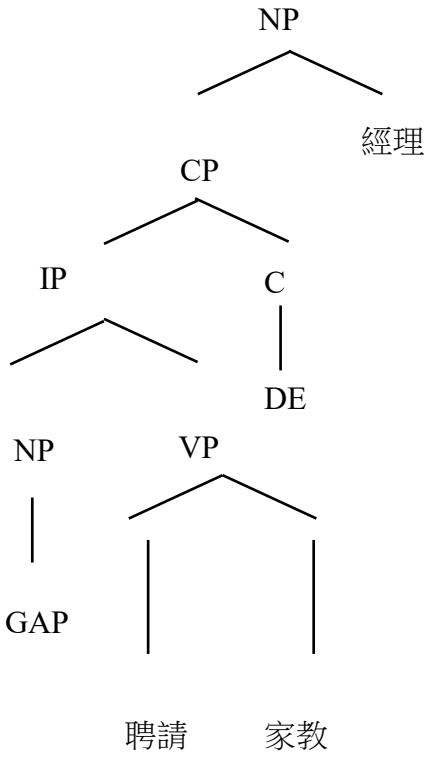
SRCs (3) stands in the higher position than that (the extracted object) in ORCs (4)

SRCs are easier to process than ORCs.

(3) The hierarchical representation of SRC



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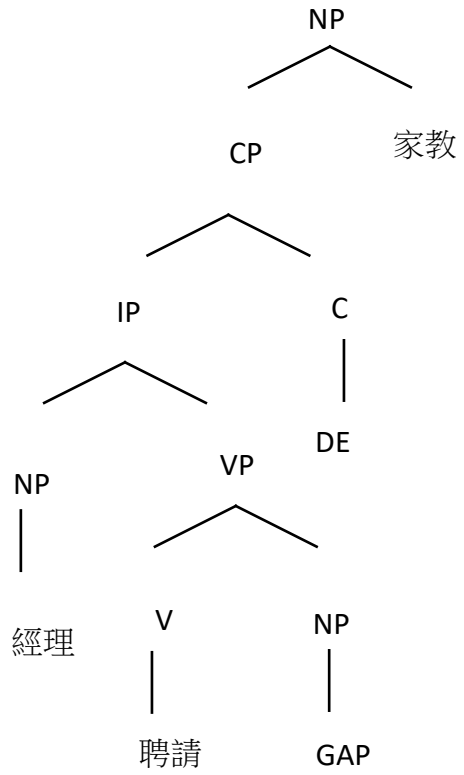
(4) The hierarchical representation of ORC



1.1.2 Memory-based account

Memory-based account differs from the structural-based theory in a way that it emphasizes that cognitive resources or working memory load influences the sentence comprehension. Dependency Locality Theory (DLT) proposed by Gibson (1998,2000) belongs to this account. Two key processes involved in language comprehension are proposed under DLT: storage cost and integration cost. Both of processes require working memory. DLT proposes that processing difficulty is associated with the storage cost of maintaining incomplete dependencies and the integration cost of connecting the

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newly input (e.g. head noun of RC) with the previous incomplete dependencies. Thus, this account asserts that longer linear distance between head noun and gap increases the memory load, and thus requires more cognitive resources. SRCs (5) involve more number of constituents intervening between the head noun and gap than ORCs (6), leading to the assumption of ORC preference.

(5) The linear representation of SRC

[**GAP** (subject) 聘請 家教 的 經理] 很聰明。

3 constituents between gap and head noun

(6) The linear representation of ORC

[經理 聘請 **GAP** (object) 的 家教] 很聰明。

1 constituent between gap and head noun

1.1.3 Experience-based theory

The frequency of the structures influences what the readers expects during the sentence processing. Readers experience difficulties when expectation turn out to be

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incorrect. This account claims that building rarer structures is more difficult than building frequent syntactic structures since readers have less experience on the less frequent syntactic structures (Jäger, et al. 2015). Based on this idea, this account would predict SRC preference, since SRCs are more frequent than ORCs in Mandarin.

1.1.4 Perspective Shifting Theory

This account (MacWhinney, 1977) argues that the processing of ORC is more difficult than SRC since readers have to shift perspective in ORC; whereas, they maintain the consistent perspective in SRC. For instance, in processing Mandarin SRC (e.g. 聘請 家教 的 經理 很聰明。), the subject of the main clause (經理) is the subject of the RC (經理). The consistent perspective is maintained. However, in ORC (e.g. 經理 聘請 的 家教 很聰明。), the subject of the main clause (家教) is not the subject of the RC (經理). Readers have to shift the perspective. Thus, this theory suggests SRC preference.

1.1.5 Word order account

Word order account focuses on how canonical the sequence of words is (Bever 1970; MacDonald and Christiansen 2002). It contends that relative clauses which have the similar word order as the simple sentence are easier to process than the ones that

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have the irregular word order. The typical Mandarin word order is SVO (Dryer, 1992; Greenberg, 1963); therefore, canonical word order in ORCs (S.+V.+DE+O.) should be easier than the non-canonical word order in SRC (V.+O.+DE+S.) in Mandarin.

The aforementioned theories do not provide consistent perspectives on the RC preference and most of them focus on the RC structure itself. Some psychological and neurolinguistics have also been carried out to delve into this issue and validate the related theories.

1.1.2 Psychological and neurolinguistics studies

Previous studies were conducted using self-paced reading tasks, eye-movement tasks and Event-Related Potentials (ERPs) measurements to investigate RC processing and processing asymmetry between SRCs and ORCs in Mandarin. Followings were the related studies.

Self-paced reading tasks were adopted intensively to investigate SRCs or ORCs preference, while the results remain inconclusive across studies. Some studies supported ORC preference in Mandarin (Hsiao & Gibson, 2003; Chen et al., 2008). Hsiao & Gibson (2003) manipulated subject-modifying SRCs and ORCs as subject in singly-embedded and doubly-embedded conditions (e.g. ORC: 教授/ professor 認識/know

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的/DE 記者/reporter 訪問/interview 的/DE 作家/author 很有名/very famous。;

SRC: 認識/know 訪問/interview 教授/professor 的/DE 作家/author 很有名/very famous.) The result revealed that in singly-embedded condition, the first two words of ORCs were processed faster than SRCs. In double-embedded condition, the third to sixth words (的/訪問 ; 記者/教授 ; 訪問/的; 作家/作家) of ORCs were processed faster than SRCs. Although the significance lies on different positions between two conditions ORCs were processed faster than SRCs in both conditions, indicating ORCs preference.

Chen et al. (2008) examined subject-modifying SRCs and ORCs and considered the variable of "working memory span". Comprehension performance showed that SRCs are more difficult to comprehend than ORCs. The reading time result indicated that participants with low working memory capacity spent more time on the first two words for the SRCs than the ORCs. This study suggested not only the important role of working memory in RC processing but also ORC preference.

ORC preference in Chinese has been challenged by other evidences of the SRC preference (Lin & Bever, 2006; Vasishth et al.,2013). Lin & Bever (2006) have argued that the result for both single embedding and double embedding in Hsiao & Gibson's

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(2003) study was confounded by other factors such as the verbs used in the RC structure. For example, among all the forty verbs used in the RCs, seven verbs take both sentential complements and objects and thirteen verbs take verbal complement. Since the verbs were ambiguous in the type of the syntactic arguments they can take, they argued that the materials were not well-controlled for syntactic ambiguity.

Therefore, Lin & Bever (2006) conducted a self-pace reading task with the better control on the materials but with the manipulation of single-embedded RCs as SRCs and ORCs. Each type of RC was manipulated in two types of modification, subject and object of the matrix clause (7). Their result showed that SRCs were processed faster than ORCs in both subject-modifier and object-modifier conditions, suggesting SRC preference. However, in regards to the processing RCs as the object-modifier, since the RCs were not positioned in the initial sentence, so the preceding word (e.g. the matrix verb: "見到/saw" in the sentence "記者 / reporter 見到/saw 商人/businessman 打傷/ hurt 的/DE) 歹徒/gangster) may influence the processing of the RCs. That is, different syntactic patterns that the matrix verb can take may lead to different processing difficulty on the following RCs. Nonetheless, the preceding context was not specifically controlled in this study.

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(7) Examples of Lin & Bever's (2006) experimental design

a. SRC modifying matrix subject

[打傷 商人 的 歹徒] 見到 記者

hurt businessman DE gangster saw reporter

b. ORC modifying matrix subject

[商人 打傷 的 歹徒] 見到 記者

businessman hurt DE gangster saw reporter

c. SRC modifying matrix object

記者 見到 [打傷 商人 的 歹徒]

reporter saw hurt businessman DE gangster

d. ORC modifying matrix object

記者 見到 [商人 打傷 的 歹徒]

reporter saw businessman hurt DE gangster

Sung and her colleagues (2016) conducted eye-movement experiment not only to address the issue of RC preference but also to discuss how RC-modifying Subject Noun Phrase (S-NPs) integrates with the main clause. The result suggested ORC preference proven by shorter gaze duration, regression path duration, total viewing time on head noun and S-NPs in ORCs. However, the regression rate for S-NPs in SRCs is lower than ORCs, indicating that S-NPs in SRCs are easier to integrate with the main clause than that in ORCs.

A few ERP studies have explored the real-time processing of RCs in Mandarin (Yang et al., 2010; Packard et al., 2010). Yang et al. (2010) investigated ERP effects on

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the processing of Mandarin object-modifying SRCs (e.g. 那個/that 議員/senator 介紹/introduce 攻擊/attack 政客 /politician 的 /DE 那個 /that/ 律師/lawyer/。That senator introduced the lawyer who attacks the politician.) and ORCs (e.g. 那個/that/ 議員/senator 介紹/introduce/ 政客/politician 攻擊/attack 的/DE/ 那個 /that/律師 /lawyer/。That senator introduced the politician whom the lawyer attacks.). Participants perform better on SRCs (mean accuracy 81%) than ORCs (mean accuracy 76%), suggesting that ORCs are more difficult to comprehend than SRCs. As for the ERPs analysis, this study divided the critical multiword segments into two regions, the RC region in which 1st noun and RC verb are included (e.g. SRC: 攻擊/attack/ + 政客 /politician/ →RC verb + RC noun ; ORC: 政客/politician/ + 攻擊/attack/→ RC noun + RC verb), and the head noun region (e.g. 那個/that/ 律師/lawyer/). The ERP result showed that for the initial word of RC region, RC verb in SRCs elicited a P600 preceded by a transient negativity. As for the second word of RC region, RC verb in ORCs elicited negativities from 290 to 500ms. Nevertheless, given that SRC and ORC are structurally different, ERPs analysis on different target words is questionable. That is, RC verb in SRCs was compared to the RC noun in ORCs. Since the structure of head noun in SRCs is as same as that in ORCs, so only the head nouns were comparable.

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Head noun in SRCs elicited right-lateralized anterior negativity, reflecting the need of memory demand in referential binding.

Packard and his colleagues' study (2010) suggested that SRCs are more difficult to process than ORCs in Mandarin, supported by larger P600 for SRCs over ORCs on the relative marker DE in subject position and on RC head noun in object position. With the similar experimental design as Lin and Bever's study (2006), the influence of the preceding word on the processing of RCs which function as the objects was not considered.

1.1.3 Interim Summary

Aside from the facts that no converging evidences over the RC preference were found, the aforementioned theories and studies focus mostly on the RC structure itself. The manipulation of the RCs was usually positioned as the subject. In the real-time reading, RCs were not always functioned as the subjects. RCs can be also embedded as the objects. Yet, studies in which RCs were manipulated as the object did not consider the preceding context. As sentence comprehension is an incremental process, the processing of the RCs can be influenced by the previous context. Those related studies do not take the notion of "incremental processing" into consideration and the

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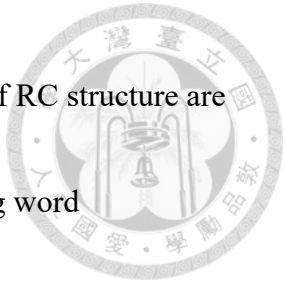

discussions over the issue of how context influences the processing of RC structure are relatively few; therefore, this study aims to investigate how preceding word incrementally modulates RC processing in Mandarin. Verb bias which carries both semantic and syntactic information is manipulated as context to address this issue. Next section reviews the theoretical background and psycholinguistic experiments regarding to "The role of verb bias in sentence processing".

1.2 Comprehension models on the role of verb in sentence processing

Two competing comprehension models have been proposed to discuss the influence of knowledge about the verb in sentence comprehension: two-stage model and constraint-based model.

1.2.1 Two-stage comprehension model

Two-stage theory proposed by Frazier (Frazier, 1987; Frazier & Clifton, 1996; Frazier & Fodor, 1978). argues that the initial parsing of an ambiguous sentence is built based on the simplest structure. Information about word semantics or verb bias does not affect this initial stage. During the second stage of sentence processing, if the initial representation does not match with the following structure, the reanalysis occurs and the parsers re-construct the structure. For example, the parsers initially interpret the noun

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following the verb as a direct object since this is the simplest structure; however, if the interpretation is wrong, the parsers re-analyze the sentence structure during the second stage.

1.2.2 Constraint-based comprehension model

In contrast, the other type of comprehension model—constraint-based model (Clifton et al., 1991; MacDonald et al., 1994) proposes that multiple types of information compete and come into play at the initial stage of sentence processing, including syntactic and semantic information such as semantic plausibility and verb bias (Garnsey et al. 1997; Wilson and Garnsey 2009). A verb contains multi-faceted information including the syntactic arguments it can take and the possible semantic constraints on its argument. Some verbs can only take a specific subcategorization frame. For instance, the subcategorization frame of the verb *bake* is <NP1 bake NP2: I bake a cake>. The verb *bake* can only take a noun phrase, or a direct object. Other verbs can take multiple possible subcategorization frames. The verb *admit* can take multiple subcategorization frames, as in *The man admitted the crime* <NP1 admit NP2> or in *The man admitted that he stole the phone* <NP1 admit NP1 VERB NP2>. The verb *admit* can not only take a direct object but also a sentential complement. Such verbs that

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can take more than one subcategorization frame can exhibit a bias; therefore, verb bias refers to the probability that the particular verb occurs in certain kind of subcategorization frame. Verbs that are frequently followed by embedded clauses and rarely followed by direct objects are termed *sentential complement (SC) biased verb* and verbs that are frequently followed by direct objects and rarely followed by embedded clauses are termed *direct-object (DC) biased verbs* (Garnsey et al, 1997). The parsers develop an expectation about the syntactic and semantic information that the verb should carry which is called "verb bias effect". The parsers have processing difficulty, if the expectation contradicts to the structure. The verb *admit* is classified as Sentential-Complement bias verb (SC bias verb) in Wilson and Garnsey's norming (2008) study. The parsers would expect a clause following the verb *admit*. If they encounter a direct object, they experience the processing difficulty. To sum, two-stage theory proposes that the initial sentence processing relies upon the simplest structure and the structure needs to be re-analyzed afterwards if the violation occurs; whereas, both syntactic and semantic information come into play at the initial parsing stage in the constraint-based model.

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1.3. The role of verb bias in sentence processing

Previous studies have investigated the role of verb bias in sentence processing (Trueswell et al.,1993; Garnsey et al, 1997; Wilson & Garnsey, 2009), and attempted to validate the two-stage model and the constraint-based model. Trueswell et al. (1993) in their series of experiments suggested that verb subcategorization information was accessed rapidly in sentence processing. They conducted a norming study to classify the verbs that are strongly biased to certain subcategorization. With the result of sentence completion test in which participants had to complete the sentence fragment "Subject Verb _____" (e.g. John insisted _____.), eight verbs were classified as Noun Phrase (NP) biased verbs and eight verbs as Sentential complement (S) biased verbs. Each of the verbs was adopted to construct the auditory sentence fragment "the noun phrase + either verb + (that)" (e.g. The old man insisted (S-bias verb) /observe (NP-bias verb). Each fragment was then paired with two targets: the nominative pronoun *he* and the accusative pronoun him (e.g. The old man insisted *him/he*; observed *him/he*). After the target was shown on the screen, the participant had to name the target word as soon as possible. The result showed that the naming times were fastest on *him* following NP-bias verb and slowest on him following S-bias verb, suggesting verb bias

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subcategorization information was immediately accessed. In their subsequent experiment which investigated how subcategorization information was used in resolving the ambiguous noun phrase (e.g. (NP-bias: The student forgot (that) the solution was in the back of the book.; S-bias: The student hoped that the solution was in the back of the book.), they proved that subcategorization information was used to determine whether the attachment of a noun phrase was the NP complement or the subject of a sentence complement. On the *be* (e.g. was) verb, in sentence with NP-bias verb, larger reading times was shown on the sentence which did not contain *that* than the sentence containing *that*. However, no such difference was found in sentence with S-bias verb. The result demonstrated that subcategorization information was used to determine the role of the noun phrase – either the NP complement or the subject of the sentence complement.

