Neuro-physiological processing of subject-verb agreement in L1 & L2 speakers of English

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Summary

The question of how people understand sentences during sentence comprehension has intrigued researchers over the past three decades. The aim of sentence processing research is, on one hand, to gain insight on the processes and factors that facilitate successful sentence comprehension, and on the other hand, enhance our understanding on how these factors may influence language acquisition. One of the linguistic phenomena that has enabled researchers to investigate these processes is subject verb (S-V) agreement. This thesis contributes to sentence processing research by investigating how the relative perceptual salience of S-V agreement violations (due to type of agreement violation and utterance position) might impact agreement processing during on-line sentence comprehension, using the ERP technique.

Previous ERP studies have often reported two ERP components—LAN and P600—in response to subject-verb (S-V) agreement violations (e.g., *the boys *runs)*. However, the latency, amplitude and scalp distribution of these components have been shown to vary depending on various factors which include experimental-related issues, language proficiency or maturational development. One factor that has been recently shown to play a role in the comprehension of S-V agreement, but has not been given attention in sentence processing research, is perceptual salience. Understanding how the relative perceptual salience of the S-V agreement violations impacts on the listeners' sensitivity to the violation is important for two reasons: i) it may enhance our understanding on how acoustic information modulate the processing and acquisition of grammatical morphemes (very few studies have used the auditory modality to investigate the processing of S-V agreement violations); and ii) it may contribute to on-going debates on the functional interpretation of the LAN/P600 ERP components.

This thesis therefore reports findings from three different populations, i.e. adult English-speakers (L1), adult Mandarin-English learners (MLEs) and 8-11-year-old children,

which constitute the three studies reported in the respective Chapter 2, 3, and 4 in this thesis. Participants were presented with four conditions varying in degree of perceptual salience depending on utterance position and type of agreement violation: utterance-medial errors of omission and errors of commission, and utterance-final errors of omission and errors of commission.

In L1 adults, we observed more robust P600 effects for errors of commission in utterance-final position and a bilateral anterior negativity (AN) effect for errors of omission in utterance-medial position. This indicated that perceptual salience of the S-V agreement violations impacted on how L1 adults processed the agreement violations. In Mandarin learners of English (MLEs), we observed a late anterior P600 for errors of omission in utterance-final position and a late posterior negativity for errors of commission in utterance-final position. Although MLEs showed sensitivity in the more perceptually salient utterance-final position, the ERP components observed differed from those observed in L1 adults. Finally, in the 8-11-year-olds, we observed a broad N400 effect with longer latency for errors of omission in utterance-final position and a centro-posterior N400 with shorter latency in utterance-medial position. Although the children showed sensitivity in the more perceptually salient utterance-final position, the ERP components elicited differed from those observed in L1 and L2 adults.

These findings highlight the importance of perceptual salience in S-V agreement processing and the potential theoretical implications it has for the processing and acquisition of grammatical morphemes such as the 3rd person singular –s. Furthermore, these findings highlight the implications of experimental designs used in ERP studies (e.g., stimuli manipulations and/or modalities of presentation) for the functional interpretation of the ERP effects observed thereof.

Personal Declaration

I, Sithembinkosi Dube certify that the work in this dissertation entitled "**Neuro-physiological processing of subject-verb agreement in L1 & L2 speakers of English"** is my original work has not been previously submitted for a higher degree in any institution other than Macquarie University. I also certify that the thesis is an original piece of research and it has been written by me. Any help and assistance that I have received during the course of this my study is appropriately acknowledged. I also certify that all the information sources and literature used are indicated in this thesis. All the studies reported in this thesis gained approval from the Macquarie University Human Research Ethics Committee, reference number: **5201200795**.

Some of the material in this thesis has already been submitted for publication. Chapter 2 is based on the publication as in (1). Chapter 3 is based on the publication as in (2).

(1) Dube, S., Kung, C., Peter, V., Brock, J., & Demuth, K. (Under review). Effects of sentence position and type of violation on the processing of subject-verb agreement: An auditory ERP study. Submitted to *Frontiers in Language Sciences.*

(2) Dube, S., Kung, C., Peter, V., & Demuth, K. (In submission). Perceptual salience matters for L2 processing of subject-verb agreement: ERP evidence from advanced Mandarin learners of English. Submitted to *Plos One.*

(3) Dube, S., Kung, C., Peter, V., & Demuth, K. (In submission). Perceptual salience matters for the processing of subject-verb agreement in 8-11 years-old English-speaking children: Evidence from ERPs. Submitted to *Journal of Cognitive Sciences.*

Signed:

Sithembinkosi Dube (student ID: 42658195)
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CHAPTER 1

General Introduction

Introduction

Most people are able to understand sentences with little apparent effort. This is an amazing feat given that comprehending a sentence entails instantaneous processing of different kinds of linguistic and contextual information. One of the goals of sentence processing research is to understand how people extract information from the sentence to generate meaning. A general perspective of comprehend sentences is that speakers extract linguistic information from the sentence and segment it at different levels of structure (phonological, lexical and morphosyntactic) by matching the input with our grammatical knowledge and discourse context (see **Figure 1**).

