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複數指涉對象的指涉歧義處理

Processing of Ambiguity with Multiple Referents

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複數指涉對象的指涉歧義處理
Processing of ambiguity with multiple referents

本論文係柯逸均君（學號 R08142016）在國立臺灣大學語言學研究所完成之碩士學位論文，於民國 112 年 1 月 9 日承下列考試委員審查通過及口試及格，特此證明

口試委員：

Chia-lin Lee（簽名）
（指導教授）

[illegible]

Chun Hsien Hsu

致謝

一轉眼突然就到了碩論的尾聲，終於要寫這份最後的致謝感言了。雖然想感謝的人很多，但此時腦中卻是一片空白，在這個當下唯一浮現的畫面卻是在碩班的某個時刻曾經跟葉遲學姊開玩笑說：「我應該會花個三天三夜來寫致謝吧，而且大概能寫到三頁」。雖然浮誇了點，不過在那個當下，心中確實是懷抱著感激的心情，想著要有多幸運才能擁有這奇蹟般的一切。

既然說到這奇蹟似的歷程，也許就先從這一切的起點開始吧。首先要感謝的是邱振豪老師，雖然很慚愧的到現在還沒讓本人知道，不過當初其實是由於老師的一個小舉動，在一封信中熱心地告訴了我神認學程的暑期實習計畫，才拯救了當時大四下茫然的我，讓我在迷惘而不知是否該堅持轉換跑道的當下，找到一條新的方向。

正式透過這項暑期實習，我才能如願地進入指導教授李佳霖老師的實驗室開始學習。這三年來接受了佳霖老師在各方面的諸多指導，對於老師的感謝實在無法在這短短的篇幅中道盡。特別想感謝老師在一開始願意接受無相關背景的我，若非如此，也許現在的我早已不在探求語言學的路上。也感謝老師幫助我度過每一段困難與挫折，並提供各種不同的資源與機會，使我得以磨練各項學術能力。回首碩班這三年，雖然一定還有許多不足之處，但也著實體會到自己有明顯的成長與改變，而這一切都要歸功於老師的指導。

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第一位是我的姐姐。在台北生活的一切日常都有你的陪伴。偶爾打球運動、逛逛街、在忙碌一整天後吃一頓大餐，又或者是一起在假日的午後四處玩耍、東奔西跑的看球賽。實在沒有辦法想像在台北的生活如果沒有你的話會有多麼的空虛而

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無趣。這樣的日常最難能可貴，還好我們有好好的珍惜了這樣平凡的每一天。

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中文摘要

指稱性成分，如代詞，係用以連接語言使用者的心理表徵以及外部實體、概念的載體，說話者及聽話者分別透過使用／解讀指稱性成分以指示／獲得所指（referent）。指稱性成分在篇章中可能帶有歧義（ambiguity），即語境中有超過一個前行語（antecedent）的存在而無法建立正確的指涉關係。當語言使用者處理這類歧義時，在事件相關電位技術（Event-Related Potential, ERP）中，經常觀察到一稱之為 Nref 的腦波成分。前人認為 Nref 效應反映的是處理歧義指稱性成分的機制，並提出兩種可能的解釋，分別是表徵維持假說（representation maintenance account）及歧義覺察假說（ambiguity detection account）。前者認為語言的處理機制會將篇章中所有可能的前行語保留在工作記憶中以待後續的去歧義處理，而後者則是認為 Nref 效應反映的是覺察到指稱性成分有歧義的歷程。為了探究 Nref 效應反映的認知歷程較趨近於上述哪一種解釋，以瞭解 Nref 效應的本質，我們在實驗中操弄代詞的前行語數量，使代詞在篇章中有一至三個可能的前行語，並以此觀察 Nref 振幅大小與代詞前行語數量之間的關係。根據表徵維持假說，在歧義消除前（disambiguate），所有可能的前行語需保留在工作記憶中，因此 Nref 效應的振幅應隨前行語數量增加而遞增；反之，若 Nref 效應是由覺察歧義的歷程所引發，則 Nref 效應的振幅應只與歧義的存在與否有關，不論前行語的數量，只要該數量與代詞所需的所指數量不一致，則皆會引發振幅大小類似的 Nref 效應。

除了探討 Nref 效應的本質之外，為探討一般認為較與語言處理無關的認知功能，如視覺工作記憶（visual working memory, VWM）與解析歧義指稱是否共用工作記憶資源，我們測量了受試者視覺工作記憶廣度（VWM capacity），並以此來檢驗 Nref 效應與其他負波成分（negativity）是否因共享工作記憶資源而反映相似的神經機制。

實驗結果顯示，當解析有歧義的代詞，即代詞有兩或三個可能的前行語時，皆引發一 Nref 效應。此外，在代詞有兩個可能的前行語時引發的 Nref 效應振幅

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大於代詞有三個可能前行語時所引發的 Nref 效應振幅，這個結果與基於上述兩個解釋的預期皆不同，因此此實驗結果並無直接支持任一種解釋。然而，雖然歧義代詞所引發的效果不如預期，我們卻在後續的歧義消除名詞上發現了類似 Nref 效應的負波成分。在前行語有三個的篇章中，歧義消除名詞出現時會使得歧義代詞的可指涉對象由三個減少為兩個；而在前行語有兩個的篇章中，歧義消除名詞的出現則是會使得代詞的可指涉對象由兩個減少為一個，即完全去歧義。在這兩種篇章條件下，前者的歧義消除名詞會相較於後者的有一個類似 Nref 效應的負波。雖然該名詞本身的指涉關係並無歧義，然而深層的篇章情境中代詞仍然可指涉到兩個前行語，因此仍然觀察到一個負向的腦波成分。此項結果說明 Nref 效應反映的較可能是保留在工作記憶中與歧義有關的心理表徵，而且能夠成功維持在工作記憶中的表徵數量上限可能只有兩個。此一結果較支持表徵維持假說。至於 Nref 效應振幅大小與視覺工作記憶廣度的相關性分析，則沒有發現任何顯著的正相關性，這可能是由於語言與視覺實驗作業的差異所導致。

總的來說，本研究試圖透過增加前行語數量的方式來探討 Nref 效應的功能性機制，並且初步地檢驗了 Nref 效應與其他負波成分的可能關聯性。同時本文亦針對 Nref 效應所反映的神經機制提出新的觀點，即 Nref 效應並不僅代表單一認知處理歷程的此一可能性。我們認為解析歧義的歷程，或許是由多個階段的認知活動組成，而 Nref 效應可能包含了不同階段的認知活動所引發的腦波成分。因此，未來研究應針對解析歧義歷程所涉及的功能與認知活動加以釐清。

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Abstract

Constructing coherent mental representations from referential processing is critical for language comprehension. However, it is not uncommon in natural language use when multiple antecedents can be eligibly taken as the referent for an anaphor, leading to processing cost reflected in a sustained anterior negativity—the Nref. The present study investigated the properties and the functional nature of the Nref effect. We used the Event-Related Potential (ERP) technique to examine the ambiguity detection account and the representation maintenance account. Participants read stories containing one, two, or three characters that were all suitable referents for a critical pronoun in the subsequent sentence, yielding unambiguous, 2-referent, and 3-referent conditions respectively. The referential ambiguity was then disambiguated with character names (e.g., '他覺得家俊與國維明天...'). This experimental design allowed us to test the Nref effect's sensitivity to increasing referential load and to observe brain responses subsequent to the ambiguity.

In addition to examining the underlying processing reflected by the Nref effect, another goal of present study was to explore the possibility of general resources subserving the working memory operations across modalities. In particular, we examined whether the neural mechanisms of the Nref effect were associated with other sustained negativities through utilizing similar working memory resources. To that end, a change detection task was incorporated to assess each participant's visual working memory (VWM) capacity and its associations with the Nref effect were investigated.

ERP data time-locked to the critical pronouns showed that ambiguous pronouns

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in both 2-referent and 3-referent conditions elicited the Nref effect, which was larger in the 2-referent condition than in the 3-referent condition. The results of the preliminary analyses reported in this thesis do not provide support for either account, and further validation and examination of the provided tentative interpretations are needed. Despite the unclear data time-locked to the pronouns, ERP data time-locked to the first disambiguation names revealed a Nref-like effect in the 3-referent condition, in which the already-seen pronouns were still ambiguous in the situation model, relative to the 2-referent condition, in which the ambiguity was resolved by the current disambiguation name. These findings suggest that the Nref effect may reflect the ambiguity-associated mental representations that are held in the working memory, and that the limit of the number of referents to be kept in the working memory may be restricted to be no larger than 2. These views are consistent with the maintenance hypothesis but require further verification. As for the correlational results, however, we did not find positive correlations between the Nref effect and the VWM capacity. These findings could be due to the differences in experimental approaches between language and visual tasks.

In sum, our findings yielded further insight into the functional interpretations of the Nref component and provided an initial investigation into the potential associations between sustained negativities. The present study has raised important questions about the sequential processing of the Nref effect. Future study is required to better characterize and identify the likely distinct functional aspects that underlies the ambiguity processing.

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Contents

doi:10.6342/NTU202300100

doi:10.6342/NTU202300100

List of Figures

doi:10.6342/NTU202300100

doi:10.6342/NTU202300100

List of Tables

doi:10.6342/NTU202300100

Chapter 1

Introduction

1.1 Referential ambiguity

The ability to successfully establish references is central to human language in that it helps comprehenders to associate linguistic expressions with the entities being referred to. Constructing coherent mental representations from referential processing is critical for language comprehension and most of the time we can accurately build the anaphoric relations in a rapid and effortless way. However, it is not uncommon in natural language use for us to produce or encounter anaphors that generate processing difficulties. One type of problematic referential expressions is referential ambiguity, which arises when more than one antecedent is available in the context to be taken as the referent for the anaphor and the comprehender is unable to establish an appropriate anaphoric relationship. Although recent research has shown that language users consciously avoid the production of ambiguous pronouns (Hwang, 2021), evidence has also shown that ambiguous referential expressions substantially exist under experimental (Hwang, 2021) and natural spoken (Poesio & Artstein, 2005, 2008) or written (Emami et al., 2018; Poesio & Artstein, 2008; Webster et al., 2018) contexts.

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1.2 ERP studies of referential ambiguity

Previous ERP studies have found that referentially ambiguous anaphors elicit a sustained, frontal negativity compared to unambiguous anaphors (the Nref effect, Boudewyn et al., 2015; Karimi et al., 2018; Nieuwland, 2014; Nieuwland, Otten, et al., 2007; Nieuwland & Van Berkum, 2006; Van Berkum et al., 1999; Van Berkum et al., 2003; for a review see Nieuwland & Van Berkum, 2008b; Van Berkum et al., 2007). The Nref effect was first discovered in Van Berkum et al. (1999) using stories like the one below:

(1) ”David had asked the two girls to clean up their room before lunchtime. But one of the girls had stayed in bed all morning, and the other had been on the phone all the time. David told the *girl* that had been on the phone to hang up.”