However, Garnsey et al. (1997) suggested that the design of Truewell and his colleagues (2003) was problematic. In Truewell et al. (2003)'s study, in each sentence set, the plausibility of the post-verbal noun phrase (e.g. the directions) to the main verb were not balanced (8). For instance, nouns that were plausible as direct object of the NP-bias verb (e.g. remembered) were sometimes less plausible for S-bias verbs (e.g.

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claimed).

(8) Examples of Truewell et al. (2003)'s study

a. Mr. Smith remembered the directions

b. Mr. Smith claimed the directions…

Hence, Garnsey et al. (1997) conducted a self-pace reading task which concerned the plausibility of the post-verbal noun phrase and increased the amount of the selected verbs. In their studies, forty-eight verbs were selected and each of them were constructed four sentence versions (9). In 9(a), the "*decision*" was plausible as the direct object of "*regretted*", but the "*reporter*" was not.

(9) Examples of the sentence structure in Garnsey et al. (1997)'s study

a. The senior senator regretted (that) the decision had ever been made public.

b. The senior senator regretted (that) the reporter had ever seen the report.

The result presented that verb bias plays an important role in initial sentence processing. For instance, in sentence with direct-object (DO) bias verbs, first-pass times on the temporarily ambiguous noun phrase (e.g. "the reporter) were slower than the same noun phrase in an unambiguous sentence (e.g. "that the reporter") and the plausible noun phrase in an ambiguous sentence. (e.g. the decision). This reflected that the noun phrase was interpreted as the direct object after these verbs. Therefore, this study also supported that verb bias can rapidly resolve the temporarily ambiguity and supported the constraint-based model.

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In Wilson and Garnsey (2009)'s study, self-paced reading task and eye-movement experiment were also conducted to investigate the verb bias. Three types of sentence were constructed for each verb type (DO-and SC-bias verb): a. verb followed by direct object continuation b. verb followed by sentential complement continuation. c. verb followed by the complementizer *that* and sentential complement continuation (10). Self-paced reading task revealed the longer reading time on the mismatch between the verb bias and sentence continuation. The direct object continuation was read significantly slower after SC-bias verbs than DO-bias verbs. In contrast, sentence complement continuation following DO-bias verbs was read significantly slower than SC-bias verbs. This result provided evidence that verb bias guides the early stage of sentence comprehension. The same paradigm was also used in the eye-tracking experiment.

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(10) Examples of Wilson & Garnsey's (2009) experiment

SC-bias verb

a. The ticket agent admitted the mistake because she had been caught.
b. The ticket agent admitted the mistake might not have been caught.
c. The ticket agent admitted that the mistake might not have been caught.

DO-bias verb

a. The talented photographer accepted the money because he was asked twice.
b. The talented photographer accepted the money might not be legally obtained.

The result showed that when readers encountered the sentential complement following the DO-bias verb, they slowed down on the disambiguation region (the underlined region) and re-read earlier sentence regions; however, when they read the direct object following the SC- bias verb, they directly went back and re-read earlier regions. The findings supported the constraint-based model. If the simplest structure is expected at the initial stage, there is no need of re-reading in the condition of direct object continuation. Yet, the readers slowed down when they encountered the sentential complement followed by DO-bias verb. This supported that verb bias led the readers to expect the potential continuations following DO-bias verb. Hence, in parsing sentences, verb bias immediately comes into play. This

An ERPs study conducted by Osterhout and Holcomb (1992) found that both grammatical violation and less-preferred but grammatical structure can be indexed by

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P600 effect. In the ungrammatical condition, the auxiliary verb in the sentence containing transitive verb (e.g., “He forced the patient *was* lying.”) elicited a more positive-going waveform within 500-800ms window than that in the sentence containing intransitive verb (e.g., “He hoped the patient *was* lying.”). As for the condition of less-preferred but grammatical structure, the auxiliary verb in the sentence containing transitively biased verb (e.g., “He charged the patient *was* lying.”) elicited a more positive-going waveform than that in the intransitively biased verb condition (e.g., “He believed the patient *was* lying.”). The finding indicated that the parsers can use the information about verb subcategorization during sentence processing.

So far, only a few studies have discussed the verb bias effect in Mandarin RC processing. Lin and Garnsey (2011) have found a verb bias effect on complex sentence processing in Mandarin. Verbs were chosen and categorized based on the corpus study done by Lu and Garnsey (2008,2009) in which fifty sentences for each verb were selected from Chinese Gigaword and then hand-coded. Two types of verb bias (DO-bias and SC-bias verbs) were manipulated as the main verb in the sentence with Mandarin objective relative clauses (11).

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(11) Examples of sentence structure

a) Baseline

老師　　討厭　　那個 家長。

Teacher　dislike　　that　parent.

b) DO-bias condition

老師　　討厭　　那個 家長　　痛罵　　的　　學生。

Teacher　dislike　　that　parent　　scold　　DE　　student.

c) SC-bias condition

老師　　相信　　那個 家長　　痛罵　　的　　學生。

Teacher　believed　　that　parent　　scold　　DE　　student.

The result showed longer reading time on the second verb (e.g. 痛罵/scold) after the DO-bias verb. This difficulty lasts on the subsequent words, relative clause marker DE, and RC head noun (e.g.學生/student). When reading DO-bias verb in the main clause, readers did not expect another verb and thus slowed down when another verb appeared. Therefore, the finding supported that verb bias influence readers' expectation on the complex sentence processing.

1.3 Current study

In view of the issues mentioned above, the goal of this study is to investigate the role of verb bias which carries both semantic and syntactic information in real-time Mandarin RCs processing. This study will apply the Event-Related Potentials (ERPs) measurement to achieve this goal due to its high temporal resolution. Several ERPs components related to language processing have been identified, such as the N400,

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P600, and frontal negativity. N400, a negative-going waveform peaking around 400ms, was characterized as reflecting the semantic processing (Kutas & Hillyard,1980a, 1980b; Kutas & Federmeier, 2000). N400 enhances for words that do not fit to the previous semantic context. In a classic study, larger amplitude of N400 was found on "cry" that was semantically incongruent to the sentence (e.g. "The pizza was too hot to cry") than "eat" that was congruent (e.g. "The pizza was too hot to eat") (Kutas & Hillyard,1980). The P600, positive-going waveform peaking around 500ms, indexes the syntactic processing (Osterhout and Holcomb,1992; Hagoort et al. 1993). Syntactic violation elicited the P600. For instance, the ungrammatical sentence elicited P600s than the grammatical sentence. "to" following the transitive verb which leads to ungrammaticality (e.g. "The woman persuaded to answer the door.") elicited P600 than that following the intransitive verb "The woman struggled to prepare the meal". As for frontal negativity, it was shown to reflect thematic-role ambiguity and (King & Kutas, 1995), the process of establishing reference (Barkley et al., 2015; Van Berkum et al, 2007; Nieuwland et al., 2006). Given the knowledge on the ERPs components regarding to language processing, two ERPs experiments would be conducted. The possible effects observed on those ERPs components might be able to address this issue.

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The purpose of the first experiment is to examine the verb bias effect on online ORCs processing. The second experiment focuses on how verb bias influences online SRCs processing. With the use of ERP technique and the understanding about the verb bias effect on ORCs and SRCs, this study attempts to discuss how verb bias incrementally affects the real-time Mandarin RCs processing. Furthermore, “word order” might also be an intervening (/or crucial??) role in this issue. The importance of word order in Mandarin has been underlined by researchers (Chao, 1968; Chen 1995; Ho, 1993). Mandarin relies heavily on word order as an underlying marking feature for meaning (Ho, 1993) since Mandarin lacks case and agreement markings (Chao, 1965; Chen 1995; Ho, 1993). Moreover, word order plays an important role in information structuring (Chen, 1995). Given that ORCs and SRCs are different in their word order; that is, ORCs follow Mandarin word order, but SRCs do not, the role of “word order” in RCs processing should be also taken into account.

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Chapter 2. Event-Related Potential Studies: The influence of verb bias on ORC processing

Current study aims to investigate the verb bias effect on real-time ORCs processing. The norming study would be conducted to categorize types of verb bias. Each type of verb bias would be followed by an object-modifying Object Relative Clause (ORC). ERP analysis for four regions of ORC would be carried out to examine the incremental influence of verb bias.

2.1 Materials and Methods

2.1.1 Participants

Thirty-four right-handed undergraduate and graduate students between the age of 18 and 28 participated in this study. Participants were all native speakers of Mandarin Chinese in Taiwan with no history of neurological or psychiatric disorders. Each participant signed the consent before the experiment and were paid $500 NT of their participation. All participants were evaluated for their working memory and verbal memory capacities with working memory test of the Wechsler Adult Intelligence Scales-fourth edition (WAIS-IV; Weschler, 2008) and reading span test.

(1) Working memory test (WAIS-IV): This test measure participants' digit span.

Participants were required to memorize and recall the numbers in forward,

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backward and ascending order. The total score of working memory is 48.

(2) Reading span: In this test, participants were required to read aloud a series of sentences (series of 2, 3 4, 5, 6 sentences), and at the end of that series, they had to recall the final word of each sentence. After recalling the final words, they had to answer one comprehension question. The total score of reading span ranges from 1 to 6 (0.5 point as a score unit). This test has been shown to correlate with participants' reading ability (Baddeley, 1979; Daeneman & Carpenter, 1980; King &Just, 1991). Table 2.1 presents the results of the behavioral tests.

Table 2.1. The result of behavioral tests

Behavioral tests	Mean score	Range
WAIS-IV (working memory capacity)	35.68 (3.97)	28-43
Reading span test	2.51 (0.77)	1.5-4.5

Note. Standard deviations are in parentheses.

2.1.2 Experimental Stimuli

This study aimed to manipulate three types of verb bias, Direct Object (DO), Sentential Complement (SC), and Equilibrium Balanced (EQ) bias verb in the ORC sentences. All the target sentences were constructed with the following syntactic structure of the target sentences: Subject + DO/SC/EQ-bias main verb + ORC structure (embedded RC noun + RC verb + RC marker DE + head noun). To achieve this goal,

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we first conducted a norming procedure to quantify the verb bias.

Norming study of verb bias

44 high frequency verbs that can take both direct object and sentential complement and have a frequency of 40 or greater per million words were selected from Academia Sinica Balanced Corpus of Modern Chinese, version 4.0 (Sinica Corpus). The reason for using the high-frequency verb is to ensure that there would be sufficient sentences using that using that particular verb in the corpus for the analysis on the classification of verb bias. The mean frequency of the high frequency verbs is 133 (± 153). The total of 300 sentences using that particular verb were extracted and the continuation following the verb was then hand coded by two raters: DO for direct object, SC for taking sentential complement, and Other for not taking either DO or SC or for not easily to be reconstructed. If the counts of the given verb taking Other category exceeded the threshold of 25%, this verb was excluded. These verbs were then classified into three types of biases: DO-bias, SC-bias, and EQ-bias verb, based on the following definitions. Verbs were classified as SC-bias if they occurred at least twice as often with a sentential complement than with a direct object and categorized as DO-bias if they appeared at least twice as often with a direct object than with a sentential complement. Verbs were

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classified as EQ-bias if they were approximately equally followed by direct objects and by sentential complements. Examples of the annotation process and the result of the classification are shown in Table 2.2.

Table 2.2. Examples of the classification of the verb bias

Types of verb bias	**Examples of annotation process**	**Percentage of taking either types of continuations**
DO-bias verb 遇到	1. 爸爸遇到 他的好朋友，阿瘦皮鞋的老闆，他說…. ***DO*** 2. 當我遇到 厭惡的人時，我鐵定... ***DO*** 3. 如果遇到 有岔路時，爸爸就慢慢的開，... ***SC*** 4. 因為地球是圓的，總有一天還是會遇到，至少還是朋友吧! ***others***	+DO: 87% +SC: 12% +others: 1%
SC-bias verb 擔心	1. 這些抗爭的焦點之一當然是環保問題，居民擔心政府或大企業的科技及建設將帶來汙染，政府則一再空泛… ***SC*** 2. 由於天氣漸漸炎熱，市長擔心登革熱及無菌性腦膜炎引發流行趨勢，昨天特別指示… ***SC*** 3. 過分擔心自己的健康，往往會造成… ***DO*** 4. 不用擔心，我還會送你回來的。 ***others***	+DO: 23% +SC: 65% +others: 13%

With the criteria mentioned above, three verbs were excluded, two for taking over 25% of the Other syntactic patterns, and one for inconsistent coding results between two

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raters. Thus, 14 DO-bias, 13 SC-bias, and 14 EQ-bias verbs with medium to high interrater agreement (DO-bias verb: kappa = 0.8, p >.05 ; SC-bias verb : kappa = 0.9; DO-bias verb: kappa = 0.8, p >.05 and EQ-bias verb: kappa = 0.3, p >.05) and no differences on the word frequency were thus chosen to construct target sentences (F= 0.9, p >.05) (Table 2.3).

Table 2.3. The characteristics of verb bias

	Percentage of taking either continuations	**Frequency of the verb (per million words)**
DO-bias verb	76% (taking direct objects)	113±111
SC- bias verb	75% (taking sentential complements)	167±190
EQ- bias verb	45%,45% (taking direct objects; sentential complements)	96±96

The construction of target sentences and fillers

The present experiment consisted of 41 target sentences with the manipulation of 14 DO-bias, 13 SC-bias, and 14 EQ-bias verbs as well as 27 fillers (Table 2.4). Each critical region of the ORC, were matched for word length, word frequency and the associations between critical words with no differences between conditions. The embedded RC noun, RC verb, and head noun were all two-character words. The word frequency of embedded RC noun and head noun in each condition was low-medium word frequency, the frequency of 58 or greater per million words, with no differences

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between conditions (embedded RC noun: F = 0.165, p > .05; head noun: F= 0.38, p > .05). To further control the word predictability, the association between words were computed using word2vec (Mikolov et al., 2013). The values of the association between words, as shown in Table 2.5, including association between main verb and embedded RC noun (F = 0.019, p > .05), as well as association between head noun and main verb (F= 2.267, p >.05), RC verb (F= 1.87, p >.05), and embedded RC noun (F=0.621, p> 0.5) has to be lower than the value 0.3 (more than 0.3: high associations between words, 0.2-0.1: medium-low associations, lower than 0.1: low associations) with no differences between conditions.

Additionally, 27 filler sentences were created for preventing the participants from developing strategies, including three syntactic structures—a. simple SVO structure: subject + main verb + (adjectives) object b. subject + main verb + sentential complement with embedded ORC/SRC, and c. subject + main verb + sentential complement (Table 2.4).

Table 2.4. Examples of target and filler sentences

Target sentences					
Main Clause		**Objective Relative Clause (ORC)**			
Subject	**Main verb (Types of**	**embedded RC noun**	**RC verb**	**RC marker**	**Head Noun**

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	verb biases)				
他	**DO-bias**: 想起	里長	資助	的	街友
他	**SC-bias:** 擔心	客人	批評	的	領隊
他	**EQ-bias**: 看見	護士	幫助	的	災民

Types of filler sentences	**Examples**
subject + main verb + (adjectives) object	他質疑長官。
subject + main verb + sentential complement with embedded ORC/SRC	他否認黨團提名立委為候選人。
subject + main verb + sentential complement	他擔心孩子想不開。

Table 2.5. The characteristics of the stimuli

	Frequency (per million words)				
Types of verb bias	**embedded RC noun**	**RC verb**	**Head Noun**		
DO-bias	24.10±25.2	59±87.94	24.10±25.2		
SC-bias	22.10±16.50	94.52±71.85	17.30±10.90		
EQ-bias	25.80±19.98	73.45±74.16	18.40±14.76		
	Association values				
Types of verb bias	**Main verb-embedded RC noun**	**Head noun-Main verb**	**Head noun-RC verb**	**Head noun-embedded RC noun**	
DO-bias	0.07 ± 0.04	0.09 ±0.06	0.11 ±0.09	0.17 ±0.11	
SC-bias	0.07 ± 0.06	0.08 ±0.07	0.08 ±0.08	0.13 ±0.08	
EQ-bias	0.07± 0.05	0.05 ±0.05	0.13 ±0.05	0.14 ±0.06	

One-third of the experimental sentences were followed by one true/false comprehension question to ensure that participants payed attention on reading

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comprehension during the experiment.

2.1.3 Predictions

The first experiment aims to shed light on how verb bias influences the ORC processing. It was hypothesized that the sentences with DO-bias verbs that were expected to be followed by a direct object, would be more difficult to process than the sentences with SC-bias verbs that were expected to be followed by a sentential complement. This processing difficulty may be shown on RC verb and head noun. Predictions on RC verb and head noun were listed as follows:

I. RC verb

The difficulty may be first shown on the RC verb which may be indexed by P600 or frontal positivity. DO-bias verbs were expected to be followed by a direct object, so the appearance of the RC verb may be a non-preferred structure that may lead to larger P600 or frontal positivity as compared to that followed by SC-bias verbs.