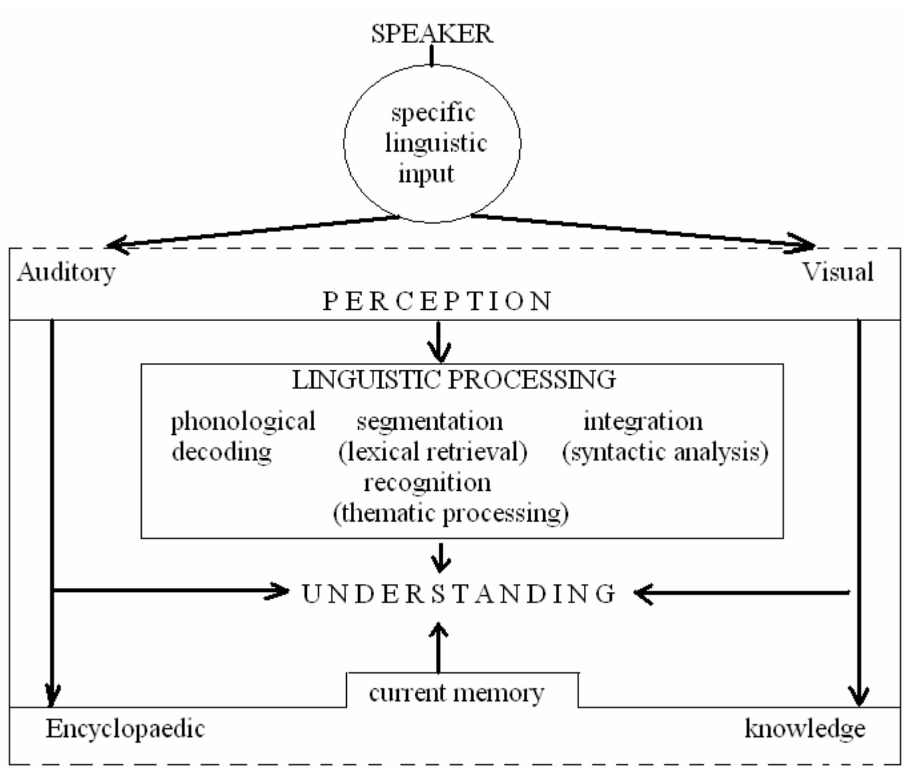

Figure 1: The process of sentence comprehension based on psycholinguistic models by Cutler & Clifton (1999) and Garman (1990).

Although these processes are generally well understood, the question of how they are employed during online processing has been a topic of debate for decades (e.g., Fodor & Ferreira, 1998; Frazier & Rayner, 1982; Friederici, 2002; Kutas & Federmeier, 2007;

Osterhout, Bersick, & McKinnon, 1997; Osterhout & Holcomb, 1993; Pearlmutter, Garnsey, & Bock, 1999; Pickering & Garrod, 2007, 2013; Trueswell, Tanenhaus, & Garnsey, 1994; Wagers, Lau, & Phillips, 2009). This debate largely focuses on how these processes interact and when the interaction is likely to take place as reflected by the two psycholinguistic views of sentence comprehension known as the serial/syntax-first (Frazier & Fodor, 1978) and the parallel/interactive (Trueswell et al., 1994) views. An important factor that underlies these views, and is of concern to this thesis, is the nature of data used in support of these theoretical perspectives, in particular, data from reading vs. speech comprehension studies.

It has been argued that most of the evidence in support of the syntax-first view is based on reading studies, which focus on how syntactic information influences sentence comprehension (e.g., Frazier, 1995; Frazier & Rayner, 1982). On the other hand, the parallel/interactive view incorporates evidence from both reading and speech comprehension studies which focus on how other types of information interact with syntactic information during sentence comprehension (e.g., Fodor & Ferreira, 1998; Marslen-Wilson & Tyler, 1980; McClelland, John, & Taraban, 1989; Hasting & Kotz, 2008; Steinhauer, Alter, & Friederici, 1999; Sundara, Demuth, & Kuhl, 2011). An important type of information that has been shown to influence sentence comprehension, but is absent from visual input, is phonological/prosodic information (e.g., Cutler & Foster, 1999; Hasting & Kotz, 2008; Steinhauer, Alter, & Friederici, 1999; Sundara, Demuth, & Kuhl, 2011). Thus, investigating sentence comprehension using speech input would give a close to real-life picture of how people comprehend everyday speech.

However, despite the implications that modality has for understanding the online processes of sentences comprehension, most evidence for these processes comes from reading studies (for example, see review of event-related potential (ERP) studies by

Molinaro, Barber, & Carreiras, 2011). The few studies that have used the auditory modality, have focused on the role of prosody at higher levels of syntactic processing, e.g., in ambiguity resolution (for a review, see Kutas & Federmeier, 2007). As a result, little is known about how phonological/prosodic information influences morphosyntactic processing during online sentence comprehension. This thesis contributes towards filling this gap by using speech stimuli to investigate how phonological/prosodic information influences subject-verb (S-V) agreement during online sentence comprehension, using the ERPs. Specifically, this was achieved by manipulating two factors that modulate the auditory perceptual salience of speech input, but have not been investigated before in studies investigating the online processing of S-V agreement during sentence comprehension. These are: perceptual salience related to *type of agreement violation* (errors of omission vs. errors of commission e.g., **The boy often* <u>*cook*</u> vs. **The boys often* <u>*cooks*</u>) and *utterance position* (verbal inflection in utterance-medial, vs. utterance-final contexts, e.g., *The boys often* <u>*cooks*</u> *on the stove* vs. *The boys often* <u>*cooks*</u>).

Our motivations for investigating the role of perceptual salience in online sentence comprehension emanates from findings reported from infants' production and perception of the 3rd person singular –s. It has been observed that children typically produce 3rd person singular morphemes more reliably when the verb occurs utterance finally compared to utterance medially (Song, Sundara, & Demuth 2009). This behaviour is thought to be due to the fact that syllables (and morphemes) occurring utterance-finally are longer in duration than those that occur utterance medially (Oller 2005; Wagner& Watson 2010; Wightman et al. 1992; Hsieh, Leonard, & Swanson 1999). This raised the possibility that children might perceive these longer utterance-final morphemes better than the utterance-medial ones. To test this hypothesis, Sundara, Demuth, & Kuhl (2011) investigated 2-year-olds' sensitivity to grammatical (inflected) vs. ungrammatical (uninflected) 3rd person singular verbs in utterance-final versus utterance-medial position in an auditory visual-fixation task (e.g. *Now he cries* vs. **Now he cry* and *He cries now* vs. **He cry now*). As expected, infants showed a difference in looking times to the grammatical vs. ungrammatical sentences when the verb and morpheme occurred utterance finally, but not utterance medially. They interpreted these findings to suggest that the increased duration of the –s morpheme at the end of the utterance provides extra acoustic cues for listeners, enhancing infants' ability to detect its presence, and ungrammatical absence. That is, infants were more sensitive to the missing morpheme utterance-finally compared to utterance medially due to the greater perceptual salience of the morpheme in durationally longer utterance final position.