The word ”girl” in the final sentence (underlined and italicized) was referentially ambiguous because the discourse context provided two eligible referents. This temporal ambiguity would not be solved until reading the relative clause following it. Compared to the counterpart condition in which only a single referent is provided in the context (e.g., ”David had asked a boy and a girl…”), the referentially ambiguous noun elicited a sustained negative deflection that starts at around 300 ms after the stimulus onset and was largest at the frontal electrode sites. This negativity was subsequently dubbed as ”Nref” in the literature.

The Nref effect has been demonstrated in various different linguistic forms and via both written and spoken modalities (e.g., ambiguous noun phrases: Boudewyn et al., 2015; Nieuwland, Otten, et al., 2007; Nieuwland & Van Berkum, 2008a; Van Berkum et al., 1999; Van Berkum et al., 2003; ambiguous pronoun: Karimi et al., 2018; Nieuwland, 2014; Nieuwland & Van Berkum, 2006; ambiguous proper names: Coopmans & Nieuwland, 2020). In addition, the Nref effect has also been replicated in different languages (e.g., Dutch, Nieuwland, Otten, et al., 2007; English, Boudewyn et al., 2015; Karimi et al., 2018; Mandarin, Lee & Lai,

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accepted).

Prior studies have documented several important characteristics of the Nref ambiguity effect. For example, the Nref effect tracks deep referential ambiguity at the situation model level rather than superficial ambiguity at the text level. Nieuwland, Otten, et al. (2007) used stories structurally similar to example (1) described above, with discourse context containing either unambiguous or ambiguous referents (e.g., one uncle and one nephew or two nephews). Their critical manipulation is that, in ambiguous discourse, either both characters remained in the story or one of the characters left (e.g., "died" or "left"). ERPs time-locked to a subsequent critical noun phrase (e.g., nephew) showed that, while both versions of the ambiguous discourse provided two potential entities that can be linked to at the 'text level', only stories where both characters stayed in the discourse elicited a Nref effect. Their findings thus suggest that the Nref effect reflects the established representations in the situation model. In the case where text-based ambiguity exists, as one character left, the critical noun phrase can be unambiguously referred to the single character remaining in the situation model, and thus no Nref effect was observed.

Converging findings that the Nref effect does not merely reflect text-based ambiguity can also be seen in studies examining factors influence the eligibility of an entity as a referent. For example, verb-based implicit causality (Van Berkum et al., 2007) and sentence-level contextual bias (Nieuwland & Van Berkum, 2006) have both been shown to affect referential interpretations. Consider the two sentences from Nieuwland and Van Berkum (2006) below:

(2a) The chemist hit the historian while *he* was laughing hard.
(2b) The businessman called the dealer just as *he* left the trendy club.

The pronoun "he" is formally ambiguous in both sentences, however, the strong contextual bias of (2b) foregrounds a particular character to be a suitable referent, while the weak bias of (2a) leaves both characters equally suitable. The ERP results

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were consistent with the behavioral assessment of contextual bias and showed that pronouns in weakly-biased contexts like (2a) elicited a Nref effect relative to pronouns in moderately-biased contexts like (2b). These studies thus suggest that both antecedents must be considered relevant to the ongoing discourse and remain in the situation model in order to induce the Nref ambiguity effect. Together, these findings suggest that the fitness of the antecedents is co-determined by discourse-level semantics, implicit causality, and contextual cues. While situation models containing multiple plausible antecedents elicit the Nref effect, factors that render potential antecedents implausible or unavailable would diminish the presence of the Nref effect.

In addition, several studies have shown that the Nref ambiguity effect is sensitive to working memory capacity, with the amplitude of the Nref effects positively correlated with working memory capacity (e.g., operation span, Boudewyn et al., 2015; counting span, Fiorentino et al., 2018; reading span, Nieuwland, 2014; Nieuwland & Van Berkum, 2006). While the relation between the Nref component and the working memory system has not been fully understood, some possible explanations have been provided in the literature (Boudewyn et al., 2015; Nieuwland & Van Berkum, 2006). Establishing references is generally thought to require comprehenders to bind anaphors to previously introduced potential antecedents in the preceding contexts, which demands working memory resources. For referential processing executed at the sentence level, anaphors and antecedents are separated only by a few words, the anaphor locally identifies the antecedent that is remained in the working memory. However, for discourse-level referential processing, the potential antecedent could already be encoded into the episodic discourse memory, and need to be retrieved back to the working memory upon relevant cues in the discourse. In both cases, working memory operation is essential for forming successful references. Along these lines, individuals with higher working memory capacity are more likely and capable of establishing anaphoric relations, while those with lower capacity are more likely to fail to maintain antecedents in the

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working memory or to recognize relevant cues to retrieve preceding referents.

Although the above-reviewed findings highlight the role of the Nref effect as an ERP signature to track referential ambiguity, the underlying neural mechanisms that the Nref effect reflects remain unclear. Several hypotheses have been proposed to try to account for the functional correlates of the Nref effect. One hypothesis is that the Nref effect may reflect the initial processes of detecting or perceiving ambiguity (ambiguity detection hypothesis) (Nieuwland, 2014; Nieuwland & Van Berkum, 2006; Van Berkum et al., 2007). In Nieuwland and Van Berkum (2006), the absence of the Nref effect for low-span readers was interpreted as a failure to notice referential ambiguity. The low-span readers did not detect the ambiguity and took the most immediate and available entity to be the referent. Thus, for low-span readers, the ambiguous pronoun was processed no differently as the unambiguous one. Nieuwland and Van Berkum (2006) argued that, if low-span readers did not elicit the Nref effect because they were unable to pursue different referential interpretations despite noticing the ambiguity, then the accompanying processing difficulty would be expected to show up in the brain responses either as a referentially induced effect with relatively shorter duration or on a different ERP component. However, no other systematical conditional differences were seen in low-span readers' data.

The hypothesis that Nref reflects the detection of referential ambiguity was also supported by the findings from Nieuwland (2014), which examined the processing of gender-mismatched pronouns (e.g., '*she*' in the sentence 'The boy thought that *he/she* would win the race'). In this study, high-span readers elicited a larger Nref effect for gender-mismatch pronouns and this was suggested as they are more able to conceive or conjecture a possible referent (that is not explicitly mentioned in the sentence) for the gender-mismatched pronouns and thus treat the pronoun as potentially ambiguous. In contrast, low-span readers were more likely to construct local references, so they did not perceive the possibility of having an unmentioned antecedent for the mismatched pronouns and thus elicited a P600 effect. Another

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piece of evidence supporting the detection account is that the Nref effect was sustained well beyond the point where disambiguating information is provided (Nieuwland, Otten, et al., 2007). Furthermore, no instantaneous effect of ambiguity resolution was observed for brain responses time-locked to the disambiguating words. That the Nref effect outlasted the disambiguation and that the ambiguity might not be resolved immediately challenge the idea that the Nref effect reflects processes dealing with the ambiguity. It could simply be that the perceiving incompatible ambiguity induced a long-lasting effect on language processing.

On the other hand, in line with the findings associating the Nref effect with working memory capacity, an alternative hypothesis is that it indexes the number of competing referents actively maintained in the working memory (referent maintenance hypothesis) (Barkley et al., 2015; Karimi et al., 2018; Nieuwland, 2014; Nieuwland, Petersson, et al., 2007; Nieuwland & Van Berkum, 2006; Van Berkum et al., 2007). To successfully comprehend a linguistic input, upon reading relevant cues (e.g., an ambiguous noun phrase, pronoun, or proper name), suitable referential antecedents need to be retrieved back and maintained in the working memory, waiting for further disambiguating information to arrive at a final interpretation. In an fMRI study, Nieuwland, Petersson, et al. (2007) investigated the cortical networks activated by referential ambiguity. They found that referential ambiguity elicited additional activations in the medial frontal and parietal regions, which is known to involve in the maintenance and storage of information in working memory (Curtis, 2006; Jonides et al., 1998; Klingberg et al., 2002) and visual imagery at episodic retrieval (Cavanna & Trimble, 2006; Fletcher et al., 1995; Wagner et al., 2005), but not in LIFG. These results suggest that readers evaluate the two referential interpretations in order to establish coherent representations. In addition, as mentioned above, the presence of two representations in the deep situation model has shown to be essential for the observation of the Nref effect, suggesting that the evaluation of two competing referential candidates may involve in the processing reflected by the Nref effect.

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More broadly speaking, based on its associations with working memory and the ERP morphology, Van Berkum and colleagues (2003, 2007) provided a link between the Nref effect and other ERP responses that impose increased working memory load. For example, the left anterior negativity, or LAN effect, observed in long-distance syntactic dependencies like wh-questions and object-relative clauses (King & Kutas, 1995; Kluender & Kutas, 1993a, 1993b; Kutas, 1997; Müller et al., 1997) has been suggested to index working memory operations due to the increasing memory load in the gap positions. Sentences like "the reporter *who the senator harshly attacked* admitted the error" tax working memory because comprehenders must process ongoing input information of "the senator" while at the same time keeping "the reporter" in mind for the following verb that links back to it. Similarly, referential dependencies induce increased working memory load like syntactic dependencies in two aspects. First, to form a referential relation, the anaphor was linked to the preceding antecedent that either still stayed in the working memory, or needed to be retrieved back into the working memory. Second, the gap between the ambiguous anaphor and the disambiguating information taxes working memory resources like the gap in object relative clauses. Both of them form long-distance relations between a current input, which is the disambiguating information for the referential dependencies, and an entity occurring in the preceding contexts, which is the ambiguous anaphor itself and the representations linked to the anaphor. Consistent with the above reasoning, Barkley et al. (2015) has also suggested that the Nref effect may not be a response specifically induced by referential ambiguity, but a member of a family elicited by distant dependencies that cost working memory resources.

As the detection and maintenance accounts make similar predictions with regard to referentially unambiguous expressions versus referentially ambiguous expressions with two potential referents, no extant data is available to distinguish between these two possibilities owing to the fact that, previous studies are restricted to examining referential ambiguity induced by only two potential referents. Thus,

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one potential factor that can help distinguish these accounts is to increase the number of potential referents in ambiguous conditions. It is not uncommon that one referential expression can be associated with more than two possible antecedents. Imagine a daily situation in which you are looking for a shirt. You may ask for help from a family member saying "Do you know where *my shirt* with the logo of the school football team is?". Obviously, the word "my shirt" can refer to all of the shirts you have, not restricted to just two of them. Another common situation is that walking on the campus with your friends, you may recognize someone you know and want to tell your friend to look at that person (probably for gossiping purposes), you might say something like "Hey, look at *that guy* there". There are usually not only one or two, but many people walking on the campus when you say that, so the referential expression "that guy" associates with multiple possible referents.