II. Head noun

When parsing the sentences with DO-bias verbs, readers might engage in the process of referential binding. That is, when they found out that the embedded RC

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noun they read was not the direct object of the main verb, they had to look for the actual direct object for the main verb. direct object for the main verb. This process difficulty of searching for the direct object and establishing the referential binding might reflect on N400 and frontal negativity, respectively.

Aside from DO-biased and SC-biased verbs, some verbs do not have clear tendency of taking either more direct objects or sentential complements. Those verbs were classified as EQ-bias verbs. The sentences with EQ-bias verbs may serve as a baseline, to be compared with DO-biased and SC-biased verbs conditions. Or alternatively, they may exhibit a similar processing pattern to either DO-bias or SC-bias condition. In order to delve into the role that each verb bias plays in the ORC processing, contrasts between conditions, including – SC-DO, SC- EQ, and DO-EQ bias contrasts, were be performed on N400 and frontal positivity.

2.1.4 Procedure

Each participant first underwent the ERPs experiment and then three consecutive behavioral assessments. For the ERPs experiment, participants were given 13 trials for practice session, 67 randomized experimental trials in two sessions. Participants were

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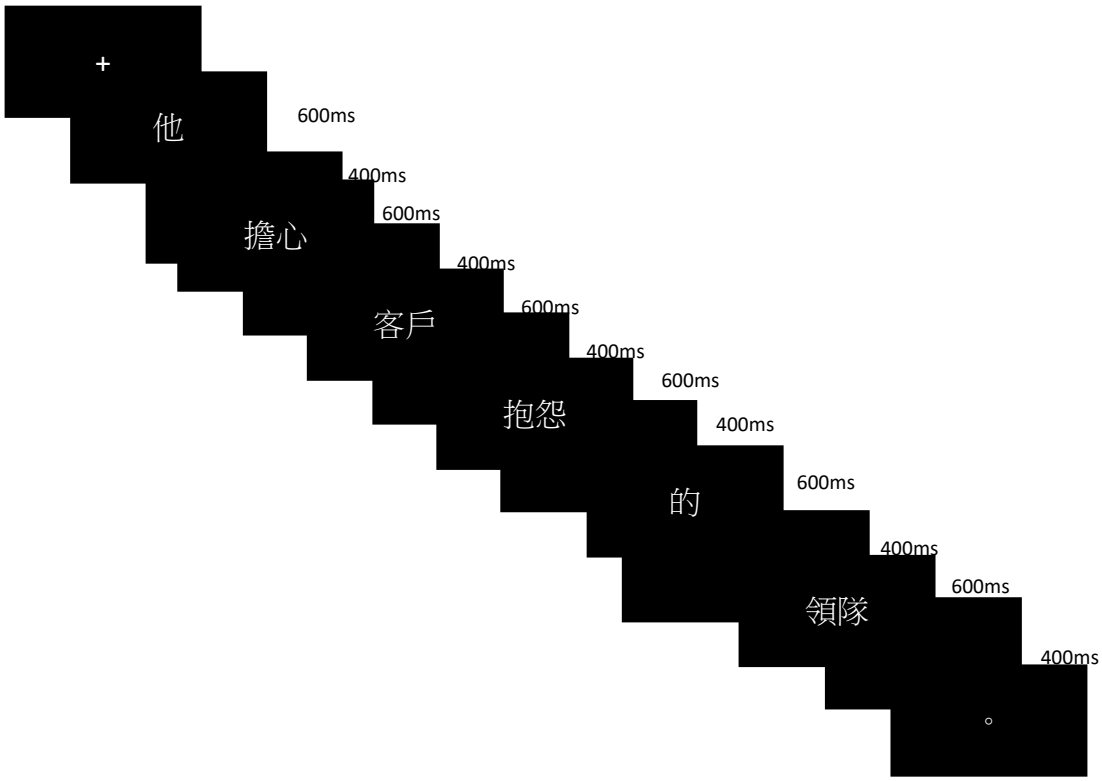
seated 90cm from the computer screen in a quiet room, with visual sentences presented centrally. Each trial began with the fixation ”+” for 200ms. Sentences were presented word by word. Each word displayed for 600ms with 400ms inter-stimulus interval (ISI). The sentence ended with a period. If the participants were ready for the next trial, they pressed the “enter” button; otherwise, the period marker “ ◦ ” lasted for 400ms. One-third of the sentences were followed by a comprehension question. When the participants saw the question, they had to respond “yes” or “no”. If the answer was incorrect, they would be signaled by “Wrong answer! Please pay attention!” on the screen. If the participants were ready for the next sentence, they pressed the “enter” button.



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2.1.5. EEG recording and data analysis

The electroencephalogram (EEG) was recorded using SymAmP2 produced by NeuroScan with 64 electrodes from the 10-20 system. All scalp electrodes were referenced to a common vertex reference located between CZ and CPZ and re-referenced offline to the average of the right and left mastoids. Vertical eye movements (VEOG) were recorded via electrodes placed on the supraorbital and infraorbital ridge of the left eye, and horizontal eye movements (HEOG) were recorded via electrodes placed at the outer canthus of both eyes. Electrode impedance was kept below 5Ω. The EEG data were continuously recorded and digitalized at a sampling rate of 1000 Hz.

All the trials were included in ERPs preprocessing and further statistical analysis. Given that the trials were relatively few, the EEG data were decomposed by applying the ensemble empirical mode decomposition (EEMD) for data analysis. Previous studies have suggested that EEMD can improve the signal-to-noise ratio (Al-Subari, Al-Baddai, Tomé, Goldhacker, et al., 2015; Al-Subari, Al-Baddai, Tomé, Volberg, et al., 2015 ; Chen, Chao, Chang, Hsu, & Lee, 2016 ; Cong et al., 2010 ; Hsu, Lee, & Liang, 2016). For instance, Hsu, Lee, and Liang (2016) applied EEMD to reanalyze the the

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dataset of Cheng et al. (2013) and showed demonstrated that only one third of the original trials were required to replicate the mismatch negativity (MMN) effect. Chen et al. (2016), Tzeng et al. (2017) also applied EEMD for N400 measurement. This study applied the same analytic procedure for N400, late positivity and frontal negativity measurement, as described as follows:

(1) The time range for EEG segments for EEMD analysis was from 200ms before stimuli onset to 1000 after the onset.

(2) The EEMD analysis was performed with 10 times of sifting and 40 ensembles. The amplitude of Gaussain noises used in the EEMD procedure was 10% of EEG signal's standard deviation.

(3) Each EEG segment was decomposed into eight Intrinsic Mode Functions (IMFs).

(4) According to the previous studies, the summation across IMF6, IMF7, and IMF8 which cover the frequency range from 0.5 to 6.5Hz were used to extract N400 signal, and IMF7 and IMF8 ranging from 1.65-3Hz for late positive or negative waveform (Chen et al., 2016, Roehm, Bornkessel-Schlesewsky, & Schlesewsky, 2007; Roehm, Schlesewsky, Bornkessel, Frisch, & Haider,

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2004). Then, the summation was averaged over all trials for each condition and each channel for each participant to yield the event-related modes (ERMs) to represent the original ERPs.

2.2 Result

One participant was excluded from further analysis due to the insufficient valid trails; therefore, this study analyzed the total data of twenty-nine participants.

2.2.1 Accuracy of comprehension test

The overall accuracy of comprehension test was 87% (SD= 0.06, range: 68% -100%), showing that participants did not have difficulty understanding the sentences and had pay attention in the experiment.

2.2.2 Statistical analysis for ERPs data: cluster-based random permutation analysis

To evaluate the temporal and topographical differences between conditions (SC vs. DO, SC vs. EQ, and DO vs. EQ), the cluster-based random permutation analysis was conducted on each of the following critical regions – embedded RC noun, RC verb, DE and head noun – for the mean amplitudes of two epochs, N400 from 250 to 500ms and late component (frontal positivity/ negativity) from 500 to 1000ms. First, for each contrast, a simple dependent-samples *t* test was performed at each electrode. Electrodes that exceeded a significance level (alpha = 0.1) were identified and formed as either

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negative or positive clusters. For each cluster, the cluster-level test statistics was calculated by taking the sum of all the individual t statistics within that cluster. Next, a null distribution was created by computing 100 randomized cluster level test statistics. The observed cluster-level test statistics was compared against the null distribution. The clusters fell into the highest or lowest 2.5th percentile were considered significant. Then, the cluster-based random permutation analysis was also performed on each time point to identify and form the time cluster. Finally, 1000 randomized cluster-level test statistics was conducted for each cluster on the basis of spatial and temporal adjacency. Thus, this procedure yielded the significant cluster that displayed the contrast between conditions.

2.2.3 ERPs result (n = 28)

The cluster-based permutation analysis

Contrasts on embedded RC noun

Figure 2.1 presented the grand-averaged ERMs waveforms elicited by embedded RC noun in three types of verb bias conditions. It showed that embedded RC noun in the sentence with DO-bias verb elicited larger positive-going waveform in the late time window than that in the sentence with SC-bias verb. The cluster-based random permutation analysis (Figure 2.2) revealed that no significant negative cluster was found

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in DO-SC contrast in time window of 250-500ms, but significant negative cluster in DO-EQ (321-460ms; $p<0.01$) and SC-EQ (330-464ms; $p<0.01$) contrast. In the late time window of 500-1000ms, DO-SC contrast (512-1000ms; $p<0.01$) elicited a significant negative cluster in left frontal-to-central regions.

Figure 2.1. Grand averaged ERMs of the embedded RC noun for DO-bias, SC-bias, and EQ-bias conditions.

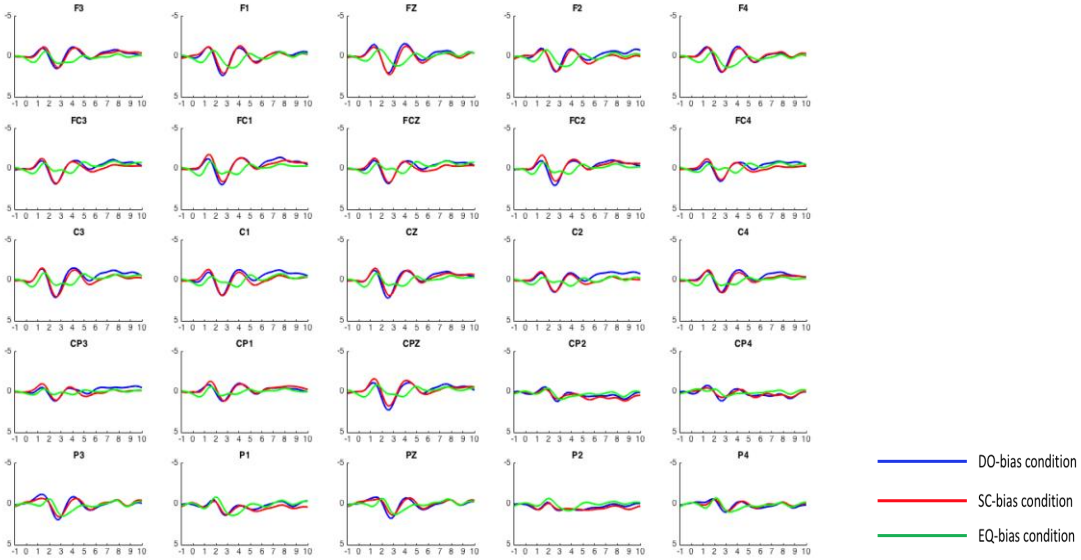

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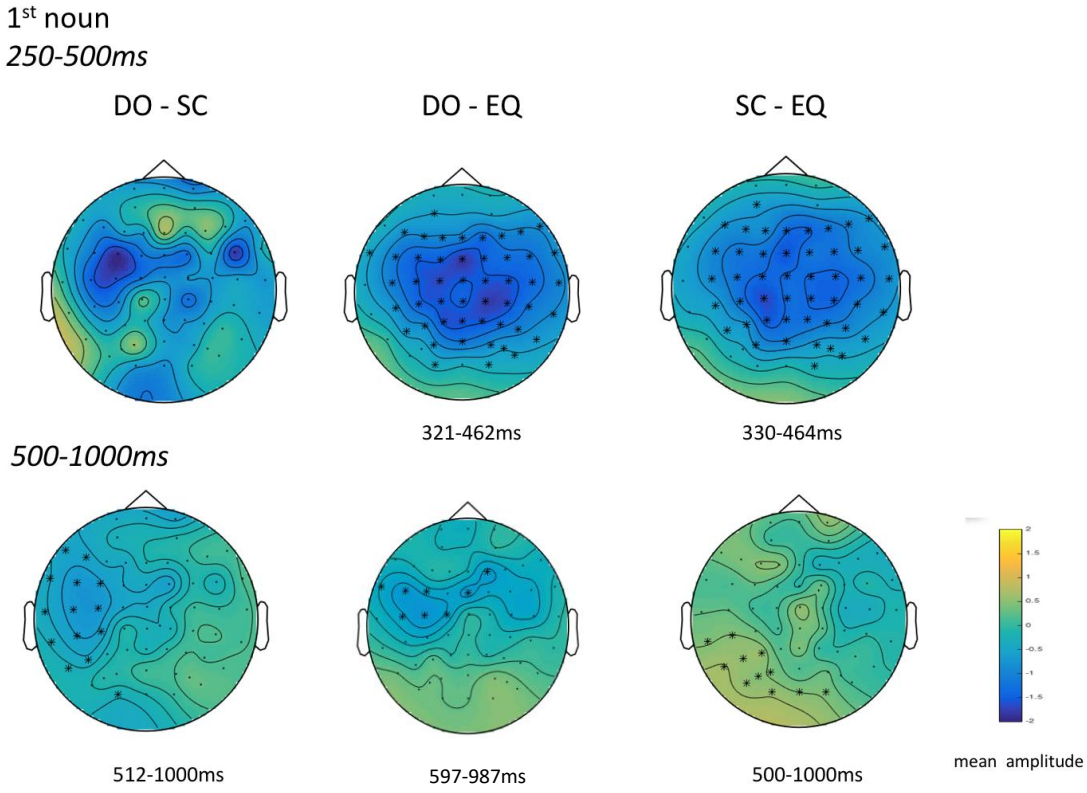
Figure 2.2. Topographic maps of embedded RC noun for DO-SC, DO-EQ, and SC-EQ contrasts in N400 and late time window (500-1000ms).



Note. Asterisks represent the significant differences for the contrasts.

Contrasts on RC verb

Figure 2.3 presented the grand-averaged ERMs waveforms elicited by RC verb. RC verb in the sentence with SC-bias verb elicited larger positive-going waveform than that in the sentence with DO-bias verb in the late time window. The cluster-based random permutation analysis (Figure 2.4) revealed that no significant negative clusters at DO-SC and DO-EQ contrast in the time window of 250-500ms were found. Yet, in the time window of 500 to 1000ms, DO-SC contrast elicited significant positive clusters

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in frontal regions (617-1000ms, $p<0.01$)

Figure 2.3. Grand averaged ERMs of RC verb for DO-bias, SC-bias, and EQ-bias conditions.