However, Sundara et al. (2011) did not explore whether children would be equally sensitive to grammatical violations involving errors of commission (*Now they cry* vs. **Now they cries*; They *cry now* vs. *They *cries now*). As these are overt errors, in contrast to those of omission, it is possible that listeners might be very sensitive to them. While effects of processing errors of omission and commission have not been reported for the processing of S-V agreement in speech comprehension, they have been reported in auditory studies investigating prosodic processing (e.g., Dimitrova et al., 2012). Dimitrova et al. (2012) used event-related potentials (ERPs) to investigate if prosodic prominence influenced how Dutch-speaking adults responded to speech stimuli manipulated for superfluous accents (similar to errors of commission) vs. missing accents (similar to errors of omission). They observed that responses to superfluous accents had an earlier latency compared to missing accents. Furthermore, superfluous pitch accents activated a specific set of neural systems that were not observed in the case of missing pitch accents. They interpreted these results to suggest that, although both types of errors resulted in incongruous pitch accents, errors of commission were more perceptually salient because they carried redundant information and hence were processed differently from missing accents. This raises the possibility that listeners' sensitivity to S-V agreement would be manifested in slightly different ways due to the overtness of the violation.

Although there is behavioral evidence suggesting that perceptual salience due to utterance position modulates listeners' response to S-V agreement violations and online evidence that overtness of the violations may further influence listeners' sensitivity to the violations, how these factors impact on S-V agreement processing during on-line sentence comprehension remains to be understood. This thesis therefore explores how effects of perceptual salience manifest during online processing of S-V agreement in three different groups of participant: monolingual English speaking (L1) adults and children as well as Mandarin-speaking adults learning English as a second language (L2). In previous language acquisition studies, younger monolingual speakers of English (Brown, 1973; Rice, Wexler, & Hershberger, 1998) and second language (L2) learners of English (Dulay & Burt, 1974; Jia & Fuse, 2007; Lardiere, 1998; Paradis, Rice, Crago, & Marquis, 2008) have been observed to exhibit unstable use of S-V agreement. This instability has been often explained in terms of immature and poor syntactic representations (e.g., Radford, 1990 *for L1 children* and Goad, White, & Steele, 2003; Liu, Bates, & Li, 1992 *for L2 learners*), respectively.

Similarly, studies using ERPs to investigate morphosyntactic processing in these populations have observed different manifestations of brain responses to morphosyntactic processing (e.g., Friederici, 2005; Meier, 2008; Osterhout, McLaughlin, Pitkänen, Frenck-Mestre, & Molinaro, 2006). These differences have been explained in terms of language proficiency (L1 vs. L2) and maturational development (adults vs. children). It is only recently that L2 comprehension studies have started to investigate the possibility that the relative perceptual salience of the grammatical morpheme may play a role in L2 grammatical processing (e.g., Peretokina, Best, Tyler, Shaw, & Di Biase, 2015; Peretokina, Tyler, & Best, 2014). How perceptual salience influences online processing of morphosyntactic information in these populations remains to be explored.

The studies presented in this thesis are therefore timely and important for i) enhancing our understanding of how linguistic information is extracted from the speech stream to generate meaningful sentences, ii) giving further insight into what factors may influence language processing/acquisition in different populations, and iii) contributing to the functional interpretation of the neural correlates of language processing by showing how methodological designs and theoretical perspectives of sentence processing may influence our understanding of the processes underlying sentence comprehension.

In the remainder of this introductory chapter, I review literature that is relevant to the theoretical and methodological issues outlined above. I give a brief overview of why S-V agreement has been used by a number of studies to investigate sentence processing and discuss how the different views account for S-V agreement processing. This is followed by an outline of the ERP components associated with S-V agreement processing and discussion of the functional interpretations of these components in light of the neuro-cognitive models of sentence comprehension. Finally, I highlight the outstanding questions that are addressed in the three studies that comprise this thesis.

The role of Subject-verb agreement in sentence comprehension

Agreement is one of the linguistic phenomena that has been widely used to provide more insight into the processes underlying sentencing processing. Subject-agreement allows speakers of a language to track syntactic relations (e.g., Eberhard, 1997; Friederici & Jacobsen, 1999; Nicol, Forster, & Veres, 1997). For example, when presented with sentences such as “*The boy often cooks*” or “*The boys often cook”*, English speakers must use the grammatical information (i.e., number) of the nominal subject to determine which verb-form qualifies as a suitable continuation of the sentence. Thus, in the first sentence, the verb-form takes the 3rd person singular –s (3SG) inflection, whereas in the second sentence, the verb remains uninflected. This process is known as subject-verb agreement (S-V agreement).

Although it has been argued that the fixed word order of English makes S-V agreement less important for agreement processing in English (e.g., MacWhinney & Bates, 1989; MacWhinney, Bates, & Kliegl, 1984), there is evidence showing that native speakers of English adhere to S-V agreement rules during sentence comprehension (e.g., Osterhout & Mobley, 1995; Pearlmutter et al., 1999). For example, participants in these studies showed difficulty in reading ungrammatical sentences with S-V agreement mismatch, resulting in different brain responses and longer reaction times, respectively. These findings provide evidence that, although subject-agreement may be considered less important in English compared to morphologically richer languages such as Spanish, the inappropriate use of S-V agreement hinders successful sentence processing.