While both the maintenance account and the detection account consider the Nref effect sensitive to the number of potential referents, they do make different predictions regarding how the number of potential referents would modulate the magnitude of the Nref effect. As the maintenance account holds that the magnitude of Nref reflects the resources exploited to hold the possible referents in the working memory, increased amplitude of the Nref effect would be expected as the number of potential referents to be held in the working memory increases (see Barkley et al., 2015 for a similar view). On the other hand, as the detection account holds that the Nref effect reflects the detection of referential ambiguity, thus similar magnitudes of the Nref effects would be expected, as both 2-referent and 3-referent conditions are both referentially ambiguous. Note that the maintenance account does not entirely contradict the detection account as detection of ambiguity may be needed so as to retrieve more than one relevant referent in the previous discourse back to the working memory.

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1.3 Sustained negativities and memory

Under the reasoning of the maintenance account, the Nref effect reflects the number of representations held in working memory. Although previous studies have never examined the ambiguity associated with multiple referents, the intention to investigate conditions like this is not without justification. In the literature of visual working memory, the negative slow wave (NSW) was reported in the retention interval of centrally presented change detection tasks (Ruchkin et al., 1997; Ruchkin et al., 1992). Critically, the NSW is sensitive to the number of items held in VWM, similar to what is proposed for the Nref effect under the maintenance account. The NSW increases in amplitude as the number of items to be held in the VWM increases and reaches an asymptotic limit at each individual's memory capacity (Fukuda, Mance, et al., 2015). In addition, the NSW has been shown to vary in topography as the type of information maintained in the working memory changes. For example, Mecklinger and Pfeifer (1996) found that the topographic distributions were different for spatial and object information to be remembered. These findings were crucially relevant to the maintenance account as these findings suggest the possibility that the Nref effect could be a different version of NSW induced by verbal stimuli. The Nref effect may differ in scalp distribution from these negative slow waves but nonetheless reflects similar neural mechanisms underlyingly. This notion is also comparable to what previous studies have suggested for the Nref effect, stating that the Nref effect may belong to a family of sustained negativities (Barkley et al., 2015) and that the Nref effect may not be reference-specific or language-specific (Van Berkum et al., 2003; Van Berkum et al., 2007).

The observations based on the NSW were further refined with experimental designs that better isolate the relevant responses for working memory load—yielding the contralateral delay activity (CDA) (Vogel & Machizawa, 2004; for a review see Luria et al., 2016). The CDA was observed in a lateralized version of change detection task and possesses similar properties with the NSW, like increasing in

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amplitude as the number of items to be held increases, and also asymptoting at each individual's memory capacity (Fukuda, Mance, et al., 2015; Ikkai et al., 2010; Vogel & Machizawa, 2004; Vogel et al., 2005). The CDA was argued to be a more precise and advanced measure of working memory load than the NSW (Drew et al., 2006). This argument was based on the fact that the CDA measures differences between contralateral and ipsilateral activities so that task-general brain responses that are not exclusively involved in visual working memory operations distributed across both hemispheres are canceled out. In addition to the refined paradigm, findings of the CDA demonstrated that its amplitude shows no further increase in the supra-capacity set size (i.e., set size 4 or more). These findings further revealed that the CDA reflects the exact items maintained in VWM rather than task difficulty in general, which is critical to our current discussion of maintenance account.

Converging with literature reporting suggestive evidence supporting model of central working memory storage (Kane et al., 2004; Morey & Cowan, 2005; Ricker et al., 2010; Saults & Cowan, 2007; Stevanovski & Jolicœur, 2007), which states that working memory depends on central and general resources that operate information regardless of the encoding modality, the Nref effect may likewise engage joint component for processing with these working memory-related ERP components. This view is consistent with the model of Baddeley (1992, 2000), proposing a domain-general executive component that interacts with subordinate and more domain-specific storage processes: a phonological loop for processing verbal and linguistic information, and a visuospatial scratchpad for processing visual and spatial information. Based on this argument, we can further assume that as the number of referents increases, a graded Nref effect will be observed. Yet, these potential associations between the seemingly unrelated ERP effects from different cognitive domains have not been explored in previous studies.

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1.4 Present study and research questions

In view of the above issues, the present study used the event-related potential (ERP) technique to investigate the functional interpretations of the Nref effect by examining the detection account versus the maintenance account. To that end, we manipulated the number of potential referents up to three rather than two as seen in previous studies (Boudewyn et al., 2015; Karimi et al., 2018; Nieuwland, Otten, et al., 2007; Nieuwland & Van Berkum, 2006; Van Berkum et al., 1999; Van Berkum et al., 2003). We use stories including one, two, or three characters that were all suitable referents for the pronoun in the critical sentence, yielding unambiguous, 2-referent and 3-referent conditions respectively (Table 1.1)

This experimental design allows us to test whether the Nref effect is sensitive to the increase in referential load and if so, how the amplitude fluctuates in accordance with the referential load. For the maintenance account to be true, the magnitude of the frontal negativities is expected to increase as the number of referential candidates increases. In contrast, under the detection account, the magnitude may remain equal whenever the number of referential interpretations is incompatible with the number of referents that the anaphor requires.

In addition, we also wish to explore the possibility of a common resource subserving working memory operations across modalities and stimuli types. Specifically, in view of prior findings showing the positive association between larger VWM capacity (as reflected by the K estimate) and larger CDA/NSW effect (Tsubomi et al., 2013; Vogel & Machizawa, 2004), we would like to examine whether participants with higher visual working memory also are more likely to elicit a greater Nref effect. To do that, we incorporated a change detection task to assess each individual's VWM capacity and examined its correlations with the Nref effect. The reasoning for adopting VWM capacity was not that we believe the VWM to have direct contributions to the referential processing. Rather, the reasoning is that if the underlying processing and the utilized working memory resources are comparable, the Nref effect will positively correlate even with working memory assessed

doi:10.6342/NTU202300100

Condition	Context passage	Critical sentence
3-referent	彥傑慵懶的躺在沙發上，看著電視上播放的綜藝節目。住一起的家俊聽著雨滴不停地打在陽台上，窗外的雨聲幾乎都要蓋過電視的聲音了。國維抱怨著，這場大雨已經持續整整兩天了，原本安排好的假日行程沒有一個可以成行。根據天氣預報，這波鋒面可能不會那麼快就結束，家俊、國維跟彥傑所期盼的好天氣看起來遙遙無期。	這場雨/ 要是/ 一直下/ 的話，/ <u>他</u>/ 覺得/ <u>家俊</u>[1]/ 與/ <u>國維</u>[2]/ 明天/ 上班時/ 一定/ 很痛苦。
2-referent	彥傑慵懶的躺在沙發上，看著電視上播放的綜藝節目。住一起的家俊聽著雨滴不停地打在陽台上，窗外的雨聲幾乎都要蓋過電視的聲音了。國維抱怨著，這場大雨已經持續整整兩天了，原本安排好的假日行程沒有一個可以成行。根據天氣預報，這波鋒面可能不會那麼快就結束，家俊、國維跟彥傑所期盼的好天氣看起來遙遙無期。	這場雨/ 要是/ 一直下/ 的話，/ <u>他</u>/ 覺得/ <u>家俊</u>[1]/ 與/ 國維/ 明天/ 上班時/ 一定/ 很痛苦。
1-referent	彥傑慵懶的躺在沙發上，看著電視上播放的綜藝節目。住一起的家俊聽著雨滴不停地打在陽台上，窗外的雨聲幾乎都要蓋過電視的聲音了。國維抱怨著，這場大雨已經持續整整兩天了，原本安排好的假日行程沒有一個可以成行。根據天氣預報，這波鋒面可能不會那麼快就結束，家俊、國維跟彥傑所期盼的好天氣看起來遙遙無期。	這場雨/ 要是/ 一直下/ 的話，/ <u>他</u>/ 覺得/ 家俊/ 與/ 國維/ 明天/ 上班時/ 一定/ 很痛苦。

Table 1.1: Example story. Text excluded to yield the 2-referent and Unambiguous conditions were shown in gray. Critical pronouns and disambiguating character names were underlined. The disambiguation names were marked with superscripts. Display segments in the target sentence are delimited by the forward slash (/).

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from a domain that was previously thought to have weak, if any, relationships with language processing.

Finally, we will explore the ERP responses time-locked to the first disambiguating character names as they provide an opportunity for the readers to retrospectively resolve the referential ambiguity associated with the preceding pronoun. With the appearance of the first disambiguating character name, the number of potential referents for the preceding ambiguous pronouns would drop from three to two in the 3-referent condition and from two to one in the 2-referent condition. As such, although the disambiguating character names themselves are not referentially ambiguous, they reflect a change of referential ambiguity in the situation model. Investigation on data in this time range could provide more insight for how referential ambiguity is processed over time.

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Chapter 2

Method

2.1 Preregistration

The design and settings of our analysis procedures (i.e., preprocessing, ERP analysis, and statistical analysis) have been preregistered at Open Science Framework (https://osf.io/zqdne). Non-preregistered analyses are designated as exploratory.

2.2 Participants

Thirty-six young adults participated in this study (18 males; mean age: 23.53 years, range: 20-30 years) and were monetarily compensated. Data from two additional participants were excluded based on a predetermined criterion that participants will be excluded from data analysis if over 15% of trials are rejected in any condition due to artifacts that cannot be blink corrected. Thirty-six participants were run because the power calculations using the software program G*Power 3.1 (Faul et al., 2009) showed that 36 participants will give us approximately 95% power (94.79%) to detect a small Nref effect (Partial eta squared = .04) between the Unambiguous and 2-referent conditions. The effect size was based on prior data from the lab. All participants were native speakers of Taiwan Mandarin with no exposure to other languages except for Taiwanese before age 5, had normal or

doi:10.6342/NTU202300100

corrected-to-normal vision, and reported no history of neurological or psychiatric disorders or brain damage. All were right-handed as measured by the Mandarin-translated version of the Edinburgh inventory (Oldfield, 1970) (mean laterality quotient = 0.84; SD = 0.18).

2.3 ERP reading experiment

2.3.1 Material

Eighty story triplets were constructed for this experiment. Story triplets were designed such that one, two, and three characters can be included coherently within each triplet using the same story structure and thus creating 1-referent (Unambiguous), 2-referent, and 3-referent conditions (Table 1.1).