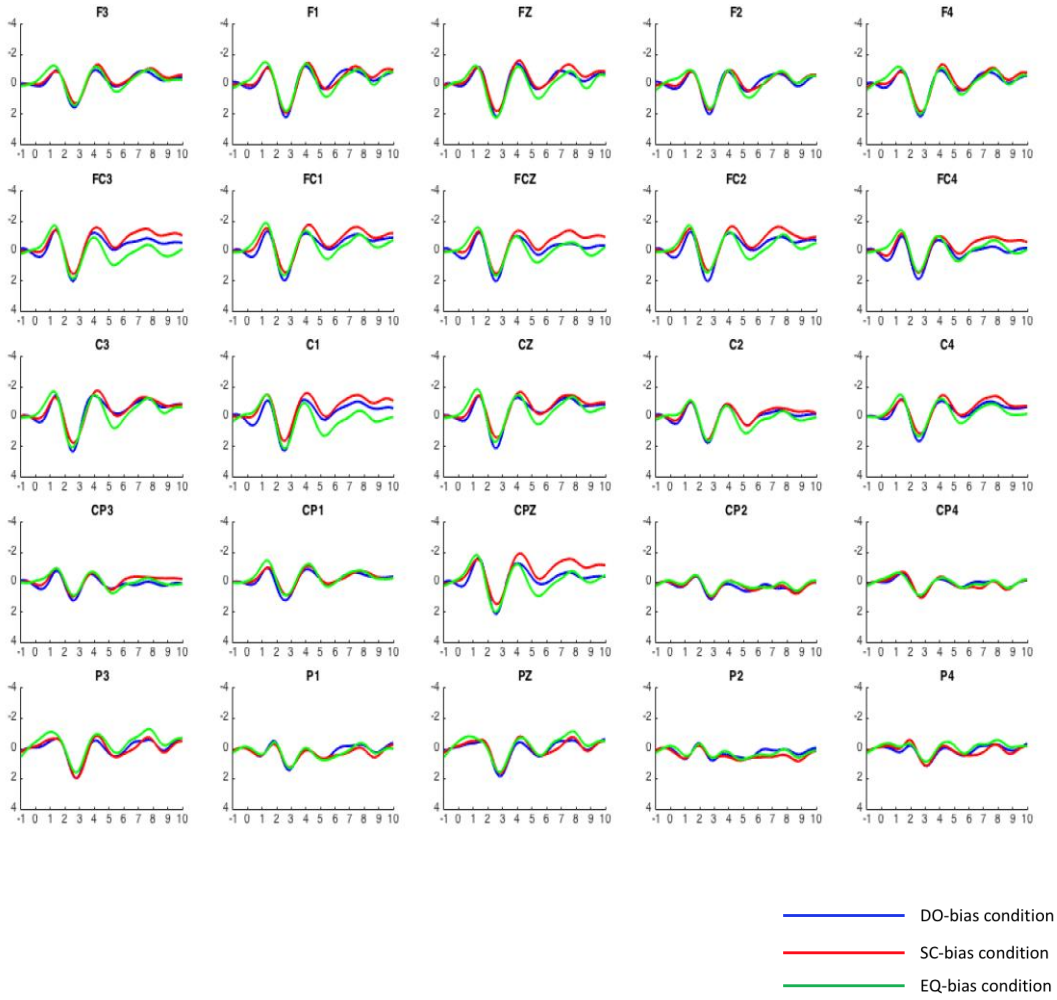

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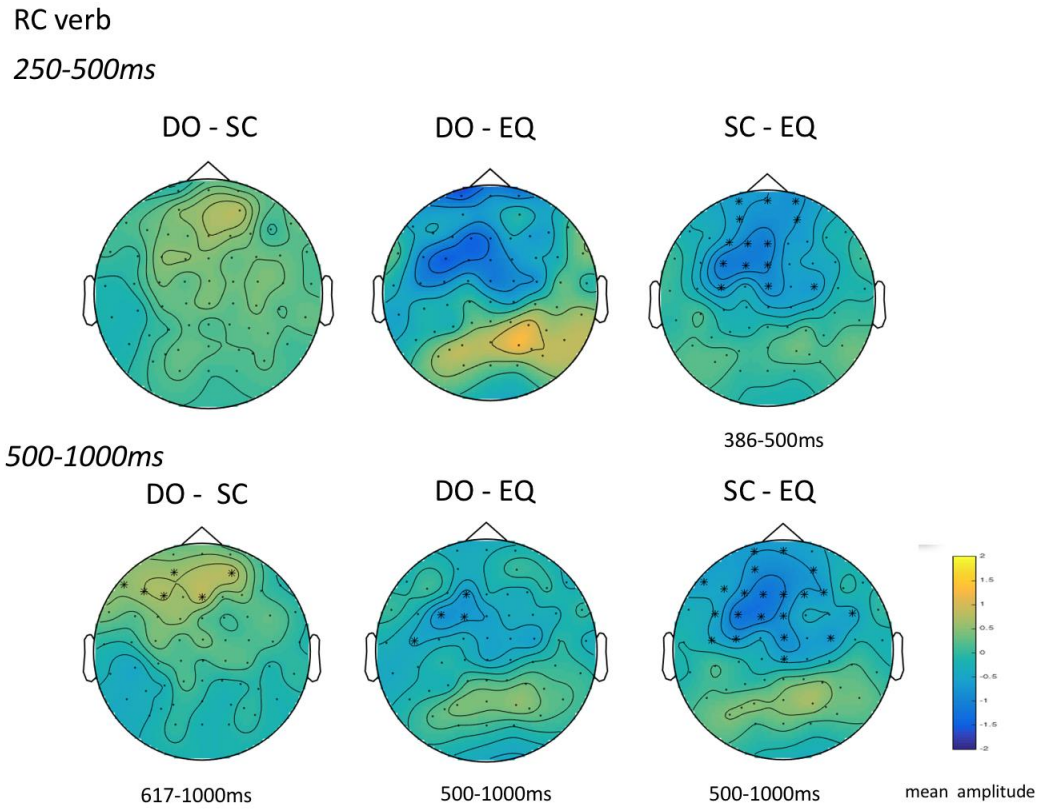
Figure 2.4. Topographic maps of RC verb for DO-SC, DO-EQ, and SC-EQ contrasts in the N400 (250-300ms) and late time window (500-1000ms).



Note. Asterisks represent the significant differences for the contrasts.

Contrasts on DE

Figure 2.5 showed the grand-averaged ERMs waveforms elicited by DE. DE in the sentence with DO-bias verb elicited negative-going waveform than that in the sentence with SC-bias verb in the time window of 250-500ms. The cluster-based random permutation analysis (Figure 2.6) revealed the significant negative clusters in central and posterior sites in DO-SC contrast (318-455ms, $p<0.01$), significant negative clusters in right central and posterior sites in DO-EQ contrast (304-500ms, $p<0.01$), and

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significant positive clusters in central and posterior regions in SC-EQ contrast (320-440ms, $p<0.01$) in the time window of 250-500ms.

Figure 2.5. Grand averaged ERMs of DE for DO-bias, SC-bias, and EQ-bias conditions.

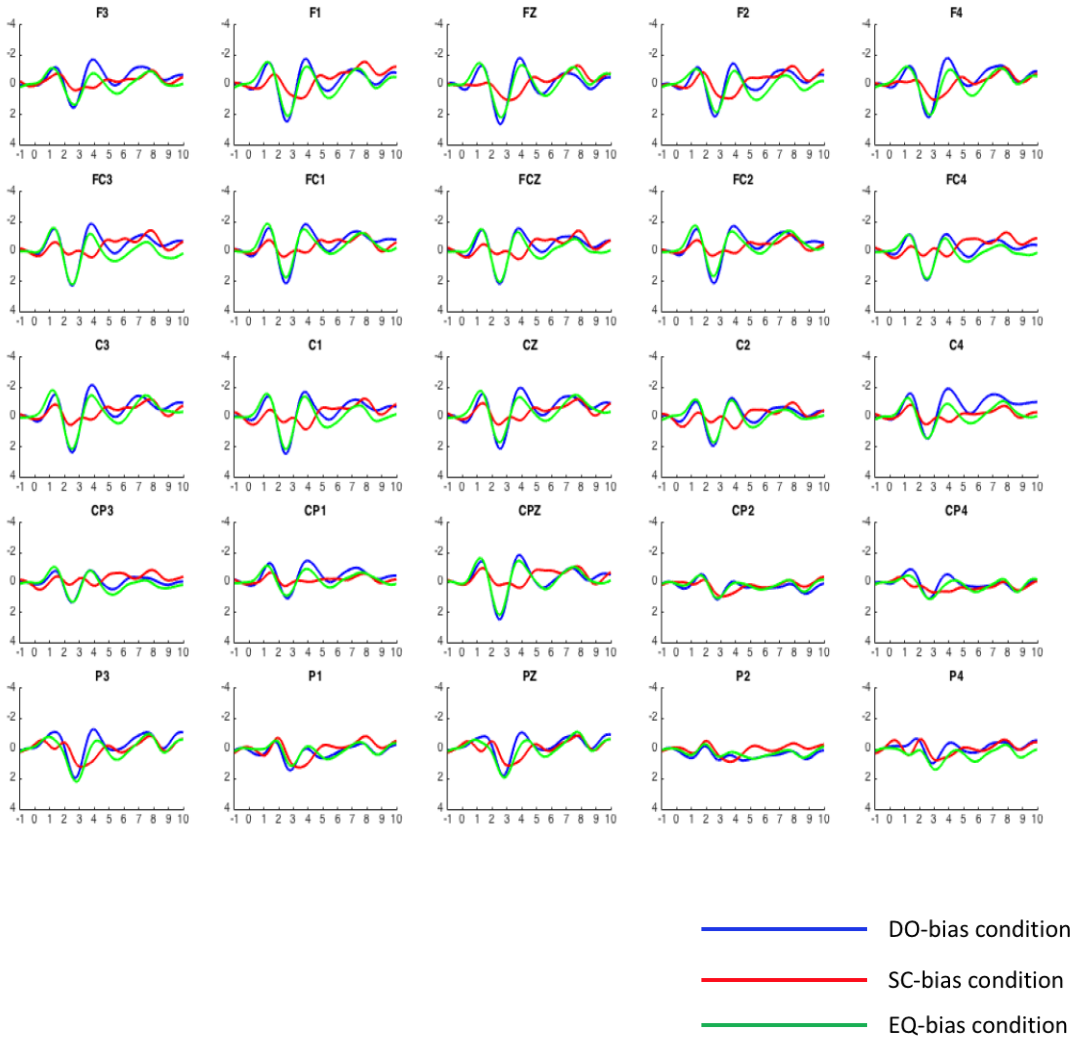

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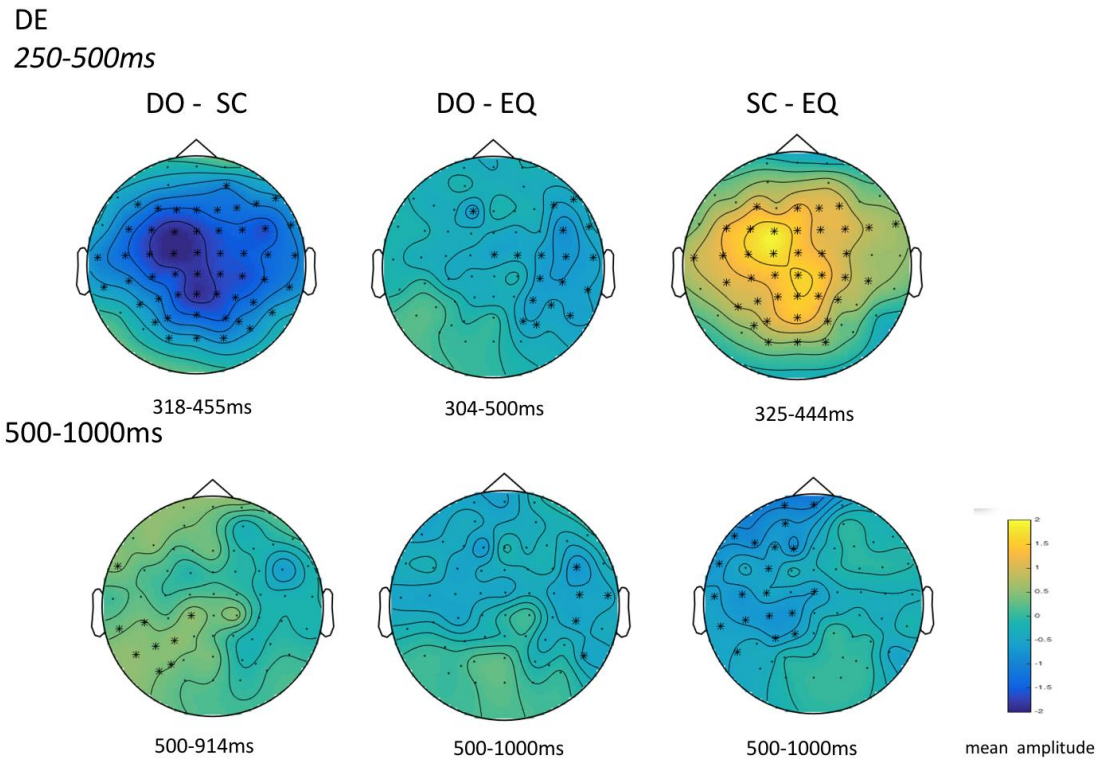
Figure 2.6. Topographic maps of DE for DO-SC, DO-EQ, and SC-EQ contrasts in the N400 (250-300ms) and late time window (500-1000ms).



Note. Asterisks represent the significant differences for the contrasts.

Contrasts on head noun

Figure 2.7 showed the grand-averaged ERMs waveforms elicited by head noun. Head noun in the sentence with DO-bias verb elicited larger N400 amplitude and a late negative-going waveform than that in the sentence with SC-bias verb. In the time window of 250-500ms, the cluster-based random permutation analysis (Figure 2.8) revealed the significant negative clusters in DO-SC contrast (320-480ms, $p<0.01$) and DO-EQ contrast (360-500ms, $p<0.01$) as well as significant positive clusters in SC-EQ

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contrast (320-440ms, $p<0.01$). As for the late time window of 500-1000ms, the result showed the significant negative clusters in DO-SC contrast (610-839ms, $p<0.01$) in the right fronto-to-central regions.

Figure 2.7. Grand averaged ERMs of head noun for DO-bias, SC-bias, and EQ-bias conditions.

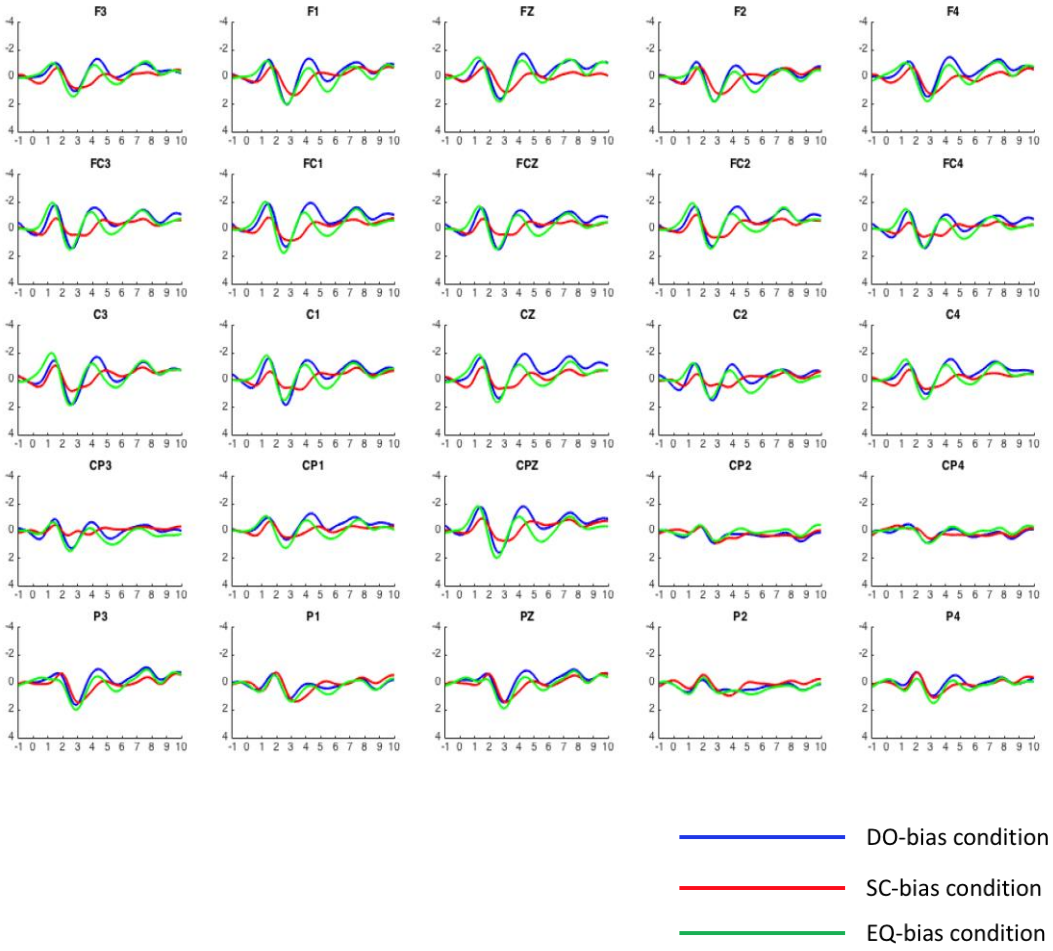

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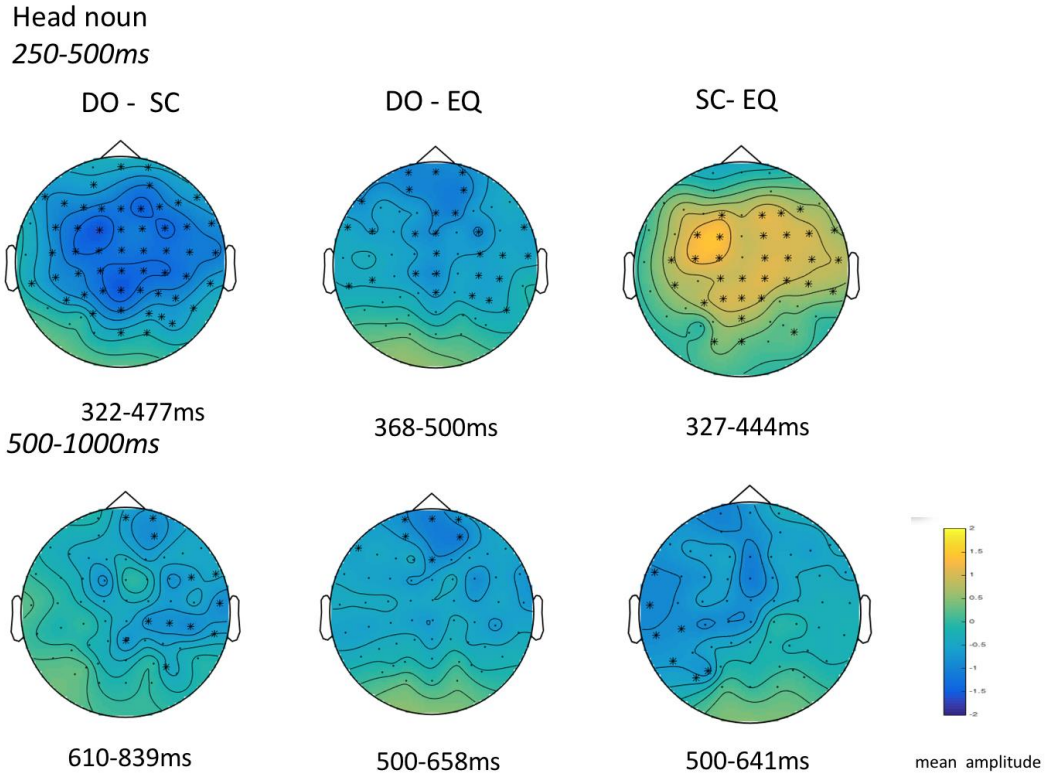
Figure 2.8. Topographic maps of head noun for DO-SC, DO-EQ, and SC-EQ contrasts in the N400 (250-300ms) and late time window (500-1000ms).