Therefore, using S-V agreement violations to investigate sentence processing in English may shed light into how different types of information are employed during online sentence processing. This would in turn address the question of when S-V agreement computation occurs during sentence comprehension and whether the initial computation of the sentence relies on syntactic factors only or is also influenced by other factors.

As highlighted above, the view that the initial computation of the sentence relies on syntactic factors only, is known as the serial/syntax first view. According to this view, the initial syntactic-structure building phase only relies on word-category information and is blind to other non-syntactic information (Frazier & Fodor, 1978). Lexical-semantic information is accessed at a later stage through identification of lexical and morphosyntactic information for thematic-role assignment (Ferreira & Clifton Jr., 1986; Frazier & Rayner, 1982; Friederici, 2002). Thus, when listeners are presented with ungrammatical sentences such as "**The boys often* <u>*cooks*</u> vs. **The boy often* <u>*cook*</u> or **The boys often* <u>*cooks*</u> *on the stove*, the initial computation of these sentences is said to be blind to other types of information provided by the different manipulations on the verb, e.g., the relative perceptual salience. Only the syntactic processes that involve syntactic structure building and thematic role assignment influence successful sentence comprehension, and these are said to occur sequentially and interact during the syntactic analysis stage. Therefore, according to the syntax-first view, S-V agreement is computed during the second phase of syntactic processing and this computation is only based on grammatical features that enable thematic role assignment. Since this view assumes that perceptual salience has no impact on S-V agreement processing, we would predict that listeners would be equally sensitive to the different S-V agreement violations, exemplified above.

However, the parallel/interactive view makes different predictions on how S-V agreement would be processed. This view is influenced by assumptions which posit that syntactic knowledge is one of a number of constraints (including frequency of syntactic structure, verb meaning and prosody) that can influence sentence comprehension at every stage of sentence comprehension (e.g., MacDonald, Pearlmutter, & Seidenberg, 1994; Marslen-Wilson & Tyler, 1980; McClelland, John, & Taraban, 1989; Trueswell et al., 1994; Trueswell, Tanenhaus, & Kello, 1993). According to this view, multiple types of information are available in parallel and successful comprehension is achieved based on the strength of the information cues available.

Another important assumption of this view, which has been applied in internal-based models of sentence processing, is that sentence comprehension also involves predictive processing where incoming sensory information is immediately incorporated into abstract linguistic representations (phonological, syntactic, semantic) that the listener already has (Bornkessel-Schlesewsky, Schlesewsky, Small, & Rauschecker, 2015; Pickering & Garrod, 2013). These abstract representations may be based on the immediate preceding context or on previous encounters with similar information.

The implications of this view therefore are that the computation of S-V agreement will be influenced by both syntactic and non-syntactic information, at the same time. Given our example sentences "**The boys often cooks* vs. **The boys often cooks on the stove"*, this view would assume that during the initial encounter of the verb, information about the relative perceptual salience of S-V agreement is available at the same time as syntactic and semantic information. It would therefore be expected that S-V agreement that occurs in more perceptually salient contexts, with overt violation or longer duration, may be processed faster than in contexts with less perceptual salience. Another implication, which is also important for this thesis, is that the process of predicting and matching incoming stimuli may differ due to previous encounters with the language. This suggests that compared to L1 adults, L2 populations and children with less exposure to English may use different predictive processes to match incoming stimuli (for discussion, see Pickering & Garrod, 2013).

Thus, unlike the serial/syntax-first view, the parallel/interactive processing view will be more suitable for exploring how other types of information such as perceptual salience and language proficiency influence sentence processing. Given that the two views also differ in their predictions about when the computation of S-V agreement occurs (late vs. early), using electrophysiological techniques such as ERPs can help us to better explore the propositions of these views. The ERPs provide temporal information of brain activity related to linguistic processes, with millisecond precision.

Subject-verb agreement processing and ERPs

Event related potentials (ERPs) are characteristic patterns of voltage change extracted from brain electrical activity recorded on the scalp by time-locking the electroencephalogram (EEG) recordings to the presentation of stimuli (Luck, 2014). Due to their excellent temporal resolution, ERPs are ideally suited for exploring the different kinds of information that modulate on-line sentence comprehension. A common way of exploring the nature of the processes that underlie the on-line computation of S-V agreement is examining participants' different brain responses to grammatical and ungrammatical sentences, e.g., *The boy often cooks* vs. **The boy often cook.* Participants may be required to attentively identify the violations by performing active or passive tasks. The ERPs are then measured based on the onset of the violation or target word. The general understanding is that the differences in the observed ERP waveforms (e.g., their polarity, amplitude, latency, and scalp distribution) between grammatical and ungrammatical sentences can inform us of the processes underlying the computation of, for example, S-V agreement. Note, however, the traditional functional interpretation of the ERP components as a modular-specific mapping of the ERP components has also been challenged (for discussion, see Dröge, Fleischer, Schlesewsky, & Bornkessel-Schlesewsky, 2016; Luck & Kappenman, 2011).