Each story consisted of two parts — a context passage and a critical sentence. The context passage consisted of four sentences. For the 3-referent condition, the context passages followed the format that each of the first three sentences introduced one character and the fourth sentence served as a voiceover sentence that concluded the story. All three characters were mentioned in the fourth sentence and their order was rotated across story templates to equalize their discourse salience. By so doing, we wish to reduce any possible influence in the discourse such as first mention or recency that has been shown to affect participants' interpretation of the ambiguous pronouns (Johnson & Arnold, 2022). Each critical sentence contained an ambiguous pronoun preceded by a few words that served as a buffer to prevent the critical pronoun from being the first word presented. Following the ambiguous pronoun, two of the characters were mentioned to disambiguate the reference of the pronoun. For the 2-referent condition, the third character was excluded from the third sentence in the context passage, the voiceover sentence, and the disambiguating part in the critical sentence without affecting the storyline. For the 1-referent condition, the second character was further excluded in the same manner.

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In an effort to validate that all stories could be plausibly continued with all possible referents up to the point of the supposedly ambiguous pronouns, we performed a norming study on the initial set of 80 story triplets. Participants read a context passage from one of the conditions and the critical sentence for the 1-referent condition, with the pronoun replaced by one of the characters that occurred in the context passage. They were asked to judge the plausibility of the critical sentence to confirm that each of the characters can be a valid subject of the critical sentence and the saliency is equal across characters within each story. Therefore, 480 items (80 stories paired with each character from 1-referent, 2-referent, or 3-referent condition, i.e., six possible continuations for each story triplet) were rated. Each continuation was rated on a 5-point Likert scale (1 means very low plausibility and 5 means very high plausibility) by 10 participants who did not take part in the EEG experiment. Story triplets containing any continuations with plausibility ratings below 3 were excluded. For the remaining 66 story triplets, the mean plausibility scores were tightly matched across conditions (1-referent: 4.2; 2-referent: 4.15, 4.10; 3-referent: 4.17, 4.08, 4.04), with minimal mean plausibility score differences among different continuations: averaged absolute differences are 0.31 for the 2-referent condition (SD = 0.26) and 0.33 for the 3-referent condition (SD = 0.26), confirming that all characters were plausible to be a subject in the critical sentence.

Each trial was followed by a yes-no comprehension question (Table 2.1). Half of the questions were about the content of the context passages (Context Comprehension, CC), one-fourth of the questions were about the content of the critical sentences (CS) that was not related to the pronoun reference and only the remaining one-fourth of the questions were about pronoun reference (PR). The correct response to half of the questions was true and to the other half was false.

Story triplets were divided into 6 lists and counterbalanced such that every participant read all 66 story triplets but was never presented with multiple conditions of the same story triplet. In addition, the plausibility values were matched

doi:10.6342/NTU202300100

Question type	True Example	False Example
Context Comprehension (CC)	這場雨已經下超過一天了。	這場雨只有持續下了一天而已。
Critical Sentence (CS)	故事中的人物明天要去上班。	故事中的人物明天要去上學。
Pronoun Reference (PR)	彥傑覺得他的室友們明天上班的時候如果還在下雨的話會很難受。	家俊覺得他的室友們明天上班的時候如果還在下雨的話會很難受。

Table 2.1: Example of comprehension questions. Text excluded to yield the 2-referent and Unambiguous conditions were shown in gray.

across conditions within each list. Each participant read 22 story triplets for each condition. The stories in the list were pseudorandomized such that there were no three consecutive trials of the same condition.

2.3.2 Procedure

Participants were seated 100 cm in front of a computer monitor in a dim, quiet testing room. They were given written instructions and a 3-trial practice before the experiment to familiarize themselves with the experimental task. At the start of each trial, a fixation cross appeared in the center of the screen for one second before the context passage was presented all at once on the screen. After participants had finished reading the passage and responded with a button press, a central fixation cross appeared again, and then the critical sentence was presented word by word in the center of the screen. Each word was presented for 300 ms and followed by a 200 ms blank screen. At the end of the sentence, the screen went blank for one second before a yes-no comprehension question appeared on the screen all at once. Participants were told to read the sentences silently and to press a button to indicate a Yes or No response to the questions. Once the participants pressed the response button, a blank screen appeared and the next trial began after one second. Participants were asked to minimize eye blinks and body movements during the word-by-word presentation of the critical sentence. The experiment was divided into three blocks with a short break in between.

doi:10.6342/NTU202300100

2.3.3 EEG recording and data analysis

The electroencephalogram (EEG) was recorded using 32 sintered Ag/AgCL electrodes from the 10–20 system (QuickCap, Neuromedical Supplies, Sterling, TX, USA). All scalp electrodes were referenced on-line to the left mastoid and re-referenced off-line to the average of the right and the left mastoids. Vertical eye movements were recorded via a pair of electrodes placed on the supraorbital and infraorbital ridge of the left eye; horizontal eye movements were recorded via electrodes placed at the outer canthus of each eye in a bipolar montage. Impedances were kept below 5 kΩ for all electrodes. The continuous EEG was amplified by the SYNAMPS2 amplifiers (Neuroscan, Inc., EL Paso, Texas, USA) with a bandpass of 0.05–100 Hz and was digitized online with a sampling rate of 1000 Hz. Offline data analysis was done using EEGLAB (Delorme & Makeig, 2004) and ERPLAB (Lopez-Calderon & Luck, 2014) toolboxes for MATLAB (Natick, MA, USA). Epochs of EEG data were taken from 200 ms before the stimulus onset to 1500 ms after. Trials contaminated by artifacts from amplifier blocking, signal drifting, muscle activity, eye blinks, and movements were rejected before averaging. If a participant had more than 15% of trials in any critical condition rejected due to blink artifacts (three trials in any condition), that participant's data was blink-corrected using independent components analysis (ICA) in EEGLAB. On average, 3.8% of the trials in critical conditions were rejected. Artifact-free ERPs were averaged by stimuli type after subtraction of the 200 ms pre-stimulus baseline. For all participants, there were at least 19 trials in each critical condition. Prior to measurement, ERPs were digitally filtered through a bandpass of 0.1–30 Hz with a 24 dB/oct roll-off. We pre-registered our ERP analysis that the ERP data were analyzed using a two-way repeated measures ANOVA with two within-subjects factors: Number of Referents (Unambiguous, 2-referent, 3-referent) and Anteriority (Anterior electrode sites: FP1, FP2, F7, F3, FZ, F4, F8, FT7, FC3, FCZ, FC4, FT8, T7, C3, CZ, C4, T8; Posterior electrode sites: TP7, CP3, CPZ, CP4, TP8, P7, P3, PZ, P4, P8, O1, OZ, O2). If there was a significant two-way

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interaction, subsequent comparisons within each level of Anteriority would be analyzed using a one-way repeated measures ANOVA with the factor of Number of Referents.

2.4 Change detection task

2.4.1 Material

All stimuli were presented on a gray background (RGB values: 180, 180, 180). The memory array consisted of either four or eight colored squares (1.08°). Colors for squares were selected randomly from a set of nine colors (RGB values: red = 255 0 0; green = 0 255 0; blue = 0 0 255; magenta = 255 0 255; yellow = 255 255 0; cyan = 0 255 255; orange = 255 128 0; white = 255 255 255; black = 0 0 0). No color was repeated within one memory array.

2.4.2 Procedure

Each trial began with a fixation period of one second. Participants were then presented with a memory array consisting of either four (set size 4) or eight (set size 8) colored squares for 150 ms, followed by a blank retention interval for 900 ms. After the retention interval, a single colored-square was presented in one of the locations in the previously shown memory array. In half of the trials, the color of the square was the same as the one presented at the same location in the memory array, and in the remaining half of the trials, the color of the square was different. Participants were instructed to indicate whether the color had changed with a button press response. Participants completed 60 trials for each set size. Trials from each set size were mixed and presented in a randomized order in two blocks. The accuracy for each set size was first converted to K estimate (K4 for set size 4 and K8 for set size 8) using this formula — $K = N * (H - FA)$, where N is the set size, H is the hit rate, and FA is the false alarm rate (Cowan, 2001; Rouder

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et al., 2011). This measure corrects for guessing by including the false alarm rate. The visual working memory capacity of each individual was then computed by averaging their K4 and K8 (Fukuda et al., 2015).

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Chapter 3

Results

3.1 Behavioral results

3.1.1 ERP reading experiment

The purpose of the comprehension questions was to encourage participants to read the storylines carefully while paying attention to the references of the temporally ambiguous pronouns (Creemers & Meyer, 2022). The mean accuracy rates of each question type are listed in Table 3.1. The results of ANOVA showed a significant effect of Question Type ($F(2, 70) = 30.61, p < .001$), with higher accuracy for questions regarding the content of the context paragraph and target sentence than referential questions [CC vs. PR: ($F(1, 35) = 30.84, p < .001$); CS vs. PR: ($F(1, 35) = 33.36, p < .001$)]. While the accuracy for referential questions was lower, there was no systematic difference among unambiguous, 2-ref, and 3-ref conditions ($F(2, 70) = 0.85, p = .43$). These results suggest that participants read the content attentively and understood the meaning of the stories. In addition, although answering referential questions imposed greater difficulty, participants performed well above chance and showed no systematic differences among conditions.

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Question types	Content questions		Referential questions			Total
	Context Comprehension (CC)	Critical Sentence (CS)	Pronoun Reference (PR)			
			Unamb	2-referent	3-referent	
Accuracy	0.92 (0.05)	0.93 (0.05)	0.75 (0.23)	0.78 (0.23)	0.73 (0.26)	0.88 (0.07)

Table 3.1: Mean accuracy rates of each question type

3.1.2 Change detection task

Accuracy for each set size of the change detection task was converted into K estimate. Individual's visual working memory capacity was then calculated as the average of K estimates for Set Size 4 (mean K4 = 2.77, SD = 0.81) and Set Size 8 (mean K8 = 2.41, SD = 1.59). This resulted in a mean K estimate of 2.59 (SD = 1.13). Our results are consistent with prior findings (Adam et al., 2015; Fukuda & Vogel, 2019). In particular, our results closely replicated the findings from a large 495-participant sample by Fukuda et al. (2015), which reported a mean of 2.7 and 2.4 for K4 and K8 respectively, and similarly increased variabilities of the k estimate from set size 4 (SD = 0.61) to set size 8 (SD =1.18). Moreover, after grouping participants into high- and low-capacity groups base on their averaged K estimate by a median split (for the present study, median K estimate = 2.77; for Fukuda et al. (2015), median K estimate = 2.53), high-K estimate showed a modest increase from K4 to K8 (M = +0.25) while low-K estimate group showed a considerable decrease (M = -0.96), which is again strikingly corresponding to their results (mean difference of high-K estimate group: +0.25; mean difference of low-K estimate group: -0.83). Our data thus also replicated the typical 4-8 drop in the literature (Cusack et al., 2009; Linke et al., 2011; Unsworth et al., 2015). These replications confirmed that the VWM capacity was reliably measured in the present study.