Note. Asterisks represent the significant differences for the contrasts.

2.3 Discussion- The incremental influence of verb bias on ORC processing

The present study aimed to examine the verb bias effect on the incremental ORC processing on P600, frontal negativity, and N400 components. The cluster-based permutation analysis was performed to characterize the spatial and dynamic of the verb bias effect on ORC processing by contrasting DO-SC, DO-EQ and SC-EQ bias conditions. The result of DO-SC contrast was summarized in Table 2.6 The marked ones were specifically pointed out for the following discussion. (For the complete result, please refer to Appendix III). Followings are the detailed discussions over the

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ERPs result on RC verb, DE, and head noun with the focus on the DO-SC contrast.

Table 2.6. Summary of the ERPs result on DO-SC contrast

ERP component	**Embedded RC noun**	**RC verb**	**DE**	**Head noun**
N400	No difference	No difference	318-455ms	322-477ms
late components	512-1000ms (positivity)	617-1000ms (positivity)	500-914ms (positivity)	610-839ms (negativity)

Our result indicated that verb bias incrementally influences the ORC processing, as first indexed by the late frontal positivity effect on RC verb in the DO-SC contrast. RC verb in DO-bias condition elicited a greater late positivity from 600 to 1000ms in frontal regions than that in SC-bias condition.

According to the literature, the less preferred but grammatical structure causes processing difficulty, as indexed by longer reading time (Lin & Gansey, 2011, Wilson &Garnsey, 2008) and P600 components (Osterhout & Holocomb, 1992). When reading the DO-bias verb as the main verb, the parsers would less likely to expect another verb which indicates the appearance of the clause. Given that the DO-bias verb can be followed by both direct object and sentential complement, with higher proportion of taking direct object, the appearance of "another verb" does not violate the sentence structure. However, DO-biased verb followed by another verb is a "less preferred but grammatical structure" (ex: 他 想起 里長 ***資助*** 的 街友。). Either of two possible

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components may reflect this phenomenon, P600 in posterior regions or P600 in frontal regions. The posterior-distributed P600 is known as an index of grammatical violation and has been associated with the less preferred but grammatical structure (Osterhout & Holocomb, 1992). Recent studies have reported that frontal positivity can also reflect the processing difficulty on the non-preferred but grammatical continuations (Kann & Swaab, 2003; Leone-Fernandez et al, 2012) and suggested that processing non-preferred grammatical continuations and ungrammatical continuations involve different mechanisms (Kann & Swaab, 2003). Kaan & Swaab (2003) manipulated four conditions to compare the non-preferred and ungrammatical continuations. Their data showed that, the ungrammatical continuations elicited a typical posterior-distributed P600, whereas, the non-preferred grammatical continuations elicited a greater positivity from 500 to 1100 ms in more anterior sites. Leone-Fernandez's (2012) study also observed a similar frontally distributed positivity was also elicited by the non-preferred grammatical continuations. For instance, in Spanish, two different locate predicates (e.g. estar en and ser en :"to be in" in English) require different subjects, object and events, respectively. event + ser en was rated as a non-preferable but acceptable continuation. Comparing with the object + ser en which is the preferable continuations, event + ser

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en, the non-preferable but acceptable continuations, elicited positive-going waveform starting around 400ms till 700ms, especially for central and frontal regions. In our study, RC verb in DO-bias condition did not elicit a typical posterior-distributed P600, but a frontally distributed positivity. Our finding of verb bias effect on RC verb demonstrated that RC verb is not preferable for the DO-bias verb in ORC processing.

This verb bias effect was also shown on the subsequent RC marker DE and head noun as indexed by the larger N400 responses on RC marker DE and head noun in DO-bias condition (ex: 他 想起 里長 資助 *的 街友*。). These findings are consistent with Lin & Garnsey's (2011) study which has demonstrated the long-lasting difficulty on the non-preferred but grammatical continuations, the parsers had difficulty on the subsequent words – DE and head noun, as indexed by the larger N400 responses on RC marker DE and head noun in DO-bias condition. When encountering the RC verb following the DO-bias verb, the parsers became more alert to expect a clause which may be more likely to be conceptualized as an event. However, when DE appeared, it signaled that it would be followed by a noun. Thus, the appearance of DE contradicted to the expectation of an "event", leading to a greater difficulty of integrating DE to "the concept of an event" formed earlier and elicited a greater N400. Nevertheless, for the

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SC-bias condition, the clause that follows the SC-bias verb can be constructed by various syntactic structures. Therefore, the parsers had less integration difficulty on the RC marker DE.

After the appearance of DE, for both DO and SC-bias conditions, the parsers would expect a noun. Yet, the larger N400 amplitude and a frontal negativity on the head noun in DO-bias conditions suggested that the processing of the head noun in these two conditions were different. In DO-bias condition, the following noun was the actual direct object of the main verb, so the parsers had to integrate the head noun with the preceding context. This integration difficulty was reflected on N400. During the integration process, the parsers had to re-assign the object of the main verb. Take one of the experimental stimuli as an example “他 想起 里長 資助 的 街友。” . The parsers would first assign “里長” as the direct object of the main verb “想起”, but when they read “DE”, they would expect the following noun “街友” was the actual direct object of “想起”. This re-assignment was indexed by a late frontally-distributed negativity. Previous studies have reported that frontal negativity appears in the process involved in establishing reference (Barkley et al., 2015; Van Berkum et al, 2007; Nieuwland et al., 2006). Referentially ambiguous nouns or pronouns has been found to

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elicit a sustained frontal negativity, relative to the unambiguous ones. Although the manipulation of the head noun in this study was not associated with the referential ambiguity, the process of integrating head noun to the preceding context involved the referential binding. That is, the parsers looked for the suitable referent (里長 or 街友) for the main verb. Therefore, frontal negativity elicited by the head noun in DO-bias condition may reflect another kind of "process of establishing referential binding".

As for the EQ-bias verbs that do not have a clear tendency of taking more direct objects or sentential complements, our findings showed that it tends to exhibit similar pattern as the DO-bias verb did. The result probably indicated that when processing the verbs without clear syntactic or semantic tendency, parsers tended to expect a simplest grammatical structure — direct object following the main verb. When they found that the main verb was not followed by a direct object, they experienced difficulty, as shown a similar pattern of processing DO-bias verb condition.

Nevertheless, out of expectation, differences in embedded RC noun in late time window were found in DO-SC condition. Since the syntactic structure of noun following verb is grammatical in either DO-bias or SC-bias condition, no difference shall be found between noun following DO-bias and SC-bias verb. Yet, the result

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showed that embedded noun following DO-bias verb elicited a larger late positivity than that following SC-bias verb. The possible explanation to that is the limited S+V+O condition. There are three types of fillers. One is SVO, the other two types are sentential complement following the main verb. Only nine sentences of SVO type out of total 68 sentences in the experiment. Therefore, the participants would have less expectations on the sentence that ends with “object”. When encountering the DO-bias verb, the participant would be more alert that it would not be followed only by the direct object, but might be the sentential complement, as shown by the sustained negativity in DO-bias condition. In the light of this, types of filler sentences were better controlled in the second experiment, with the inclusion of more simple SVO structure of sentences.

To sum, our findings suggested verb bias effect on ORC processing and proposed the possible explanations for its long-lasting effect. The findings implied that ORC following the DO-bias verb is more difficult to process than that following the SC-bias verb and exhibits the similar pattern as ORC following EQ-bias verb

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Chapter 3. Experiment 2: The influence of verb bias on SRC processing

Experiment 2 intends to examine the verb bias effect on real-time SRC processing. Based on the categorization of verb bias defined in the first experiment, three types of verb bias (DO, SC, and EQ bias verbs) would be followed by an object-modifying Subjective Relative Clause (SRC) in this experiment. ERP analysis on four regions of SRC sentences, namely the RC verb, embedded RC noun, RC marker DE, and the head noun, would be conducted to investigate the incremental influence of verb bias on SRC comprehension. Similar to the SC advantage in ORC processing that demonstrated in Experiment 1, it was also expected to show the SC advantage in SRC processing in Experiment 2. However, aside from the verb bias effect, the influence of word order in sentence processing should be considered in the current experiment. Different from ORCs in which the syntactic structure follows the typical Mandarin word order Subject-Object-Verb (SVO) (e.g. subject+ main verb+ RC noun: SVO), SRCs (e.g. subject+ main verb+ RC verb: SVV) violates the typical SVO word order. Since ORCs follows the typical word order, the clear contrasts between conditions in the first experiment are simply resulted from the verb bias effect. Yet, the violation of typical word order in SRCs might lead to the influence of both the role of word order and verb bias in SRCs processing.

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3.1 Materials and Methods

3.1.1 Participants

Thirty-four right-handed undergraduate and graduate students between the age of 18 and 26 participated in this study. Participants were all native speakers of Mandarin Chinese in Taiwan with no history of neurological or psychiatric disorders. Each participant signed the consent for before the experiment and were paid $500 NT of their participation. All participants were evaluated for their working memory and verbal memory capacities with working memory test of the Wechsler Adult Intelligence Scales-fourth edition (WAIS-IV; Weschler, 2008) and reading span test. Detailed information about the behavioral tests was listed in Chapter 2. Table 1 presents the result of the behavioral tests.

Table 3.1. The result of behavioral tests

Behavioral tests	Mean score	Range
WAIS-IV (working memory capacity)	37(3.8)	31-44
Reading span test	2.4(0.7)	1.5-4

Note. Standard deviations are in parentheses.

3.1.2 Experimental Design

This study aimed to manipulate three types of verb bias, Direct Object (DO), Sentential Complement (SC), and Equilibrium Balanced (EQ) bias verb, which are

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followed by a SRC, leading to the following syntactic structure of the target sentences: Subject + DO/SC/EQ-bias main verb + SRC structure (RC verb + embedded RC noun + RC marker DE + head noun). In order to make the sentences with SC-bias verb more complete, in SC-bias condition, the SRC was followed by a verb, leading to the structure of sentential complement. The current experiment shared the same verbs with the first experiment. The classification of verb bias has already been defined in the first experiment.

The construction of target sentences and fillers

The present experiment consisted of 41 target sentences with the manipulation of 14 DO-bias, 13 SC-bias, and 14 EQ-bias verbs as well as 42 fillers (Table2). Each critical region of the SRC, were matched for word length, word frequency and the associations between critical words with no differences between conditions. The embedded RC noun, RC verb, and head noun were all two-character words. The word frequency of 1st noun and head noun in each condition was low-medium word frequency which has a frequency of 65 per million with no differences between groups (embedded RC noun: $F = 1.0$, $p > .05$; head noun: $F= 0.99$, $p > .05$). To further control the word predictability, the association between words were computed using word2vec

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(Mikolov et al., 2013). The values of the association between words, , as shown in Table 3, including the association between 1st noun and RC verb ($p > .05$), and the association between head noun and main verb ($F= 1.461$, $p >.05$) , RC verb ($F= 1.11$, $p >.05$), or embedded RC noun($F= 0.328$, $p >.05$ has to be lower than the value 0.3 (more than 0.3: high associations between words, 0.2-0.1: medium-low associations, lower than 0.1: low associations) with no differences between groups.

Additionally, 42 filler sentences were also created for preventing the participants from developing strategies, including three syntactic structures—a. simple SVO structure: subject + main verb + (adjectives) object b. subject + main verb + sentential complement with embedded ORC/SRC, and c. subject + main verb + sentential complement (Table 2).

Table 3.2. Examples of target and filler sentences

Target sentences						
Main Clause		**Subjective Relative Clause (SRC)**				Sentential Complement
Subject	**Main verb (Types of verb biases)**	**RC verb**	**Embedded RC noun**	**RC marker**	**Head Noun**	
他	**DO-bias**: 想起	聘請	家教	的	經理	
他	**SC-bias:** 擔心	提出	證據	的	職員	報復

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他	**EQ-bias**: 看見	招募	志工	的	導演	

Types of filler sentences	Examples
subject + main verb + (adjectives) object	他蒐集證據。
subject + main verb + sentential complement with embedded ORC/SRC	他懷疑老師讚美的學生作弊。
subject + main verb + sentential complement	他聽說產品出現瑕疵。

Table 3.3. The characteristics of the stimuli

	Frequency (per million words)				
Types of verb bias	**embedded RC noun**	**Head noun**			
DO-bias	25.52±28.1	19.92±20.0			
SC-bias	20.54±26.5	15.83±18.80			
EQ-bias	13.60±10.18	25.61±21.1			
	Association values				
Types of verb bias	**RC verb-Embedded RC noun**	**Head noun-Main verb**	**Head noun-RC verb**	**Head noun-Embedded RC noun**	
DO-bias	0.1± 0.07	0.08± 0.08	0.13± 0.08	0.09± 0.07	
SC-bias	0.1± 0.04	0.1± 0.06	0.11± 0.08	0.1± 0.08	
EQ-bias	0.1±0.04	0.06±0.05	0.09±0.08	0.12±0.08	

One-third of the experimental sentences were followed by one true/false comprehension question to ensure that participants pay attention on reading comprehension during the experiment.

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3.1.3 Predictions

Based on the result of the Experiment 1 in which verb bias did influence the online ORC processing, it was expected that verb bias would also affect the SRC processing. Inasmuch as the syntactic structure of target sentences adopted in the current experimental design violates the typical SVO word order in Mandarin, the role of word order should also be taken into consideration for the evaluation of verb bias effect in the present study. Two general hypotheses were made as follows. Firstly, if only verb bias plays the role in SRC processing, it was expected that SRC following DO-bias verb would be more difficult to process than that following SC-bias verb. Secondly, if both "word order" and "verb bias" influence the SRC processing, processing difficulty might arise in either condition since all the main verbs were followed by the other verb (RC verb).

In addition, this processing difficulty may be shown on RC verb and head noun. Predictions on the RC verb and head noun for each condition were listed as follows:

I. RC verb

Considering the verb bias effect demonstrated in the ORC processing, verb bias effect in the SRC processing may be first reflected by RC verb in the contrast

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between DO-bias and SC-bias conditions. RC verb in the sentence with DO-bias verbs were expected more likely to be followed by a direct object and thus may elicit a greater positivity of P600 to reflect the grammatical violation. Nevertheless, if "word order" also plays a role, RC verb in the sentence with SC-bias verbs may also cause processing difficulty since it can be assigned by various grammatical roles and which may result in a greater negativity of N400.

II. Head noun

While encountering a DO-bias verb, parsers would try to search for the direct object for the main verb. Larger N400 on head noun under DO-bias condition than that under SC-bias condition might be expected to reflect such a processing cost. However, since SC-bias verb is more likely to followed by sentential complements, the head noun might be mistaken as the subject of the sentential complement or the object of the main verb. Such a processing difficulty may result in thematic-role ambiguity and higher working memory demand and indexed by the greater negativity of frontal negativity.