The two ERP components that have been traditionally associated with the processing of S-V agreement violations are the left anterior negativity (LAN) and the P600. The LAN often occurs between 300 and 500 ms after the onset of the violation and has been observed to have either a left anterior scalp distribution. (e.g., Coulson, King, & Kutas, 1998; Friederici, Pfeifer, & Hahne, 1993; Gunter, Friederici, & Schriefers, 2000; Osterhout & Holcomb, 1992; Hahne & Friederici, 1999; Kaan 2002). In L2 adults, this negativity is often realised as an N400 that occurs between 300 and 500 ms after the onset of the violation and has a centro-posterior scalp distribution (e.g., Kutas & Hillyard, 1980; Osterhout, McLaughlin, Kim, Greenwald, & Inoue, 2004). The P600 typically occurs between 500 and 1000 ms after violation onset and is often observed with a centro-posterior scalp distribution (e.g., Osterhout & Mobley, 1995), or with a broad scalp distribution (e.g., Molinaro et al., 2011). The P600 has been observed after the LAN (a biphasic LAN/P600 effect) or on its own (e.g., Coulson et al. 1998; Hagoort & Brown 2000; Kaan et al., 2000; Osterhout & Mobley, 1995).

Based on the evidence from previous studies, which reported evidence that correlated morphosyntactic processing to the L(AN) and the P600, Friederici (2002) proposed a neuro-cognitive model of auditory sentence comprehension which instantiates the syntax-first view discussed above. According to this model, the LAN observed from 300-500 ms is correlated with the second phase of syntactic processing, when lexical-semantic and morphosyntactic information are processed to assign thematic roles. It is also understood to reflect the detection of morpho-syntactic violations, such as agreement mismatch (Batterink & Neville, 2013; Bornkessel & Schlesewsky, 2006; Friederici et al., 1993; Hagoort, Wassenaar, & Brown, 2003; Kos, Vosse, Van Den Brink, & Hagoort, 2010; Osterhout, Holcomb, & Swinney, 1994; Osterhout et al., 1996). On the other hand, the P600 effects observed from 500-1000 ms are correlated with the third phase of processing when the different types of information are integrated. This is generally understood to reflect syntactic reanalysis or repair (e.g., Friederici, 2011; Gunter, Friederici, & Schriefers, 2000; Hahne & Friederici, 1999, 2002) .

However, there is accumulating evidence from a number of morphosyntactic studies that has challenged this proposed one-to-one mapping between these ERP components and specific types of processing. For example, some studies using the auditory modality have reported a negativity in the same time window as the LAN, but with a *bilateral* anterior scalp distribution (known as anterior negativity, or AN) (e.g., Hahne & Friederici 2002; Shen, Staub, & Sanders, 2013). Others have reported N400 effects instead of the traditional LAN effects, e.g., aspect marking in Hindi (Choudhary, Schlesewsky, Roehm, & Bornkessel-Schlesewsky, 2009), and gender marking in Spanish (Wicha, Moreno, & Kutas, 2004). Furthermore, some studies have failed to observe the LAN in studies investigating morphosyntactic processing (e.g., Hagoort & Brown, 2000; Kaan, Harris, Gibson, & Holcomb, 2000; Kos et al., 2010; Osterhout et al., 1994). The variability of the LAN in morphosyntactic processing studies has therefore led some researchers to doubt that the LAN reflects morphosyntactic processing (e.g., Tanner, 2015).

In terms of the P600, this has also been observed to vary in its presence, latency, amplitude and scalp distribution depending on several factors, e.g., nature of the task, and morphological features. For example, some studies did not observe any significant positivity for agreement violation at all (e.g., Kutas & Hillyard, 1983; O'Rourke & Van Petten, 2011). The absence of the late positivity was argued to be related to the use of a passive task (e.g., Coulson et al. 1998; Kolk & Chwilla, 2007). On the other hand, other studies did report a P600 effect but the effect vary in terms of latency and amplitude. The variations have been attributed to the morphological features being tested (e.g., gender vs. number or person+gender; Nevins et al., 2007). These variable realisations of the P600 have led to different functional interpretations, which includes: costs associated with recovery from the ungrammatical parse (e.g., Osterhout & Holcomb, 1992; Osterhout, McLaughlin, Kim, Greenwald, & Inoue, 2004), general difficulty in syntactic integration (e.g., Kaan et al., 2000), or general strategic processes (e.g., Coulson et al., 1998; Kolk & Chwilla, 2007).

In order to account for all these variations of the LAN and P600, alternative neuro-cognitive accounts based on assumptions of the interactive/constraint-based view have been proposed (e.g., Bornkessel-Schlesewsky & Schlesewsky, Small, & Rauschecker, 2015). These accounts propose that ERP components should be interpreted in terms of general cognitive mechanisms such as predictive interactive processes rather than domain-specific linguistic processes. These models argue that ERP components may appear to be quantitatively or qualitatively different due to general cognitive processes associated with, for example, the nature of the incoming information. However, these differences should not be interpreted to indicate different underlying neural components. For example, in processing S-V agreement violations that vary due to perceptual salience, different cognitive processes may be engaged for processing more perceptually salient versus less perceptually salient, yet the underlying morphosyntactic process remains the same. Unlike the modular accounts of morphosyntactic processing, the constraint-based internal models therefore leave room for accounting for effects of perceptual salience as well as differences between L1 and L2 processing of S-V agreement (for discussion, see Pickering & Garrod, 2013).

However, despite the ongoing debate about the functional significance of the LAN and P600 effects, there is generally a strong correlation between grammatical violations and the presence of the LAN and/or P600 in L1 adults (Molinaro et al., 2011). We therefore continue to use these traditional ERP components to further explore the validity of the predictive-based models that argue for general cognitive processes instead of domain specific mapping of the neural correlates of sentence processing. A brief review of some of the specific factors that have been commonly reported to affect morphosyntactic processing in the different populations that comprise the studies reported in this thesis is given below.

In L1 adult studies, the factors that influence the realization of the LAN and/or P600 effects include: the modality of presentation (auditory vs. visual), the nature of the task (passive vs. active), the complexity of violation, ERP-data processing (mastoid referencing, baseline correction) and individual differences (see reviews by Molinaro et al., 2011; Steinhauer & Drury, 2012). The effect of these factors on S-V agreement processing is discussed in detail in Chapter 2.