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3.2 Pre-registered analyses

3.2.1 ERP analyses

Grand average ERP responses time-locked to the onset of the pronouns in the critical sentences are shown in Figure 3.1. As can be seen, relative to unambiguous pronouns, a sustained negativity starting from about 300 ms post stimuli onset to the end of the epoch over frontal and left lateral electrode sites can be seen clearly in the 2-referent condition and, to a much lesser extent, in the 3ref condition. Nevertheless, the results of ANOVA showed no significant effect of Number of Referent ($Fs \leq 2.2, ps \geq .12$) or interactions with Anteriority ($Fs \leq 2.7, ps \geq .07$) in all pre-registered time windows (300-600/600-1000/1000-1500 ms).

3.2.2 Correlation analyses

The correlational results showed that visual working memory capacity did not correlate with mean amplitude differences between the Unambiguous and 2-referent conditions ($rs \leq .03, ps \geq .53$) or between the Unambiguous and 3-referent conditions ($rs \leq -0.05, ps \geq .7$) in any of the pre-registered time windows (Figure 3.2).

3.2.3 Interim summary

In summary, these ERP results replicated prior findings of the Nref effect when the pronouns were referentially ambiguous with two potential referents. For the critical condition which we added in this present study—the 3-referent condition, in which the ambiguous pronouns had three potential referents, a smaller and temporally more restricted negativity was observed. Despite the numeric trends, neither effect reached statistical significance. Our results also failed to show any correlations between the mean amplitude differences and the visual working memory capacity. As a close inspection of the data revealed a great number of individual variations in

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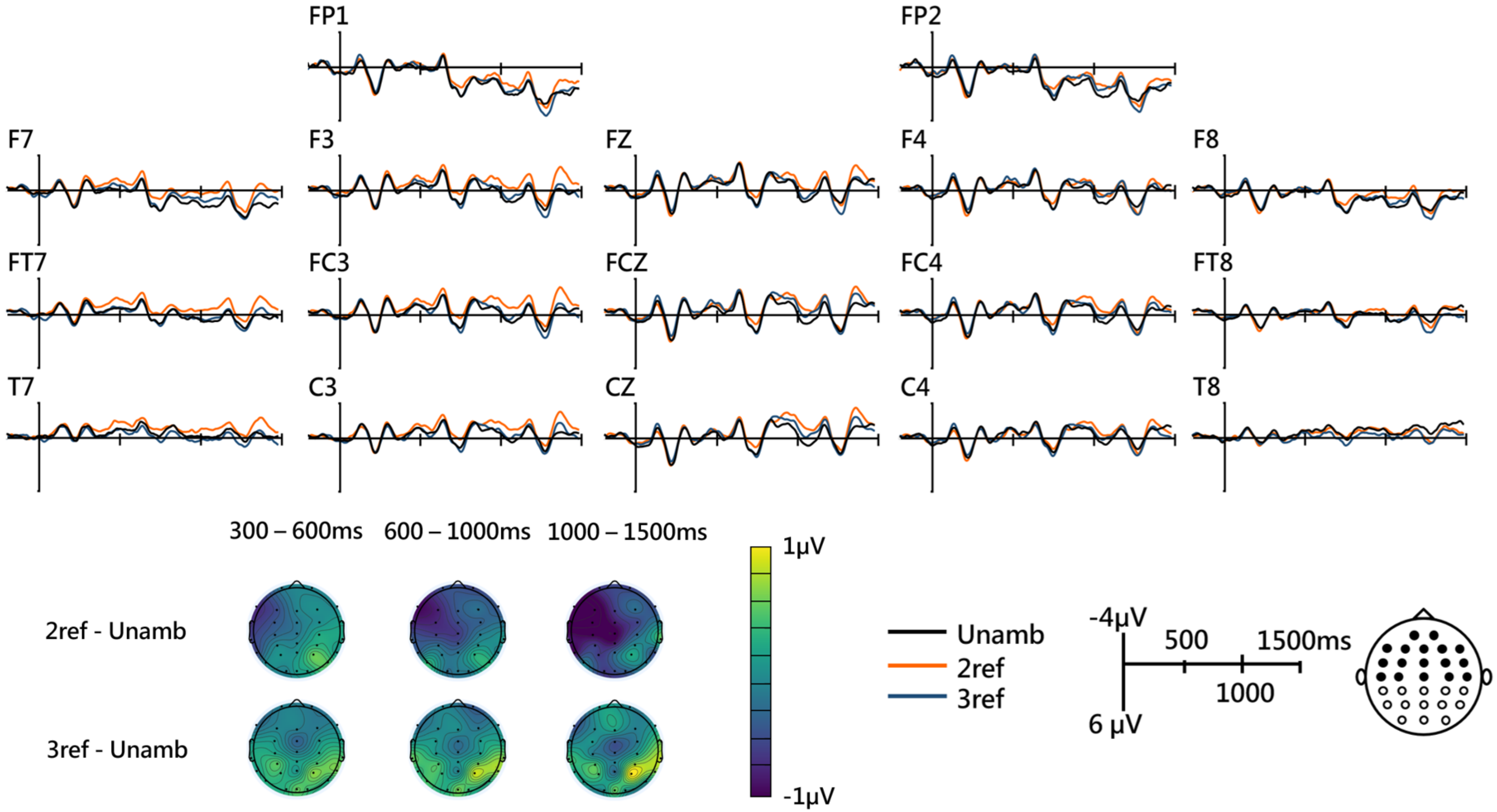

Figure 3.1: Grand average event-related potentials (ERPs) are plotted at frontal electrode sites for target pronouns in Unambiguous (solid black), 2-referent (orange line), and 3-referent (blue line) conditions. Positions of the plotted sites are indicated by filled circles on the head diagram (nose at top). For this and all following figures, negative values are plotted up; waveforms were additionally filtered with a low pass at 20 Hz for illustration purposes.

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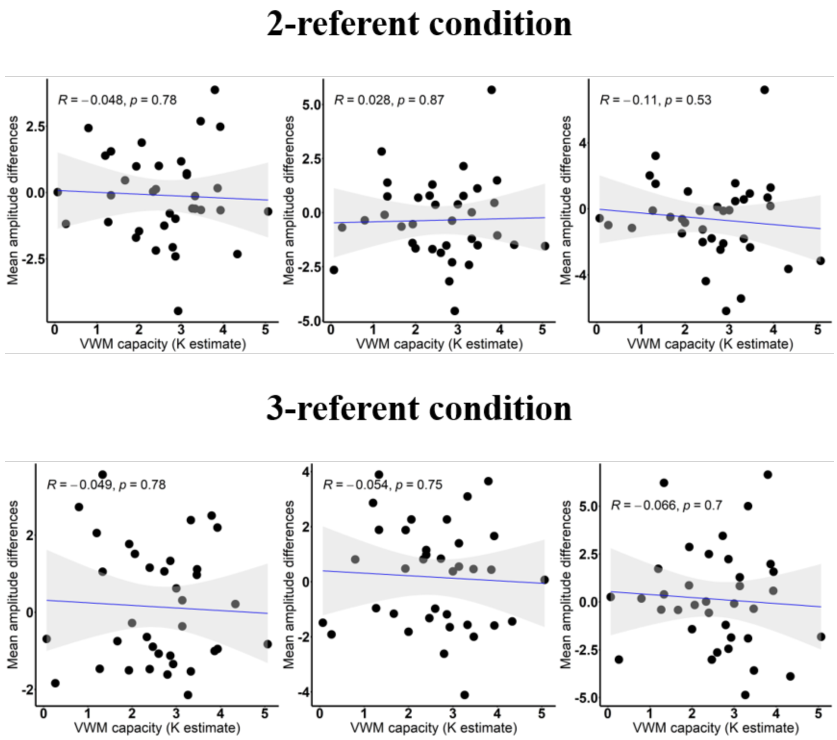

Figure 3.2: Scatterplots of mean amplitude difference and VWM capacity. The solid lines represent the best-fit of the correlation. Mean amplitude differences measured at all three pre-registered time windows are presented (left: 300-600 ms; middle: 600-1000 ms; right: 1000-1500 ms).

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the distribution of conditional differences, we next conduct an explorative analysis to better capture the Nref effect across individuals.

3.3 Exploratory analyses — Spatial ROI for target pronouns

Our pre-registered ERP analyses showed that the left-frontal Nref effect seen in the waveforms was not statistically significant in the pre-determined time windows. Visual inspection of the individual data revealed that the topographic distributions of the effect showed great individual differences. For this reason, we performed exploratory analyses to individualize the spatial region of interest (ROI) for each participant.

First, we identified the maximal point of the Nref effect among the frontal channels for each individual by locating the latency and the channel where the 2-referent minus Unambiguous difference was the biggest. As peak-based measures are sensitive to high-frequency noise, each individual's ERP data were first filtered with a low pass 5Hz to avoid spurious peaks from high-frequency noise (Luck, 2014). Mean amplitudes of the 200 ms centered around the peak of the data recorded from that channel were then computed for each subject. Anchoring the channel with the maximal mean amplitude, we next compared it to its neighboring channels to determine the coverage of the spatial ROI of the effect. The neighboring channels were defined as those included in the 3 by 3 grid surrounding the maximal channel (Figure 3.3). For example, if the maximal channel is CZ, then FC3, FCZ, FC4, C3, C4, CP3, CPZ, and CP4 will be compared; if the maximal channel is FP1, then F7, F3, and FZ will be compared. The mean amplitudes of the neighboring channels were measured in the same 200 ms time window as the maximal channel. Neighboring channels with mean amplitude differences that are greater than 50% of the mean amplitude difference measured from the maximal channel were included into the spatial ROI. This criterion yielded a mean of 3.94 channels for the spatial