Aside from DO-bias and SC-bias verbs, EQ-bias verbs do not have a clear tendency of taking either more direct objects or sentential complements. The

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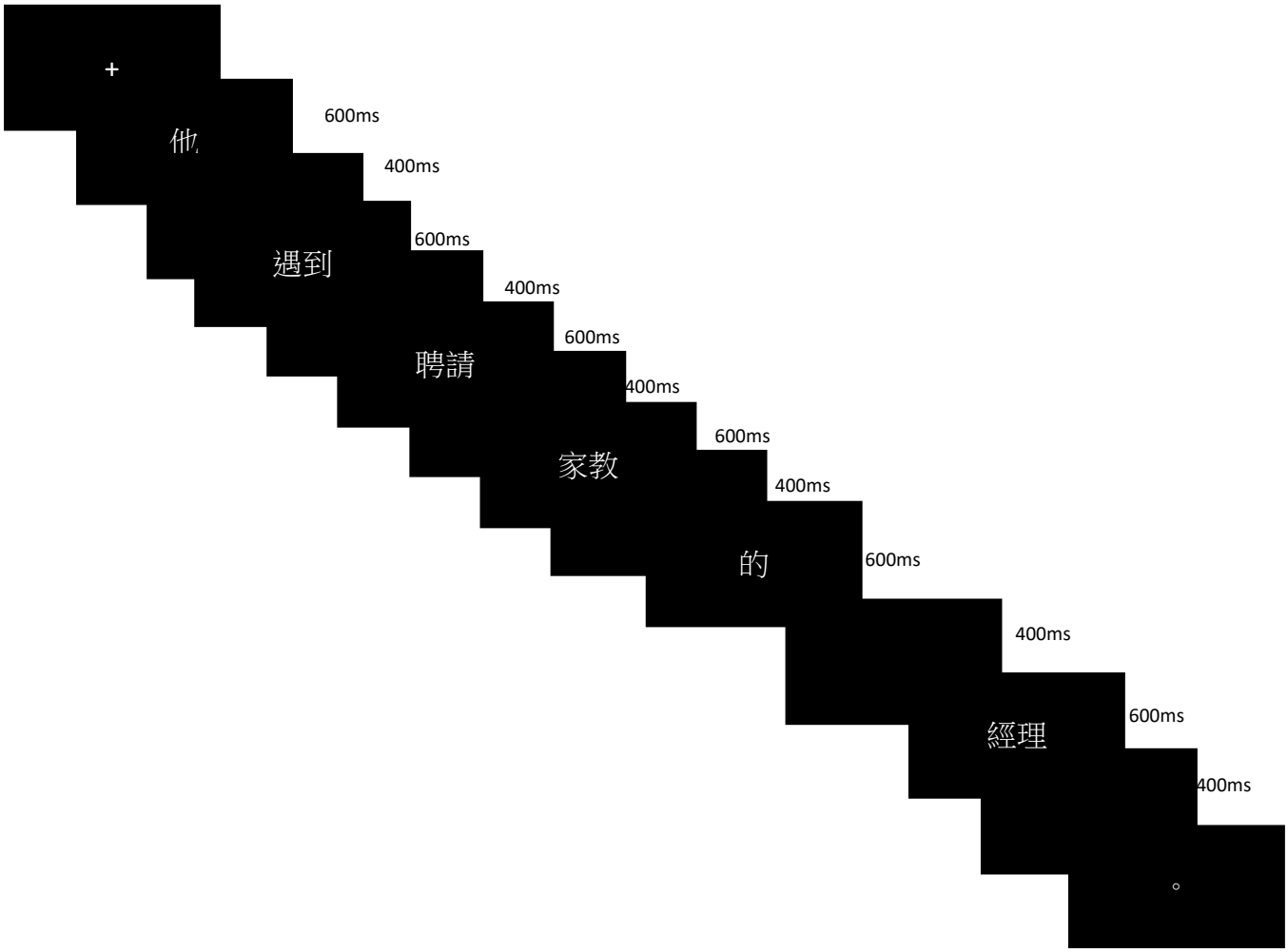
sentences with EQ-bias verbs may serve as a baseline, as compared to the other two conditions to see if they may exhibit a similar processing pattern to either DO-bias or SC-bias condition.

In order to delve into the role that each verb bias plays in the ORC processing, differences between conditions were compared – SC-DO, SC- EQ, and DO-EQ bias contrast.

3.1.4 Procedure

The procedure of the current study is as same as that of the first experiment



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3.1.5 EEG recording and data analysis

The current study follows the same EEG recording and data analysis as the first experiment.

3.2 Result

Three participants were excluded from further analysis due to the insufficient valid trails; therefore, this study analyzed the total data of twenty-eight participants.

3.2.1 Accuracy of comprehension test

The overall accuracy of comprehension test was 95% (SD=0.04, range: 92%-100%), showing that participants did not have difficulty understanding the sentences and had pay attention in the experiment.

3.2.2 Statistical analysis for ERPs data: cluster-based random permutation analysis

To evaluate the temporal and topographical differences between conditions (SC vs. DO, SC vs. EQ, and DO vs. EQ), the cluster-based random permutation analysis was conducted on each of the following critical regions – **RC verb, embedded RC noun, DE and head noun** – for the mean amplitudes of two epochs, N400 from 250 to 500ms, frontal negativity from 500 to 1000ms. The procedure of cluster-based random permutation analysis was explained in details in Chapter2.

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3.2.3 ERPs result (n = 28)

The cluster-based permutation analysis

Contrasts on RC verb

Figure 3.1 showed the grand-averaged ERMs waveforms elicited by RC verb in three types of verb bias conditions. Visual inspection shows that RC verb in the sentence with SC-bias verb elicited larger N400 than that in the sentence with DO-bias verb, but it elicited a larger positive-going waveform than that in DO-bias condition in the later time window. For the analysis of peak latency in DO-EQ and SC-EQ contrast, a significant delay in N400 latency was shown in both DO-EQ ($p < 0.01$) and SC-EQ ($p < 0.01$) contrast. It was found an 50ms delay in N400 peak latency on the EQ-bias condition as compared to the DO-bias and SC-bias conditions. The cluster-based random permutation analysis (Figure 3.2) revealed that SC-DO contrast yielded significant negative cluster in the time window of 250-500ms (318-500ms, $p<0.01$). DO-SC contrast yielded significant positive cluster in left fronto-central region (773-956ms, $p<0.01$) in later time window. Both DO-bias and SC-bias condition yielded larger positive clusters than the EQ-bias condition.

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Figure 3.1. Grand averaged ERMs of the RC verb for DO-bias, SC-bias, and EQ-bias conditions.

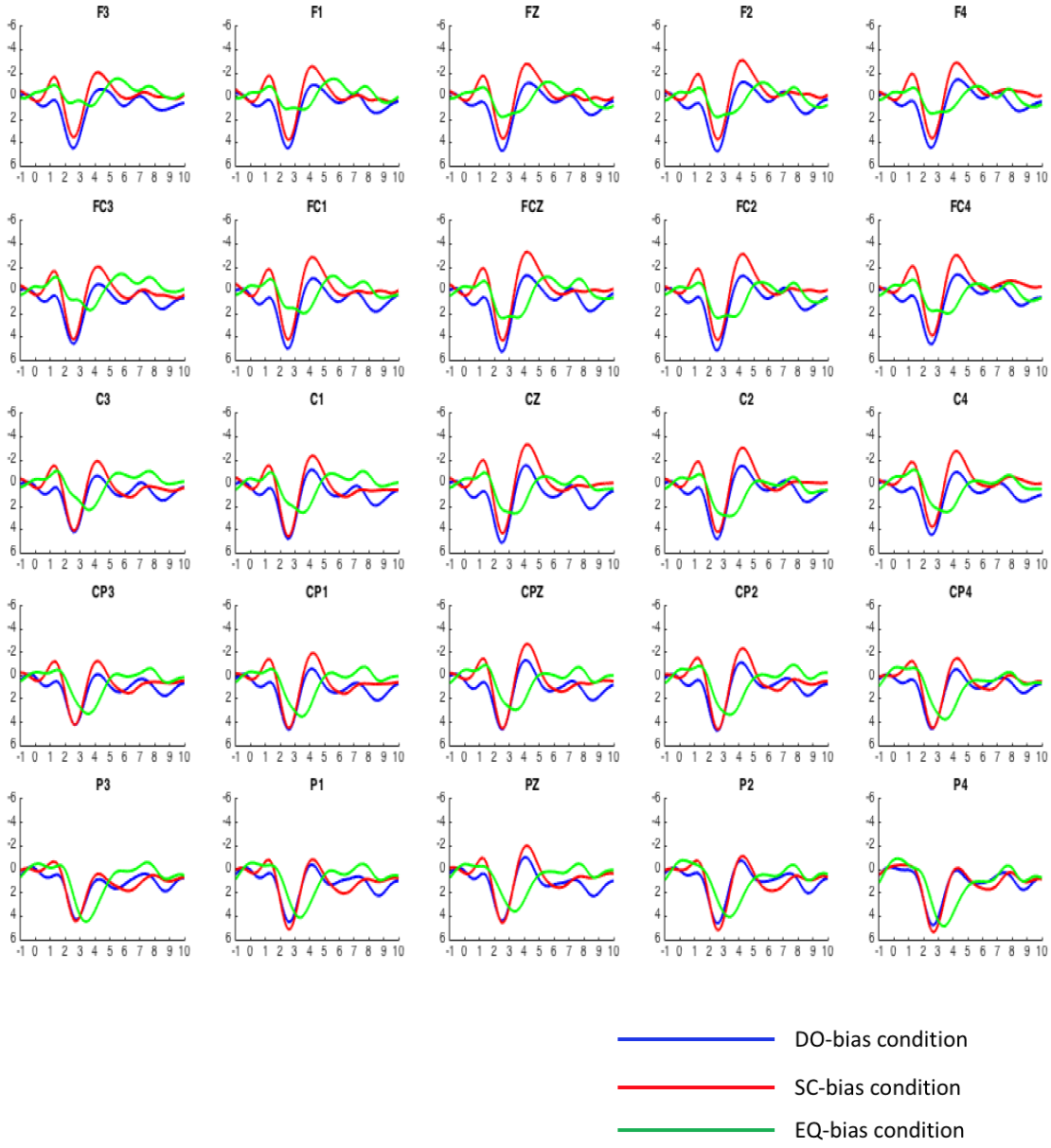

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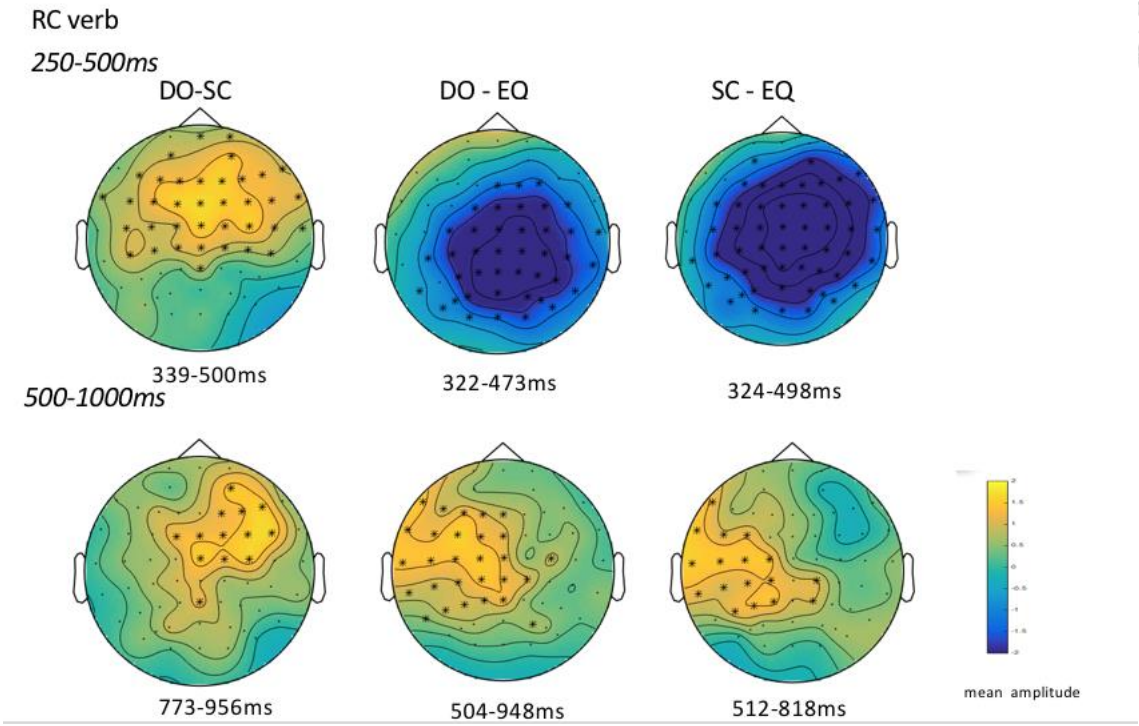
Figure 3.2 Topographic maps of RC verb for SC-DO contrast in N400(250-500ms), and DO-SC contrast in late time window (500-1000ms).



Note. Asterisks represent the significant differences for the contrasts.

Contrast on embedded RC noun

Figure 3.3 presented the grand-averaged ERMs waveforms elicited by embedded RC noun in three types of verb bias conditions. The result showed that no differences were found in DO-SC contrast; however, embedded RC noun in both the sentence with SC-bias verb and DO-bias verb elicited larger negative-going waveform than that in sentence with EQ-bias verb. The cluster-based random permutation analysis (Figure 3.4) revealed that in the time window of 250-500ms, there was no difference in DO-SC contrast, but significant negative cluster in DO-EQ (373-500ms, $p<0.001$) and SC-EQ contrast (375-500ms, $p<0.001$). In the later time window, significant negative clusters

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were found in both DO-EQ contrast (500-747ms p<0.001) and SC-EQ contrast (500-854ms, p<0.001).

Figure 3.3. Grand averaged ERMs of embedded RC noun for DO-bias, SC-bias, and EQ-bias conditions.

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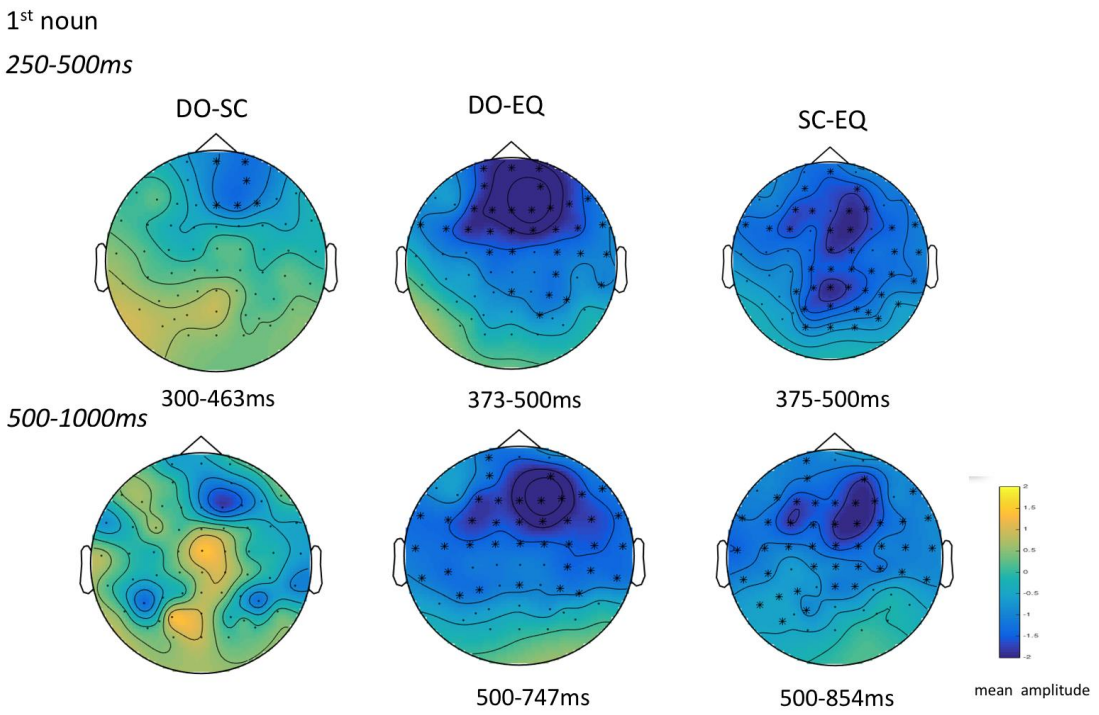
Figure 3.4. Topographic maps of embedded RC noun for DO-SC, DO-EQ, and SC-EQ contrasts in N400 (250-300ms) and late time window (500-1000ms).



Note. Asterisks represent the significant differences for the contrasts.