In L2 studies, the factors that influence the presence of the LAN and/or P600 include: differences in L1-L2 linguistic structures, age of L2 exposure, type of exposure to the L2 (immersion vs. classroom learning), level of L2 proficiency, and individual differences (see Kotz, 2009; McLaughlin et al., 2010; Steinhauer, White, & Drury, 2009; Van Hell & Tokowicz, 2010). The effect of these factors on S-V agreement processing is discussed in detail in Chapter 3.

In child studies, the factors that influence the presence of the LAN and/or P600 include: maturational development and experimental tasks (e.g., Clahsen, Lück, & Hahne, 2007; Friederici, 1998, 2002; Hahne, Eckstein, & Friederici, 2004; Courteau et al., 2013; Meier, 2008). The effect of these factors on S-V agreement processing is discussed in Chapter 4.

This brief overview highlights factors that have been considered to influence morphosyntactic processing and the functional interpretation of ERP components in adults and children. It also highlights that none of the previous ERP studies have considered auditory perceptual salience due to type of agreement violation and due to utterance position as possible factors that may influence on-line S-V agreement processing. A lack of reports on such effects is in part due to the fact that most ERP studies of sentence comprehension conducted with L1 and L2 adults have used the visual modality, which is not sensitive to auditory perceptual salience. It could also be related to the inadequate traditional domain-specific view of neuro-cognitive accounts that typically fail to account for how phonological information, including perceptual salience, influences syntactic processing.

Thesis focus, aims and structure

In this thesis, we investigate how the relative perceptual salience of S-V agreement violations (due to type of agreement violation and utterance position) might impact on on-line speech comprehension using ERPs. We investigated this in three different populations, i.e. adult English-speakers (L1), adult Mandarin learners of English (MLEs) and 8-11-year-old English-speaking children. These three groups constitute the three studies reported in the respective Chapter 2, 3, and 4.

We hoped that the findings of this research will provide further evidence regarding the processes that underlie sentence comprehension, given that no previous study has investigated how the relative perceptual salience of S-V agreement influences the online computation of morphosyntactic information in L1 and L2 adults, and in L1 children. According to the predictive-based models of sentence processing, it is possible that the relative perceptual salience of S-V agreement may manifest differently during sentence processing in these three populations as a result of their prior language experiences (see Pickering & Garrod, 2013) on the role of prior language experience in predicting incoming input).

Since it is not known how perceptual salience might affect the processing of S-V agreement violation, we first tested, in Chapter 2, adult native speakers of Australian-English to establish a baseline for further investigating MLEs and children's sensitivity to S-V agreement violations as function of perceptual salience. These L1 participants were presented with four conditions varying in degree of perceptual salience depending on utterance position and type of agreement violation: utterance-medial errors of omission and errors of commission, and utterance-final errors of omission and errors of commission. We expect that the S-V agreement violation that are more perceptually salient (i.e. errors of commission and utterance-final agreement violations) will elicit more robust ERP effects, (LAN and/or P600), compared to the other conditions that are less perceptually salient. This difference may shed light on whether perceptual salience influences the cognitive processes underlying sentence processing (e.g., predictive processing or decision certainty), and how this contributes to the functional interpretation of the ERP components for S-V agreement processing.

After establishing a baseline for investigating the effect of perceptual salience on S-V agreement violation processing in Chapter 2, we examine to what extent the relative perceptual salience of S-V agreement violations (due to type of agreement violation and utterance position) impacts the processing of grammatical information during sentence comprehension in MLE using the same paradigm as that used in the L1 study. We expect MLE with less exposure to English will show different ERP results from the L1 speakers due to their lower English proficiency. This may shed light on whether limited exposure to language constrains the influence of perceptual salience on sentence processing, and how this may contribute to the functional interpretation of the ERP components for S-V agreement processing.

Then, in Chapter 4, we investigate the effect of perceptual salience on the on-line processing of agreement violation in children using the same paradigm as the L1 study. One of the major aims of this chapter is to examine whether children process the agreement information in the same way as adults. If so, we would expect to observe the same ERP results in Chapter 2. If not, children’s processing of agreement violation could be potentially constrained by neural maturation (Brauer, Anwander, & Friederici, 2011; Meier, 2008). In this case, we would observe different ERP effects in the L1 children compared to the adults. This may shed light on whether maturational development constrains the processing of perceptual salience during sentence comprehension, and how this may contribute to the functional interpretation of the ERP components for S-V agreement processing. In the last chapter—Chapter 5 (General Discussion)—we summarise the findings of the previous three chapters and discuss how the overall findings enhance our understanding of the role of perceptual salience in S-V agreement, and sentence processing in general. We also discuss the implication the findings have for understanding processes that underlie sentences comprehension. In particular, we discuss how the functional interpretations of the neural correlates of language and methodological designs contribute to sentence processing research and highlight future research directions.

Taken together we hoped that these studies would make a major theoretical and methodological contribution to the field of sentence processing. Since few studies have explored issues of S-V agreement using the auditory modality, this study sought to contribute to the field by using a more ecologically valid method, which resembles natural speech comprehension, to investigate the role of perceptual salience in S-V agreement processing. Since many studies of S-V agreement have only explored one of the conditions examined here, and/or collapsed across multiple types of violation, it was hoped that this study would provide evidence for whether type of agreement violations and utterance position matter when investigating the processes underlying S-V agreement comprehension. Including the three different populations allowed for a further exploration of how factors like language proficiency and maturational development interact with processes underlying the computation of morphosyntactic information.

General issues to note about the content of the three studies

i) Some parts of the introductory sections may appear repetitive in the three studies that comprise this thesis, given the overlapping motivations of the thesis.

ii) The same research paradigm was used in all three studies (materials).

iii) All stimuli are in Appendix A.

iv) Since the three studies were prepared as papers to be submitted in different journals, the formatting and reference style used in these studies differ.