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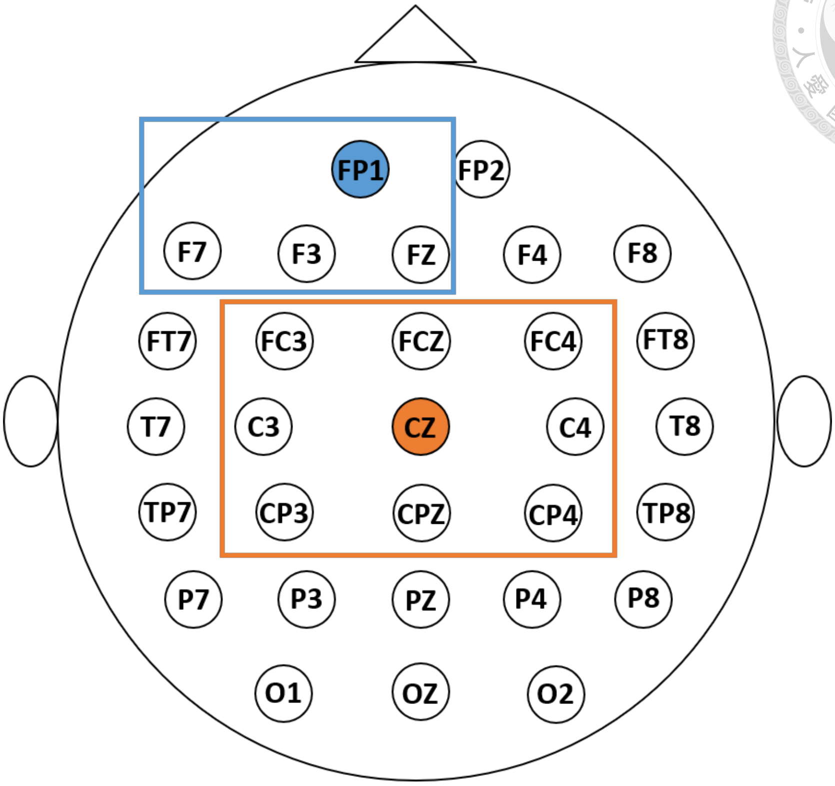

Figure 3.3: Example of 3 by 3 grid centering around the maximal channel. If the maximal channel is CZ, then FC3, FCZ, FC4, C3, C4, CP3, CPZ, and CP4 will be included as shown in orange line; if the maximal channel is FP1, then F7, F3, and FZ will be included as shown in blue line.

ROI (range: 1-9 channels).

Using the individualized spatial ROIs, we then measured the mean amplitudes of Unambiguous, 2-referent, and 3-referent conditions during the pre-registered time windows (300-600/600-1000/1000-1500ms) from the original datasets that were filtered with a bandpass of 0.1–30 Hz and were not additionally filtered. Mean amplitudes measured from each individual's spatial ROI were submitted to an ANOVA with a factor of Number of Referent. The results showed a significant main effect of Number of Referent in all of the pre-determined time windows (300-600 ms: $F(2, 70) = 12.84, p < .001$; 600-1000 ms: $F(2, 70) = 27.25, p < .001$; 1000-1500 ms: $F(2, 70) = 19.86, p < .001$). Subsequent pair-wise analyses

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with corrections for multiple comparisons by Bonferroni correction showed that, relative to the Unambiguous condition, both 2-referent and 3-referent conditions elicited significant Nref effects in the 300-600 ms time window (2ref: $F(1, 35) = 24.69, p < .001$; 3ref: $F(1, 35) = 8.61, p < .01$) and the 600-1000 ms time window (2ref: $F(1, 35) = 61.05, p < .001$; 3ref: $F(1, 35) = 7.27, p = .01$), but only the 2-referent condition elicited a significant Nref effect in the 1000-1500 ms time window after correction for multiple comparisons (2ref: $F(1, 35) = 41.14, p < .001$; 3ref: $F(1, 35) = 4.51, p = .04$). The comparisons of the referential ambiguity effects between the 2-referent and 3-referent conditions were significant in both 600-1000 ms and 1000-1500 ms time windows, indicating more pronounced Nref effects in the 2-referent condition than the 3-referent condition (300-600 ms: $F(1, 35) = 5.07, p = .03$; 600-1000 ms: $F(1, 35) = 21.47, p < .001$; 1000-1500 ms: $F(1, 35) = 24.13, p < .001$).

Based on data extracted from individualized ROIs, we further correlated each individual's mean amplitude differences between 2-referent and Unambiguous conditions and between 3-referent and Unambiguous conditions with their visual working memory capacity (K estimate) in all of the three pre-registered time windows. Despite the numeric trend for a negative correlation between 2-referent and Unambiguous conditions in the 1000-1500 ms time window ($r = -0.29; p = .09$) and between 3-referent and Unambiguous conditions in the 600-1000 ms ($r = -0.31; ps = .07$), no significant correlations were found.

To recap, in view of the great individual differences in the topographic distribution, we conducted exploratory analyses to identify each individual's spatial ROI. Based on individualized ROIs, the Nref effect was statistically reliable in all pre-registered time windows for the 2-referent condition and was statistically significant in the 300-600 and 600-1000 ms time windows for the 3-referent condition. Subsequent comparisons revealed that, relative to the 2-referent condition, the 3-referent condition elicited a reduced Nref effect. For the correlational analyses, while the numerical pattern showed a negative correlation between the Nref effect

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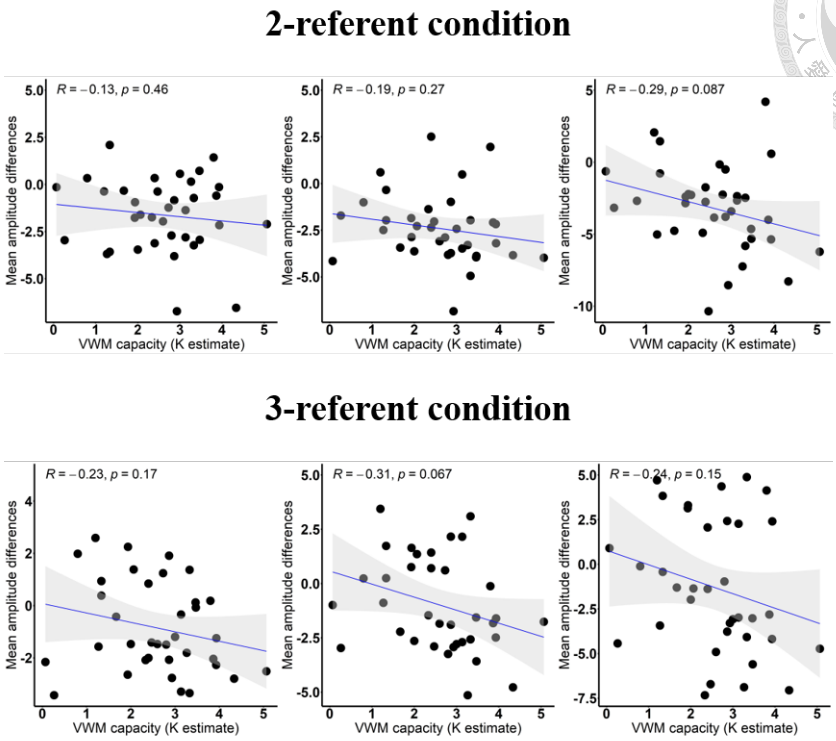

Figure 3.4: Scatterplots of mean amplitude difference based on individualized ROIs and VWM capacity. The solid lines represent the best-fit of the correlation. Mean amplitude differences measured at all three pre-registered time windows are presented (left: 300-600 ms; middle: 600-1000 ms; right: 1000-1500 ms).

and the K estimate, the trend was not statistically significant (Figure 3.4).

3.4 Exploratory analyses — Ambiguity effect on disambiguation words

We also examine the ERP responses time-locked to the first disambiguation words to explore the brain responses subsequent to the referential ambiguity (Figure 3.5). We focused on the first disambiguation words—the first mentioned character names in the critical sentence of the 3-referent condition and the only mentioned character names in the 2-referent condition, because of its unique status. Upon the presenta-

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tion of the first disambiguation words, the available referents for the already-seen ambiguous pronouns were reduced from three to two for the 3-referent condition and from two to one for the 2-referent condition. In other words, even though the referent for this disambiguation name is clear and there is no referential ambiguity associated with this name, the comparison of this disambiguation words between these two conditions was analogous to the comparison of target pronouns between 2-referent and Unambiguous condition in that both were comparing an ambiguous scenario (with two potential referents for the pronoun) to an unambiguous scenario (with only one possible referent for the pronoun).

As shown in Figure 3.5, relative to the 2-referent condition, a sustained negativity starting from about 500 ms post stimuli onset to the end of the epoch over frontal electrode sites can be seen clearly in the 3-referent condition. Mean amplitudes measured between 300-600 ms and 600-1000 ms post stimuli onset were submitted to an ANOVA with a factor of Anteriority (Anterior vs. Posterior) and a factor of Number of Referent, which now is a two-level factor (first disambiguation in 2-referent vs. 3-referent condition). For the 300-600 ms time window, the results showed a significant main effect of Anteriority ($F(1, 35) = 8.67, p < .01$), but no effect of Number of Referent or an interaction ($Fs \leq 1.4, ps \geq .24$). For the 600-1000 ms time window, the results showed a significant main effect of Number of Referent ($F(1, 35) = 8.11, p < .01$) and a significant interaction between Number of Referent and Anteriority ($F(1, 35) = 4.6, p < .05$). Subsequent comparisons showed a significant main effect of Number of Referent for the anterior channels ($F(1, 35) = 9.8, p < .01$) but only nearly significant for the posterior channels ($F(1, 35) = 3.3, p = .08$).

To summarize, relative to the disambiguating words that fully resolved the pronoun, a sustained frontal negativity was observed for the disambiguating names that still allow the pronouns to refer to the other two remaining characters.