Contrast on DE

Figure 3.5 showed the grand-averaged ERMs waveforms elicited by DE. DE in the sentence with DO-bias verb elicited larger N400 than that in the sentence with SC-bias verb and EQ-bias verb. The cluster-based random permutation analysis (Figure 3.6) revealed DE in DO-bias condition yielded significant negative clusters than that in SC-bias condition (310-500ms, $p < 0.01$) and EQ-bias condition (372-500ms, $p<0.01$) in the time window of 250-500ms, but no significant negative clusters in DO-SC contrast and DO-EQ contrast were found in the later time window.

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Figure 3. 5. Grand averaged ERMs of DE for DO-bias, SC-bias, and EQ-bias conditions.

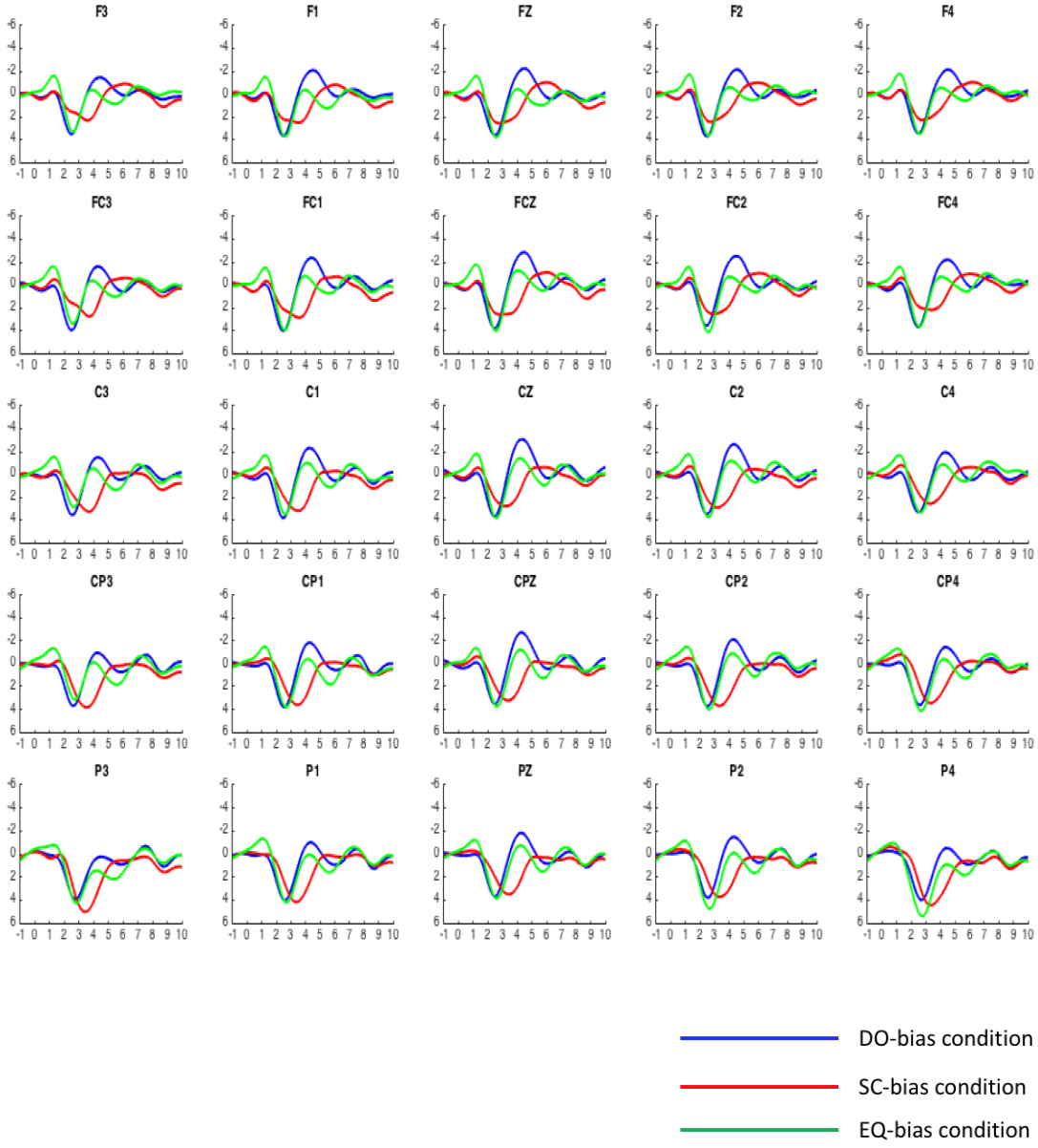

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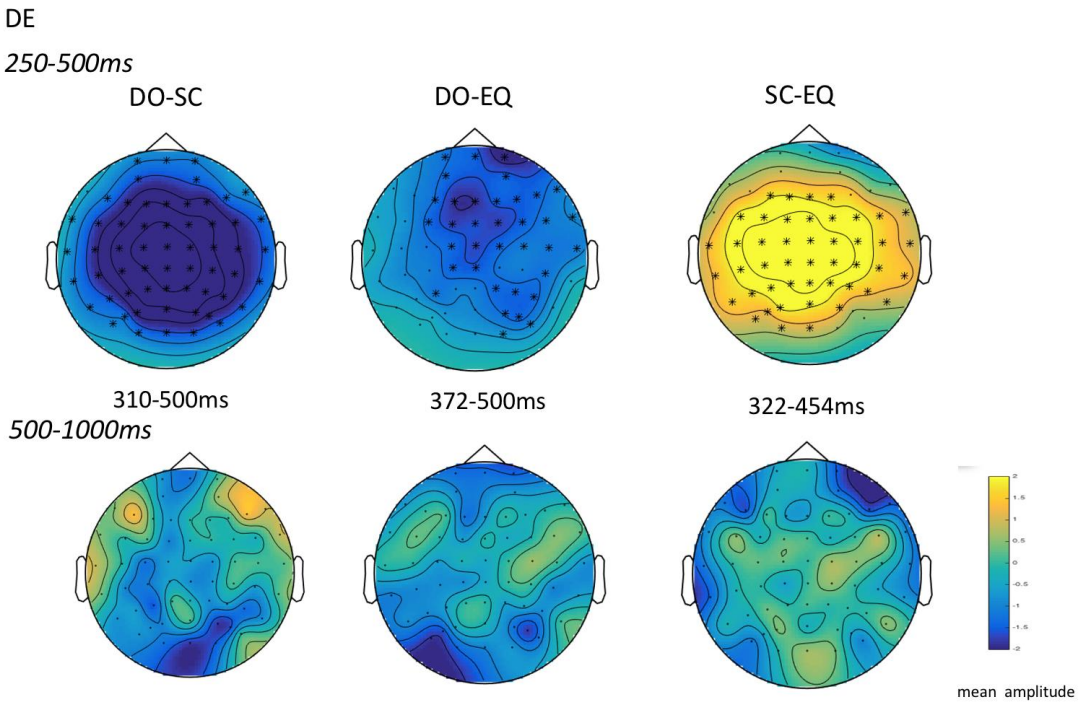
Figure 6. Topographic maps of DE for DO-SC, DO-EQ, and SC-EQ contrasts in N400 (250-500ms) and late time window (500-1000ms).



Note. Asterisks represent the significant differences for the contrasts.

Contrast on head noun

Figure 3.7 presented the grand-averaged ERMs waveforms elicited by head noun. Head noun in the sentence with DO-bias verb elicited larger negative-going waveform than that in the sentence with SC-bias verb that in the time window of 250-500ms; however, head noun in SC-bias condition elicited larger positive-going waveform than that in DO-bias condition in the later time window of 500-1000ms. The cluster-based random permutation analysis (Figure 3.8) revealed that in the time window of 250-500ms, head noun in the DO-bias condition yielded significant larger negative cluster

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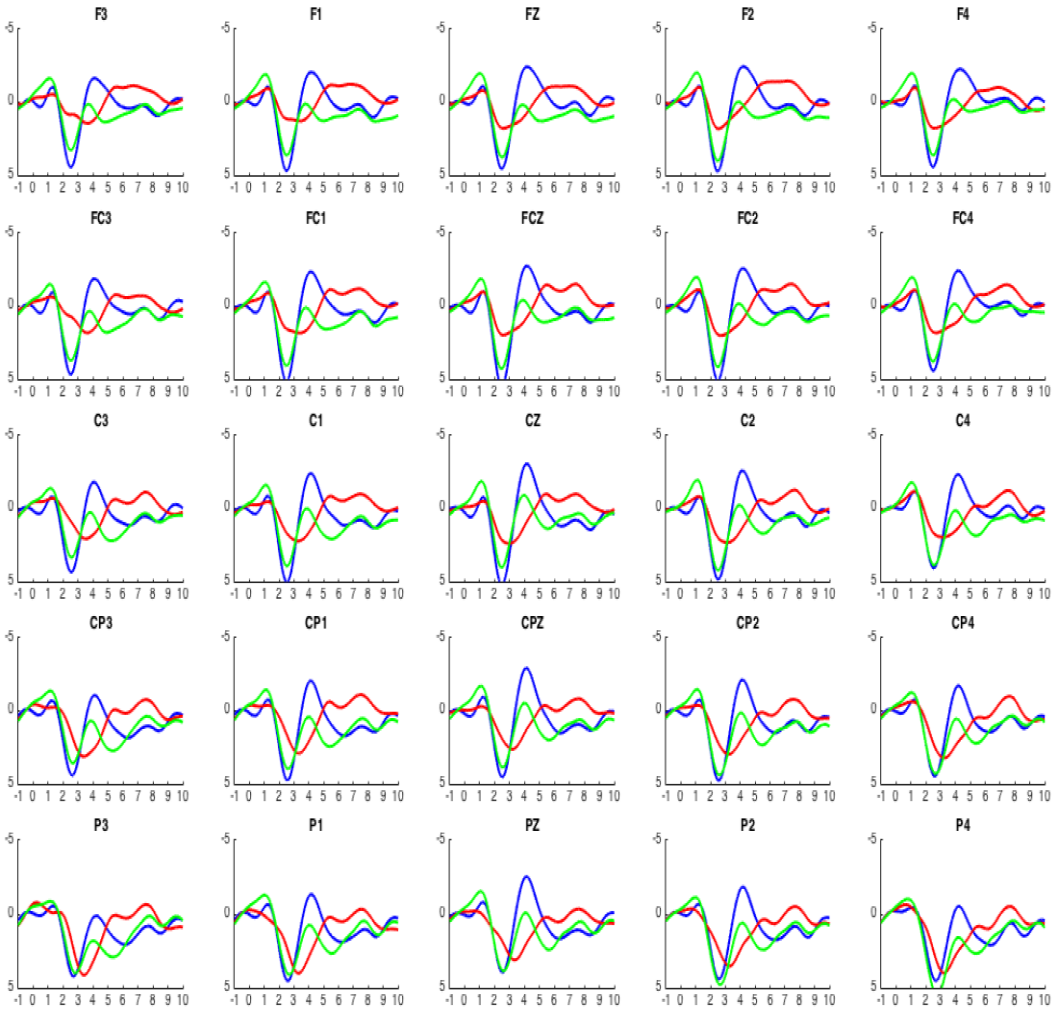
than that in the SC-bias condition (324-493ms, p<0.001) and EQ-bias condition (334-500ms, p< 0.01). Head noun in SC-bias condition elicited larger positive cluster in posterior region than that in EQ-bias condition (329-444ms). Yet, in the later time window, head noun in the DO-bias condition yielded significant larger positive cluster than that in the SC-bias condition (540-879ms, p<0.001). No significant clusters were found in DO-EQ contrast.

Figure 3.7. Grand averaged ERMs of head noun for DO-bias, SC-bias, and EQ-bias conditions.



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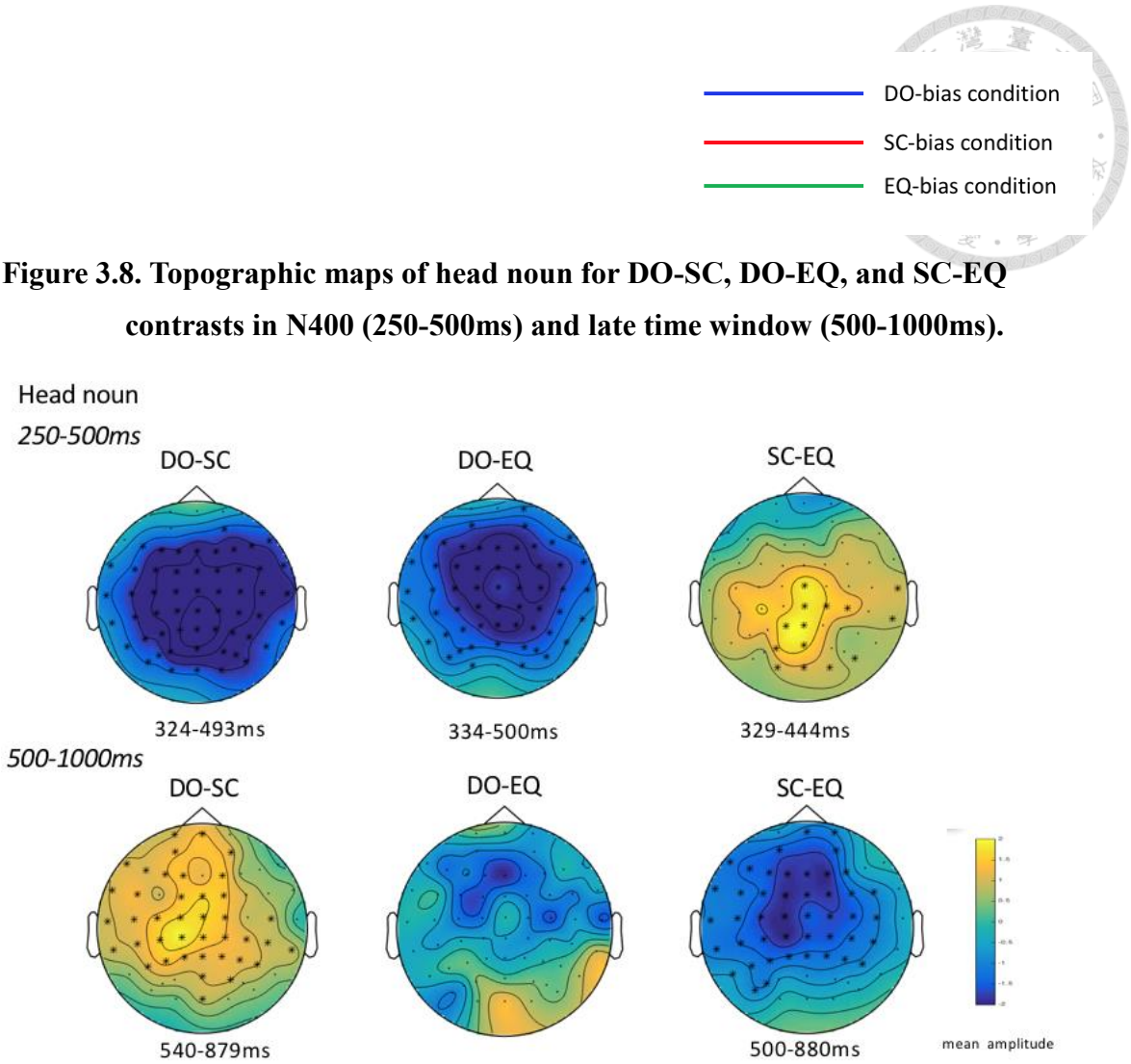

Figure 3.8. Topographic maps of head noun for DO-SC, DO-EQ, and SC-EQ contrasts in N400 (250-500ms) and late time window (500-1000ms).

Note. Asterisks represent the significant differences for the contrasts.

3.3 Discussion- The incremental influence of verb bias on SRC processing

The present study aimed to examine the verb bias effect on the incremental SRC processing on P600, frontal positivity, frontal negativity, and N400 components. The cluster-based permutation analysis was performed to characterize the spatial and temporal dynamics of the verb bias effect on SRC processing by contrasting DO-SC, DO-EQ and SC-EQ bias conditions. Consistent with the result of the Experiment1, the

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result demonstrated the verb bias effect on SRC processing. It was first reflected on the RC verb in DO-SC contrast -- larger frontal positivity on RC verb following DO-bias verb and larger N400 on RC verb following SC-bias verb. Such an effect on the initial structure of RC lasted on the subsequent RC marker DE and head noun in the DO-SC contrast. Moreover, the result also called attention to the significant role of word order in Mandarin.

Table 3.4. Summary of the ERPs result on DO-SC contrast

ERP component	**RC verb**	**1st noun**	**DE**	**Head noun**
N4000	339-500ms	300-463ms	310-500ms	324-493ms
late components	773-956ms (positivity)	No difference	No difference	540-879ms (negativity)

The result of DO-SC contrast was summarized in Table 3.4 The marked ones were specifically pointed out for the following discussion. (For the complete result, please refer to Appendix III). Followings are the detailed discussions over the ERPs result on RC verb, DE, and head noun with the focus on the DO-SC contrast.