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CHAPTER 2

Effects of type of agreement violation and utterance position on the auditory processing of subject-verb agreement: An ERP study

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Abstract

Recent event-related potentials (ERPs) studies have shown that native speakers attend to subject-verb (S-V) agreement during sentence comprehension. However, it is not known whether, and how, they use other non-syntactic types of information, such as the relative perceptual salience of S-V agreement during online processing of spoken sentences. To address this gap, we used ERPs to measure the brain activity of Australian English-speaking adults while they listened to sentences in which the S-V agreement differed by *type of agreement violation* (errors of omission vs. errors of commission) and *utterance position* (verbal inflection in utterance-medial vs. utterance-final contexts). We observed LAN/P600 effects for the overall grammaticality effect, however, these effects manifest differently due to perceptual salience effects. In contexts where the S-V agreement violation had higher perceptual salience (errors of commission and utterance-final position), only a P600 effect with a broader scalp distribution and larger mean amplitude was observed. However, in contexts where the S-V agreement violation had lower perceptual salience (errors of omission and utterance-medial position), only an anterior negativity with bilateral scalp distribution was observed. These findings support the view that perceptual salience influences S-V agreement during sentence comprehension. The implications these findings have for sentence processing theories, experimental designs and the functional interpretation of the language-related ERPs are discussed.

Introduction

Most native speakers are able to understand sentences instantaneously, with little apparent effort. However, empirical evidence has shown that the processes underlying language comprehension are by no means simple (Nichols 1986; Pearlmutter, Garnsey, and Bock 1999; Wagers, Lau, and Phillips 2009; Rayner and Clifton Jr. 2009; Nicol, Forster, and Veres 1997). For example, when presented with sentences such as "*The boy often cooks on the stove*" or "*The boys often cook on the stove*", English speakers must establish the grammatical relations between the subject and the verb—a phenomenon known as subject-verb agreement (S-V agreement). In order to determine which verb-form qualifies as a suitable continuation of the sentence, they must keep track of the grammatical information (i.e. number) of the subject noun phrase. Thus, in the first sentence, the verb-form takes the 3rd person singular –s (3SG) inflection, whereas in the second sentence, the verb remains uninflected. Use of inappropriate verb-forms such as in "**The boy often cook on the stove*" and "**The boys often cooks on the stove"* is not acceptable.

Subject-verb agreement has been widely used in psycholinguistic studies to provide insight into the processes underlying sentence comprehension. Although S-V agreement may be considered less important in English compared to morphologically rich languages, such as Spanish or Italian (see MacWhinney and Bates 1989; MacWhinney, Bates, and Kliegl 1984 on this view), it has been shown that native English speakers are highly sensitive to the inappropriate use of S-V agreement (e.g., Osterhout and Mobley 1995; Pearlmutter, Garnsey, and Bock 1999; Nicol, Forster, and Veres 1997; Hagoort, Brown, and Groothusen 1993; Coulson, King, and Kutas 1998; Kaan 2002). Therefore, investigating how speakers respond to different manipulations of S-V agreement violations during sentence comprehension may help us understand how sentences are processed.

Subject-verb agreement and sentence processing

There are two psycholinguistic views that have influenced sentence processing research. One view is that sentence comprehension is facilitated by syntactic processes such as assignment of syntactic categories and grammatical relations, which occur sequentially known as the serial/syntax-first view (e.g., Frazier and Fodor 1978; Friederici 2002). According to this view, other cues that may be associated with S-V agreement present in the sentence, such as auditory perceptual salience due to phonological/prosodic context are not taken into account. The other view is that sentence comprehension is facilitated by different processes (syntactic and non-syntactic) which initiate as soon as the input is available; although their interaction may depend on the nature of the incoming input—known as the parallel/interactive view (e.g., Trueswell, Tanenhaus, and Garnsey 1994; Trueswell, Tanenhaus, and Kello 1993) which has been applied to internal models of sentence comprehension (e.g., (Pickering and Garrod 2007; 2013; Trueswell, Tanenhaus, and Garnsey 1994; Trueswell, Tanenhaus, and Kello 1993) According to the latter view, speakers' sensitivity to S-V agreement may be influenced by other cues available in the input, not just syntactic factors.

There is now accumulating evidence from sentence-comprehension studies showing that agreement processing is influenced by syntactic and non-syntactic factors. Some of these include morphological features salience (Nevins et al. 2007; Barber and Carreiras 2005), experimental tasks (Kolk et al. 2003), orthographic saliency and language proficiency (e.g., Osterhout et al. 2006). However, most of these are reading studies (for review, see Molinaro, Barber, and Carreiras 2011). The few studies that have used speech comprehension have focused on agreement attraction (Shen, Staub, and

Sanders 2013) or other factors like prosody (e.g., Steinhauer, Alter, and Friederici 1999), or speaker identity (phonetic cues) (e.g., Hanulíková and Carreiras 2015). Although the role of acoustic perceptual salience has been reported to be important for sentence comprehension, little is known about the role of auditory perceptual salience in the processing of morphosyntactic information, such as S-V agreement.

In particular, two factors that have received relatively little attention in speech comprehension studies are perceptual salience, due to (i) the overtness of the violation (errors of omission vs. commission), and (ii) the prosodic context of the target word (utterance-medial vs. utterance-final). Therefore investigating how relative perceptual salience of S-V agreement (due to the overtness of the violation and the prosodic context of the target word) impacts on listeners' sensitivity to agreement violation may shed more insight on the factors that influence successful sentence comprehension. However, while little is known how relative auditory perceptual salience may impact on on-line S-V agreement processing, the role of auditory perceptual salience due to utterance position and type of violation has been reported elsewhere.