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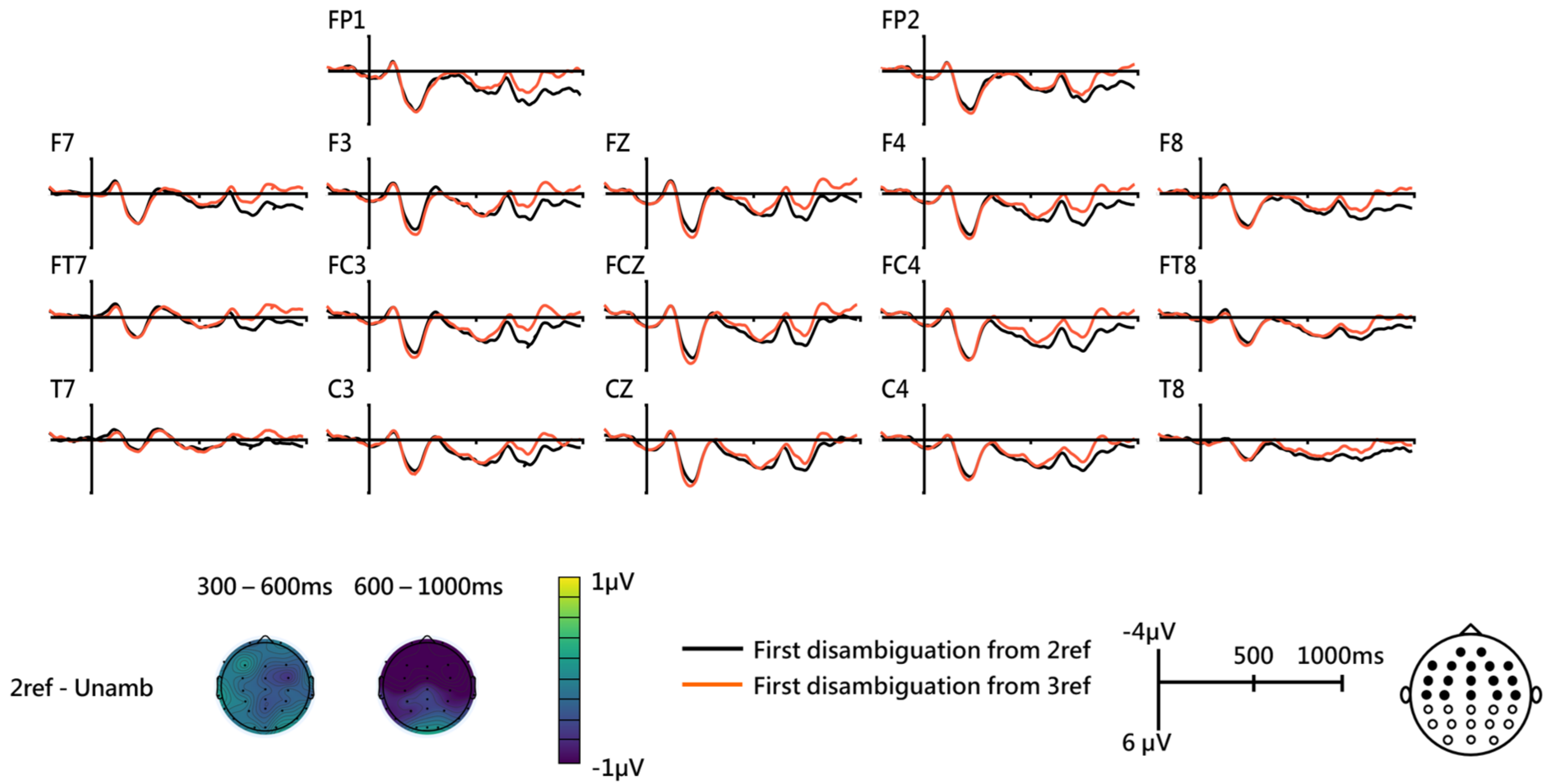

Figure 3.5: Grand average event-related potentials (ERPs) are plotted at frontal electrode sites for the first disambiguation names in 2-referent (solid black) and 3-referent (orange line) conditions.

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Chapter 4

Discussion

The goal of this study was to investigate the properties and the underlying processing reflected by the Nref effect. Specifically, we examined the sensitivity of the Nref effect to the increase in referential load. To that end, we manipulated the number of characters in a discourse context so that the pronoun in the critical sentence could refer to one, two, or three possible antecedents. The 3-referent condition has not been done by any studies before and is the critical condition that was designed to tease apart the detection account and the maintenance account for the Nref effect. Our results showed differential Nref effects time-locked to the critical pronouns in the 2-referent and 3-referent conditions. These results may seem to support neither the ambiguity detection account or the maintenance account. However, there are alternative explanations for these result patterns, interpretations of these findings thus require further validation. Despite the tentative conclusions to data time-locked to the pronouns, results time-locked to the disambiguation name revealed continuing ambiguity effect even after the ambiguous pronoun. Our data showed a negativity response to first disambiguation character names in the still ambiguous condition—the 3-referent condition relative to the then unambiguous condition—the 2-referent condition. This negativity showed a similar topographic distribution and temporal characteristic as the Nref effect, which provided further insight to the functional nature of the Nref component. In

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what follows, we elaborated on each of these points in turn.

4.1 Graded Nref effect in the 2-referent and 3-referent conditions

The results of the critical pronouns offered direct evidence to neither the maintenance account nor the detection account. Our data showed that ambiguous pronouns with two potential referents elicited a sustained frontal negativity relative to the unambiguous pronouns. By contrast, a much reduced group-level Nref effect was seen to ambiguous pronouns with three potential referents. These result patterns were not statistically significant under the conventional α = 0.05 threshold in our pre-registered time windows for either the 2-referent or the 3-referent condition in all time windows. The Nref effect in our data was more left-laterally distributed, consistent with what has been reported in the previous studies (Boudewyn et al., 2015; Nieuwland, 2014). However, close inspection of our data revealed a large amount of inter-individual distributional variation, in line with past findings that showed individual differences in the Nref effect (Boudewyn et al., 2015; Nieuwland & Van Berkum, 2006; Lee & Lai, accepted). In light of this, we conducted a subsequent analysis to more focally analyze the Nref effect tailored according to each individual's effect distribution. Specifically, we determined the spatial ROI restricted for each participant among the frontal channels (see Boudewyn et al., 2015 for a similar approach). With individualized ROIs, the analyses revealed a significant Nref ambiguity effect for the 2-referent condition in all pre-registered time windows and a significant Nref ambiguity effect for the 3-referent condition in the 300-600 ms and 600-1000 ms time windows. Our results also showed graded Nref effects across the ambiguity conditions, with the Nref being larger in the 2-referent condition than in the 3-referent condition across all time windows. Based on these preliminary analyses, these results thus provided direct evidence for neither account.

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One relevant important observation is the individual differences seen in the 3-referent condition. Some participants in fact elicited a frontal positivity to the ambiguous pronouns in this condition. As a result, the reduced Nref effect might be generated by averaging two groups of participants that elicited responses of opposite directions. For those participants who elicited negative responses, it would be important to try to remove the influence of the positivity effect, so as to compare the Nref effects between the 3-referent condition and the 2-referent condition more fairly. If the amplitudes are similar between these two conditions, then our results will still be consistent with the detection account. If, on the other hand, the amplitude of the Nref effect is stronger in the 3-referent condition than in the 2-referent condition, our results will be more consistent with the maintenance account, suggesting that the amplitude of the Nref effect reflects the number of representations kept in the working memory.

With regard to the positive effect observed for a subgroup of participants, one possible explanation for the positive response in the 3-referent condition is the P600 effect observed for referential failures, such as when an anaphor does not match the gender of the potential antecedents (Nieuwland & Van Berkum, 2006; Osterhout et al., 1997; Osterhout & Mobley, 1995; Van Berkum et al., 2007), or the LPC effect elicited by referentially ambiguous but syntactically well-formed noun phrases that was also seen in a subgroup of participants and was suggested to be associated to task-related processing strategy (Nieuwland & Van Berkum, 2008a). However, there was no gender-mismatch for the ambiguous pronouns in our study and the topographic distribution of the observed positive effect was not similar to that of a typical LPC effect.

Another more likely explanation for the positive response in the 3-referent condition is the frontally distributed positivity observed for topic shift (Hirotani & Schumacher, 2011; Hung & Schumacher, 2012; Xu & Zhou, 2016). For example, Hung and Schumacher (2012) used stimuli like the following:

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(3a) 張三怎麼了/李四毆打了張三

(3b) 李四怎麼了/李四毆打了張三

They found that relative to the counterpart in the condition maintaining topic continuity (3b), the critical word "李四" in the topic-shift condition (3a) elicited a frontal positivity. The enhanced frontal positivity was suggested as reflecting the update and the reorganization of the discourse structure. In view of the concern of different degrees of discourse saliency associated with different characters, care was taken during stimuli construction so that all three characters were mentioned in the voiceover sentence. This voiceover sentence may inadvertently lead to a perceived topic shift by a subgroup of participants when the critical pronoun in the subsequent sentence narrows the focus down to only one of the characters.

Subsequent endeavors should be devoted to investigating how the Nref effect patterns may change if the influence of the perceived topic shift can be extracted and removed.

4.2 Nref-like effect to the first disambiguating name

Despite the less pronounced Nref effect time-locked to pronouns in the 3-referent condition than in the 2-referent condition, subsequent exploratory analyses on data time-locked to the first disambiguation name showed a Nref-like response in the 3-referent condition than in the 2-referent condition.

That an ambiguity effect was observed long after the ambiguity happened showed that referential processing is flexible and is carried out over time (Arnold et al., 2018; Klin et al., 2006; Klin et al., 2004; Levine et al., 2000). These data provide very interesting observations. As proper names, the first disambiguation character names were referentially explicit and unambiguous. However, their presence marked the change in the ambiguity status of the pronouns in the situation model. Upon the presentation of the first disambiguating name, that character was

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excluded from the possible candidates for the pronouns whereas the other two characters continued to be considered as possible referents. A similar elimination process also happens upon the first disambiguation character names in the 2-referent condition, rendering the pronoun no longer ambiguous in the situation model.

Our finding of an ambiguity effect on the proper names at the disambiguating position also weighs in on the debate between two opposing view about the referential functions of proper names. While some researchers suggest that proper names initiate new topics and referents to establish referents but not initiate back association to link with prior antecedents (e.g., Barkley et al., 2015), others believe that proper names can initiate both anaphoric formation and antecedent activation under appropriate and suitable conditions (e.g., Coopmans & Nieuwland, 2020). Below we briefly describe two representative studies for each view.

Barkley et al. (2015) claimed that different from the typical referential functions of pronouns to proceed with the topic and maintain the focus on the antecedents (Marslen-Wilson et al., 1982; Vonk et al., 1992), i.e., referential maintenance (Silverstein, 1986), the functions of proper names are to initiate new topics and referents, i.e., referential establishment, and thus proper names are unable to initiate back association to link with antecedents. Barkley et al. (2015) found that co-referential pronouns elicited an LAN effect compared to pronouns without preceding co-referents (4), but such differences were not observed between proper names with and without preceding co-referents (5).

(4)

a. After a covert mission that deployed Will for nine terrible months, he longed for home.

b. After a covert mission that required deployment for nine terrible months, he longed for home.

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(5)

a. After a covert mission that deployed him for nine terrible months, Will longed for home.

b. After a covert mission that required deployment for nine terrible months, Will longed for home.