The processing difficulty between SC-bias verb and DO-bias verb condition were first shown on the RC verb, as indexed by late frontal positivity in DO-SC contrast and larger N400 in SC-DO contrast. RC verb in DO-bias condition elicited larger frontal

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positivity in the late time window (773-956ms) than that in SC-bias condition. Since the markers for the tense and aspect are absent in Mandarin, two interpretations of the syntactic function can be made on the processing of RC verb following DO-bias verb. One is the “verb”, the other is the “normalization of the verb” functioning as the subject or noun modifier. The dominant word order of Mandarin syntactic structure is SVO. If word order precedes over the verb bias effect, RC verb interpreted as the “verb” violates the Mandarin word order. It might be reflected by typical P600. However, if both verb bias and word order play important roles, RC verb which can be seen as a “verb” and “participle” can be interpreted as a non-preferred structure. The processing difficulty of non-preferred but grammatical structure might be reflected by frontal positivity. The result corresponded to the second hypothesis. RC verb in the DO-bias condition is a less preferable sentence pattern. Less preferable sentence structure reflected by frontal positivity was consistent with the result of RC verb in experiment 1 and the prior studies (Kann & Swaab, 2003; Leone-Fernandez et al, 2011).

However, processing difficulty on RC verb in the sentence with SC-bias verb was reflected by larger N400 on RC verb in SC-bias condition than that in DO-bias condition. Sentential complement following the SC-bias verb can be represented by

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three syntactic structures. Firstly, in Mandarin, the subject can be omitted, so the main verb can be followed by a sentential complement without subject(e.g.他擔心(他)提出證據會被報復。) The RC verb in this case could be interpreted as the main verb of the sentential complement. Secondly, the main verb can be followed by the sentence which begins with the normalized verb (e.g.他擔心提出證據會對公司造成傷害。) RC verb "提出" could be seen as the normalization of the verb. Thirdly, the RC structure as the embedded subject of the sentential complement or as the direct object. Thus, multiple syntactic roles could be assigned to this RC verb in SC-bias condition. The variability of syntactic structure following the SC-bias verb provides an advantage for processing ongoing syntactic structure; therefore, the parsers would not have difficulty.

Nevertheless, although multiple grammatical roles can be assigned to the "verb" (RC verb) following SC-bias verb, the appearance of this "second verb" (RC verb) following the main verb still exhibited processing difficulty, as reflected by the larger N400 elicited by RC verb in SC-bias condition than that in DO-bias condition. Hence, the word order SVO in Mandarin might also play a significant role in SRCs processing to account for the difficulty of integrating the "second verb" (RC verb) to the preceding information (main verb: SC-bias verb). The word order and the characteristics of SC-

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bias verb competed in terms of the role in sentence processing, bringing about the integration difficulty on the RC verb following SC-bias verb.

This verb bias effects were also evident on the subsequent RC marker DE and head noun, as those demonstrated in the Experiment1. In Experiment1, the verb bias effect which was first shown on the RC verb lasts on its subsequent words, RC marker DE and head noun, as respectively reflected by larger N400 in DO-SC contrast and larger frontal negativity in DO-SC contrast. The long-lasting effects also appeared in current study. Firstly, both RC marker DE and head noun in DO-bias condition elicited larger N400 than that in SC-bias condition. In parsing the sentence with DO-bias verb, parsers tried to look for the actual direct object for the main verb. Before reaching the head noun, the parsers experienced one re-analysis; that is, the previous embedded RC noun was not the direct object of the main verb, but the head noun. The costs arise from the process in which the accruing semantic or syntactic contextual representation must be overridden or revised. When parsing the head noun in DO bias condition, the parsers finally found the correspondent direct object for the main verb. This cost was reflected by larger N400 on DE and head noun in DO-SC contrast. Secondly, head noun in SC-bias condition elicited a larger sustained negativity from 400ms than that in DO-bias

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condition. It implied that parsers experienced different processing difficulty in parsing SRC sentence with SC-bias verb than that with DO-bias verb. The parsers constantly looked for the corresponding direct object for the main verb when parsing DO-bias condition. In contrast, when reading sentence with SC-bias verb, parsers expected that the sentential complement follows the SC-bias verb, so they had to find the subject of the sentential complement and maintain the information that the RC intended to modify (e,g. subject). However, there were two possible thematic role assignments on the head noun. One is SRC as the direct object of the main verb, leading to the interpretation of the head noun as the direct object. The other is SRC as the subject of the sentential complement, leading to the interpretation of the head noun as the subject. Thus, the sustained negativity elicited by head noun in SC-bias condition than that in DO-bias condition might be related to the thematic-role ambiguity resulting in the cognitive demands for recruitment of additional memory resources.

Sustained negativities have been conceived as indexing cognitive demands (King & Kutas, 1995; Yang et al., 2010). Prior studies have found that the structure which is more difficult for thematic role assignments and requires high memory demand produces frontal negativity in both English (King & Kutas, 1995) and Chinese (Yang et

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al., 2010). For instance, the study of King & Kutas (1995) indicated that a larger sustained frontal negativity on the early region of ORC (e.g. The reporter who "the senator" harshly attacked admitted the error.) as compared to SRC (e.g. The reporter who "harshly attacked" the senator admitted the error.) reflected the larger memory demand to track multiple thematic roles and to maintain the noun until the appearance of the corresponding verb in processing English ORC. Besides, larger left anterior negativity starting from 250ms on the main verb in ORC (e.g. The reporter who the senator harshly attacked "admitted" the error.) than that in SRC (e.g. The reporter who harshly attacked the senator "admitted" the error.) was reported as an indication of working memory demand.

Mandarin lacks the specific marker for the thematic role assignments. In present study, the sentences were perceived with the word-by-word presentation, so parsers had no clear idea about the suitable thematic role for head noun until the appearance of the period marker or the main verb of the sentential complement. Since SC-bias verb is more likely to followed by sentential complements, parsers would have higher expectation on the appearance of the sentential complements. The purpose was not only to maintain the information in the working memory that the RC structure tries to

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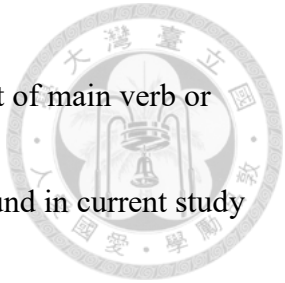

modify, but also to check whether the head noun was the direct object of main verb or the subject of the sentential complement. However, the waveform found in current study (sustained negativity starting from 400ms) was different from the waveform described in the previous studies in onset and latency. The sustained negativity observed in prior studies starts earlier from 250ms. Hence, the later sustained negativity induced by head noun in SC-bias condition than that in DO-bias condition leave open the possibility that it might reflect the high memory demand and thematic-role ambiguity. Given the results and interpretations mentioned above, differences in temporal dynamics and the ERPs component between SC- and DO-bias condition reflected by larger N400 on DE and head noun in DO-bias condition and sustained negativity on head noun in SC-bias condition revealed that the processing difficulty of SRC with DO-bias and SC bias verb was distinct from each other.

As for the EQ-bias verb which was shown to exhibit similar pattern as the DO-bias verb did in the experiment 1, current findings showed that it did not exhibit the similar processing pattern with either DO-bias verb or SC-bias verb. Nonetheless, we were not sure if the inconsistent findings between the Experiment 1 and Experiment 2 might be caused by the factor of word order. Future studies to directly manipulate word order are

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needed to address this question.

To conclude, our current findings not only suggested the verb bias effect on SRC processing but also implied that the crucial influence of word order leads to distinct processing difficulties among types of verb bias.

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Chapter 4. Concluding remarks

In this study, two ERPs experiments were conducted to explore the incremental influence of verb bias on ORC (experiment 1) and SRC (experiment 2) processing. The result indicated that verb bias affects ORCs and SRCs processing. Moreover, due to the different internal word order between ORCs and SRCs, the verb bias affects ORCs and SRCs differently. Since ORCs follow the typical canonical Mandarin word order, verb bias effect on ORCs processing is rather less complex. Verb bias effect on ORCs processing was first demonstrated by the larger frontal positivity elicited by the RC verb following DO-bias verb than that following SC-bias verb. It suggested that RC verb was a non-preferable but grammatical structure following the DO-bias verb. In addition, this effect lasts on the subsequent RC marker DE and head noun. In DO-SC contrast, RC marker DE in DO-bias condition elicited larger N400 responses, indicating the difficulty of integrating DE to the "the concept of event" formed earlier. Head noun following DO-bias verb elicited frontal negativity, suggesting the need of establishing the referential binding between the DO-bias verb and its suitable referent. The long-lasting difficulty of DO-bias verb on subsequent RC marker DE and head noun supported the incremental influence of verb bias on ORC processing. Moreover, EQ-

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bias verbs that do not have a clear tendency of taking more objects or sentential complements exhibit a similar pattern as the DO-bias verbs did. This finding suggested that when encountering the verbs without clear tendency over specific syntactic patterns, parsers might incline to expect the dominant grammatical structure — direct object following the main verb. Instead, they encountered a more complex structure following the EQ-bias verb, leading to the integration difficulty and the establishment of referential binding.

Experiment 2 which examined the verb bias effect on SRC processing substantiated the verb bias effect on RCs processing, but also called attention to the role of word order. The non-canonical word order of SRCs confounds the verb bias effect on SRCs processing which could be supported by distinct processing difficulty between conditions. The difficulty on processing SRCs following DO-bias verb lies on the processing of non-preferable but grammatical structure, as first indexed by the larger frontal positivity on RC verb following the DO-bias verb than that following the SC-bias verb. This ERPs finding on processing non-preferable but grammatical structure was consistent with that demonstrated in the experiment. It indicated that when parsing the initial structure (e.g. RC verb) of either SRCs or ORCs following the DO-bias verb,

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the expectation over the dominant grammatical structure following DO-bias verb was violated. This difficulty also lasted on the subsequent words, as indexed by larger N400 responses on RC marker DE and head noun in DO-bias condition than that in SC-bias condition. It reflected the cost of the process in which the accruing semantic or syntactic contextual representation must be constantly overridden or revised until the appearance of the actual correspondent direct object.

Nevertheless, different from the result of the Experiment 1 in which ORCs following SC-bias verbs did not exhibit processing difficulty, the result of the Experiment 2 demonstrated the processing difficulty in parsing SRCs following SC-bias verbs. Difficulty was reflected by larger N400 responses on RC verb and the sustained negativity on head noun in SC-bias verb condition, as compared to the DO-bias condition. These results suggested that when parsing SRCs following SC-bias verbs, the parsers did not take the advantage of the characteristics of SC-bias verbs which are expected to take multiple syntactic structures. The possible explanation might be the non-canonical word order and the characteristics of SC-bias verb competed in terms of the role in SRCs processing, leading to the integration difficulty on the RC verb. Moreover, when parsing the head noun following SC-bias verbs, the parsers required

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cognitive demand for additional memory resources due to the thematic-role ambiguity. Therefore, SRCs following either SC-bias verbs or DO-bias verbs exhibited distinct processing difficulty. Different from the processing of ORCs following EQ-bias verbs that exhibited similar pattern with DO-bias verbs, the processing of SRCs following EQ-bias verbs did not exhibit similar processing pattern with either DO-bias verbs or SC-bias verbs. This inconsistency could be probably explained by the influence of both verb bias and the role of word order in processing SRCs following EQ-bias verbs.

Our data provided a better understanding of the verb bias effect on Mandarin RCs processing. The result of verb bias effect in two types of Mandarin RCs and long-lasting effect indicated that parsers are able to use immediately either the syntactic or semantic information embedded in the verb to predict the upcoming sentence structure. It also supported the constraint-based model which purposed the activation of multiple information influences the early sentence processing.

Nonetheless, two questions were not able to be answered in current experiment. One is the preference over ORCs or SRCs and the other is the inconsistency of processing EQ-bias verbs between following ORCs and SRCs. However, the indication of the role of word order provided insights into the issue of RC processing preference.

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The theoretical account of word order prefers ORCs over SRCs; therefore, ORC preference can be predictable. Due to the experimental design, current study was not able to provide correspondent evidence. Future study with the consideration and better control of RC's preceding words (e.g. ORCs and SRCs are preceded by the same type of verb bias and compared based on the same condition.) can further address the issue of RC preference.

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Appendix I. Examples of stimuli in Experiment 1

Condition	stimuli
DO-bias	他提出上訴必備的要件 他展現法術散發的能量 他談到犯人要求的贖金 他遇到經理聘請的家教 他接受提案開出的補助 他探討社運傳達的訴求 他聽到廣播報導的醜聞 他瞭解敵人提及的真相 他關心教練責備的學員 他見到同事讚美的秘書 他想起里長資助的街友 他支持球隊發起的抗爭 他等待新娘請來的鼓手
SC-bias	他預估支出帶來的效益 他聽說派對引起的火災 他規定店家購買的餐具 他明白女友在乎的細節 他擔心客人批評的領隊 他發現藝人力挺的名店 他主張平權訴求的法案 他證明理論帶出的價值 他記得團長賞識的新人 他懷疑員警包庇的店長 他同意局長慰問的漁民 他知道社工關心的孤兒 他相信議員指責的商家
EQ-bias	他承認戀情造成的困擾 他害怕對手掀起的鬥爭 他確定行程需要的開銷 他質疑班長提名的總務 他期待明星主持的尾牙

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	他不滿上司公佈的懲處 他提到姊姊欣賞的影星 他看出漏洞導致的損失 他想到劇團推薦的編劇 他忘記總監指定的助手 他反對賭場提出的合約 他看見護士幫助的災民 他感謝社長招募的舞者 他看到法官遺失的公文

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Appendix II. Examples of stimuli in Experiment 2

Condition	stimuli
DO-bias	他提出因應糧荒的備案 他展現提升業績的企圖 他談到要求贖金的毒梟 他遇到聘請家教的經理 他接受重建部落的補助 他探討保障農民的法規 他想起援助街友的里長 他聽到撫慰病患的笛聲 他瞭解策劃謀殺的幕僚 他關心參觀劇場的團員 他見到讚美秘書的同事 他支持發起抗爭的球隊 他等待請來鼓手的新娘
SC-bias	他預估贊助賽事的專款可順利取得 他聽說影響選情的緋聞就要公開了 他規定提高產量的機具須改善 他明白搶下標案的計謀策劃已久 他知道關心孤兒的社工是誰了 他主張改善低薪的提案並不合理 他證明提高房價的決策是對的 他記得報名公演的舞者上過頭版 他同意爭取權益的房東是出於善意 他發現經營餐廳的名醫住在附近 他相信求助議員的家屬沒有說謊 他懷疑喜愛甜食的老婆懷孕了 他擔心提出證據的職員報復
EQ-bias	他承認隱瞞皇室的戀情長達五年 他看見幫助災民的護士也受傷了 他害怕闖入會場的流氓影響會議 他確定揭發賄選的情報是假的 他期待主持尾牙的演員有好的表現

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	他提到保障外配的福利 他感謝招募志工的導演 他看出導致虧損的漏洞 他想到逆轉審判的證據 他看到捐贈古董的畫家 他質疑提名總務的班長有私心 他不滿公佈懲處的上司 他反對推動修法的遊行 他忘記遞送合約的助手

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Appendix III

Summary of the ERPs result in Experiment 1: contrasts between three conditions

ERP component	condition contrasts	1st Noun	RC verb	DE	Head noun
N400	DO-SC	No difference	No difference	318-455ms	322-477ms
	DO-EQ	321-460ms	No difference	304-500ms	368-500ms
	SC-EQ	330-464ms	386-500ms	325-444ms	327-444ms
late components	DO-SC	512-1000ms (positivity)	617-1000ms (positivity)	500-914ms (positivity)	610-839ms (negativity)
	DO-EQ	597-987 (negativity)	500-1000ms (negativity)	500-1000ms (negativity)	500-658ms (negativity)
	SC-EQ	500-1000 (positivity)	500-1000ms (negativity)	500-1000ms (negativity)	500-641ms (negativity)

Summary of the ERPs result in Experiment 2: contrasts between three conditions

ERP component	condition contrasts	RC verb	1st noun	DE	Head noun
N400	DO-SC	339-500ms	300-463ms	310-500ms	324-493ms
	DO-EQ	322-473ms (delay N4 on EQ)	373-500ms	372-500ms	334-500ms
	SC-EQ	324-498ms (delay N4 on EQ)	375-500ms	322-454ms	329-444ms
late components	DO-SC	773-956ms (positivity)	No difference	No difference	540-879ms (negativity)
	DO-EQ	504-948ms (positivity)	500-747ms (negativity)	No difference	No difference
	SC-EQ	512-818ms (positivity)	500-854ms (negativity)	No difference	500-800ms (negativity)

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