However, contrary to what has been suggested by Barkley and colleagues (2015), Coopmans and Nieuwland (2020) found a sustained frontal negativity elicited by proper names (e.g., '*John*') that were linked to an unspecified reference group (e.g., "*The players in the football team* are very good. The top scorer of the team was *John*") compared to proper names with repeated antecedents (e.g., "*John* and Peter are the best players in the football team. The top scorer of the team was *John*") or with no direct antecedent (e.g., "David and Peter are the worst players in the football team. The top scorer of the team was *John*"). Based on these results, they indicated that proper names do trigger antecedent activation and formation of anaphoric relations.

Our findings provide evidence showing that proper names can initiate both anaphoric formation and antecedent activation under appropriate and suitable conditions. However, we believe that the sustained negative ambiguity effects observed in our study reflect subtle but importantly different forms of antecedent activations from that in Coopmans and Nieuwland (2020). In Coopmans and Nieuwland (2020), the proper names triggered the activation of an unspecified reference group, which is compatible with the entity referred by the proper name, as an antecedent. However, in the present study, there was no compatible reference group that can be activated by the proper names. Instead, the proper name more likely triggered the activation of the other two proper names that remained to be potential referents. As opposed to what Barkley and colleagues (2015) suggested — that the search for antecedents is exclusively cued by pronouns, the present

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study found that proper names could also cue the retrieval of antecedents. Our findings suggest the feature of initiating anaphoric formation may largely depend on contextual factors like discourse-level semantics.

4.3 A proposed account for the observed data

Based on the above discussions, below we sketch a possible explanation for the observed data patterns. As we mentioned in the Introduction, the maintenance account does not entirely contradict the detection account as detection of ambiguity may be needed so as to retrieve more than one relevant referent in the previous discourse back to the working memory. Along this line, the sustained nature of the Nref effect may represent different stages of ambiguity processing. It can thus be suggested that after encountering ambiguous expressions, our brain first recognizes the existence of ambiguity, and then active elaborative inferences come in to try to manage the ambiguity by retrieving and actively maintaining the preceding potential referents in the working memory for the following disambiguation. Indeed, although the current study was not designed to directly examine this possibility, our results nonetheless provide some suggestive evidence supporting this hypothesis (illustrated in Figure 4.1).

As illustrated in Figure 4.1, upon encountering the ambiguous pronoun, the detection component came first as an initial processing and thus we observed a reduced Nref effect for the 3-referent condition at the earlier time window (300-600/600-1000 ms), but not at the later period (1000-1500 ms). For the 2-referent condition, the maintenance component came right after the detection, so the negativity was sustained at the time window of 1000-1500 ms. In contrast, for the 3-referent condition, the maintenance component appeared after encountering the first disambiguating word, where the potential referents were reduced to two. Therefore, we observed a negativity for the first disambiguating word in the 3-referent condition.

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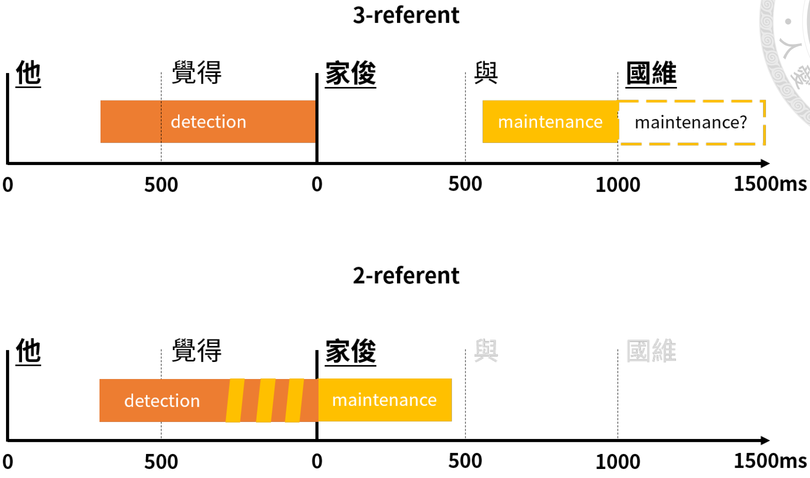

Figure 4.1: Schematic diagram of the hypothesized sequential processing reflected by the Nref effect. The target pronoun and the first disambiguation name were separated by one or two words.

One important caveat to this interpretation is that the sequential effects we described here were time-locked to different words that were separated by at least one word. It is possible that the referential ambiguity processing is extremely flexible and that different stages of processing can be done separately depending on the difficulty of retrieving relevant antecedents. This explanation is in line with findings showing that accessibility of the referents affects referential processing (Klin et al., 2006; Klin et al., 2004; Levine et al., 2000; Streb et al., 2004). Alternatively, it can be possible that due to our experimental design, in which the pronouns were always followed by the disambiguating information, participants had adapted to this referential structure. Therefore, different stages of processing were triggered respectively by pronouns and the disambiguating words, probably because retrieving and maintaining three referents from a discourse was strongly demanding. In addition, as the disambiguation constantly followed the ambiguous pronoun at a predictable position, it became unnecessary for the maintenance component to be operated immediately. However, we are more cautious about this interpretation because there is another possible explanation. The seemingly

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sequential and divided effect in the 3-referent condition could also result from the higher noise level of the 3-referent condition. The target pronoun and the first disambiguation name were separated by one or two words, so for stories having only one intervening word, the disambiguation name was already presented at 1000 ms after the onset of the target pronoun. While for stories having two intervening words, the first disambiguation name was presented 1500 ms after the onset of the target pronoun. Therefore, for the 3-referent condition, the 1000-1500 ms time window is noisier because although the ambiguity sustained within this time window, the ambiguity was stemmed from having either two or three referents for different groups of stories. This might be the reason of not observing a Nref effect in the 1000-1500 ms time windows. Future work is required to directly examine the time course issue of the underlying processing raised by the present study. A possible follow-up study might be to better control the distance between the ambiguous target and the disambiguation.

4.4 Correlating the Nref effect with the K estimate of VWM capacity

Another goal of this study was to explore whether the Nref effect was associated with other sustained negativities through general working memory resources. To that end, we assessed each participant's VWM capacity and correlated it with the Nref effect. We hypothesized that high-span individuals will elicit a greater Nref effect, corresponding to the positive correlations found both between the Nref effect and verbal working memory measurement (Boudewyn et al., 2015; Fiorentino et al., 2018; Nieuwland, 2014; Nieuwland & Van Berkum, 2006) and between K estimates with the CDA (Tsubomi et al., 2013; Vogel & Machizawa, 2004).

Contrary to our expectations, we observed no correlations between the K estimate and the mean amplitude differences for both 2-referent and 3-referent

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conditions. The following exploratory analyses measuring ERP responses in each individual's spatial ROI also showed no significant correlations. One straightforward explanation might be that there is no association between these brain responses and referential processing does not utilize similar working memory resources with visual processing. However, we believe that the above explanation is not the case and our results of not finding a connection were more likely explained by methodological differences between our experiment and the visual detection experiments.

There are several reasons why an association between the Nref response and K-estimate was not obtained. First, we would like to point out that subtle differences exist between the visual and language tasks we adopted here. For the visual change detection task, participants already knew the to-be-remembered items in advance, while that was not the case for the passage comprehension task. Therefore, the language task induced greater difficulty in forming precise and accurate representations in the working memory. Consequently, individuals who are weaker at executing memory operations may even be unable to initiate the processing that was reflected by the Nref effect (Nieuwland & Van Berkum, 2006). In contrast, it is less likely for the visual task that individuals with low VWM span cannot at least maintain one single item in their VWM and elicit no CDA effect. Furthermore, representation formation may be more unreliable due to influences of other cognitive abilities that are known to be involved in language comprehension, such as print exposure (Lee & Lai, accepted), verbal ability, and attention (Boudewyn et al., 2015). In addition, our stimuli were discourses rather than sentences, in which more solidly available and syntactically prominent antecedents can be more easily identified locally, so reading strategies may be largely engaged in the participant's comprehension. For example, previous studies have shown that when the standard of discourse coherence is met, the anaphoric inference might become optional and the anaphor was left underspecified (Klin et al., 2006; Klin et al., 2004; Levine et al., 2000), suggesting that the participants may settle for

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”good-enough” representations (Ferreira et al., 2002). Another concern for the stimuli is that the discourse is presented in written form rather than spoken form and the reading is self-paced, so individual differences in reading strategies and attentional resources could have a greater influence on their discourse processing. Future study may consider presenting the stimuli in spoken form to confirm that the perception of the discourse context is validated.

Taken together, under the influences of the abovementioned factors, the presence of the Nref effect itself contains considerable variations and thus if a subgroup of participants fails to initiate the processing reflected by the Nref effect, then it will be more difficult for us to observe the underlying association between the Nref effect and the VWM capacity. In addition, while the limit of the VWM capacity was well-studied in the literature, the “referential capacity” remains unclear. Supposing that the magic number is two for natural language processing (although the limit may vary depends on the material; for example, three characters occurring in a sentence might be more accessible than in a long passage), then it will be more difficult for us to inspect the relationships because the Nref effect itself does not possess a continuous range to be measured, but is manifested as a discrete all-or-none effect. A further study with a proper task that can trigger more reliable and consistent Nref effects for most of the individuals is needed to provide a more robust index of referential processing.

4.5 Concluding remarks on the nature of the Nref response

Research has provided several possible hypotheses about the underlying neural mechanisms of the Nref effect, and whether the Nref effect reflects referent maintenance or ambiguity detection. Based on the previous discussion, our data suggest that the Nref effect reflects a process of retrieving relevant referents associated with a perceived referential ambiguity. This referential process can be flexibly

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engaged and is tightly associated with the ambiguity status in the situation model. This proposal is not incompatible with the view that hypothesizes that the Nref effect reflects controlled processing to resolve the ambiguity (e.g., elaborative reference inference, or searching and retrieving cues from the memory of the discourse) (Nieuwland, 2014; Nieuwland, Petersson, et al., 2007). In the literature, terms such as ambiguity detection, retrieval and maintenance have been adopted to describe the incremental development of referential processing. Implications and differences behind these terms need to be clearly distinguished for the theories to advance. Future study is also needed to examine the sequential processing of the Nref effect to better characterize and identify these likely distinct functional aspects of ambiguity processing.

Consistent with previous studies (Boudewyn et al., 2015; Nieuwland & Van Berkum, 2006); Lee & Lai, accepted), we found individual differences in the responses upon encountering an ambiguous expression. In addition, some of the issues emerging from our findings relate specifically to the underlying phases of ambiguity processing. The negative ambiguity effect observed for later disambiguating information suggests that the underlying process can be operated in an adjustable way and it may not necessarily be confined to ambiguity or problematic reference itself because the ambiguity should be identified earlier. The underlying mechanisms may be more associated with the mental representations relevant to the ongoing discourse, consistent with the maintenance hypothesis.

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Chapter 5

Reference

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