The role of perceptual salience in sentence comprehension

It has been observed that children typically produce 3rd person singular morphemes more reliably when the verb occurs utterance-finally compared to utterance medially (Song, Sundara, and Demuth 2009). This behaviour is thought to be due to the fact that syllables (and morphemes) occurring utterance finally are longer in duration than those that occur utterance medially (Christophe et al. 2003; Christophe et al. 2004; Oller 2005; Wagner and Watson 2010; Wightman et al. 1992; Hsieh, Leonard, and Swanson 1999). This raised the possibility that children might perceive these longer utterance-final morphemes better than the utterance-medial ones. To test this hypothesis, Sundara, Demuth, and Kuhl (2011) investigated 2-year-olds' sensitivity to grammatical (inflected) vs. ungrammatical (uninflected) 3rd person singular verbs in utterance-final versus utterance-medial position in an auditory visual-fixation task (e.g. *Now he cries* vs. **Now he cry*;. *He cries now* vs. **He cry now*). As expected, infants showed a difference in looking times to the grammatical vs. ungrammatical sentences when the verb and morpheme occurred utterance finally, but not utterance medially. They interpreted these findings to suggest that the increased duration of the –s morpheme at the end of the utterance provides extra acoustic cues for listeners, enhancing infants' ability to detect its presence, and ungrammatical absence. That is, infants were more sensitive to the missing morpheme utterance finally compared to utterance medially due to the greater perceptual salience of the morpheme in durationally longer utterance-final position.

However, Sundara et al. (2011) did not explore whether children would be equally sensitive to grammatical violations involving errors of commission (*Now they cry* vs. **Now they cries*; They *cry now* vs. *They *cries now*). As these are overt errors, in contrast to those of omission, it is possible that listeners might be very sensitive to them. While effects of processing errors of omission and commission have not been reported for the processing of S-V agreement in speech comprehension, they have been reported in auditory studies investigating prosodic processing (e.g., Dimitrova et al. 2012). Dimitrova et al. (2012) used event-related potentials (ERPs) to investigate if prosodic prominence influenced how Dutch-speaking adults responded to speech stimuli manipulated for superfluous accents (similar to errors of commission) vs. missing accents (similar to errors of omission). They observed that responses to superfluous accents had an earlier latency compared to missing accents. Furthermore, superfluous pitch accents activated a specific set of neural systems that were not observed in the case of missing pitch accents. They interpreted these results to suggest that, although both types of errors resulted in incongruous pitch accents, errors of commission were more perceptually salient because they carried redundant information and hence were processed differently from missing accents. This raises the possibility that listeners' sensitivity to S-V agreement would be manifested in slightly different ways due to the overtness of the violation.

Although there is behavioral evidence suggesting that perceptual salience due to utterance position modulates listeners' response to S-V agreement violations and online evidence that overtness of the violations may further influence listeners' sensitivity to the violations, how these factors influence the on-line S-V agreement processing remains to be understood. Using auditory stimuli allows for a more ecologically valid way to investigate the processes that underlie the on-line sentence processing as it more closely approximates natural speech comprehension in real life. The present study thus contributes towards sentence-processing research by exploring how auditory perceptual salience, due to type of agreement violation and utterance position, impacts on the on-line processing of S-V agreement using the ERPs.

Event-related potentials (ERPs) and S-V agreement processing

The ERPs are an ideally suited tool for exploring the different kinds of information that modulate on-line sentence comprehension due to their excellent temporal resolution. These are characteristic patterns of voltage change extracted from brain electrical activity recorded on the scalp by time-locking the electroencephalogram (EEG) recordings to the presentation of stimuli. The differences in ERP responses (e.g., the polarity, amplitude, latency, and scalp distribution) to different types of stimuli (e.g. ungrammatical vs. grammatical sentences) can inform us of the processes underlying the computation of specific linguistic elements, e.g., S-V agreement.

The two ERP components that have been traditionally associated with the processing of S-V agreement violations are the left anterior negativity (LAN) and the P600. The LAN often occurs between 300 and 500 ms after the onset of the violation and has been observed to have either a left anterior scalp distribution. (e.g., Coulson, King, and Kutas 1998; Friederici, Pfeifer, and Hahne 1993; Gunter, Friederici, and Schriefers 2000; Osterhout and Holcomb 1992; Hahne and Friederici 1999; Kaan 2002). The P600 typically occurs between 500 and 1000 ms after violation onset and is often observed with a centro-posterior scalp distribution (e.g., Osterhout and Mobley 1995) or with a broad scalp distribution (e.g., Molinaro et al. 2011). The P600 has been observed after the LAN (a biphasic LAN/P600 effect) or on its own (e.g., Coulson et al. 1998; Hagoort and Brown 2000; Kaan et al. 2000; Osterhout and Mobley 1995). Based on the evidence from previous studies, which reported evidence that correlated morphosyntactic processing to the L(AN) and the P600, Friederici (2002) proposed a neuro-cognitive model of auditory sentence comprehension which instantiates the syntax-first view discussed above.

According to this model, the LAN observed from 300-500 ms is correlated with the second phase of syntactic processing, when lexical-semantic and morphosyntactic information is processed to assign thematic roles. It is also understood to reflect the detection of morpho-syntactic violations, such as agreement mismatch (Batterink and Neville 2013; Bornkessel and Schlesewsky 2006; Friederici et al. 1993; Hagoort, Wassenaar, and Brown 2003; Kos, Vosse, Van Den Brink, and Hagoort 2010; Osterhout, Holcomb, and Swinney 1994; Osterhout et al. 1996). On the other hand, the P600 effects observed from 500-1000 ms are correlated with the last phase of processing, when the different types of information are integrated. This effect is generally understood to reflect syntactic reanalysis or repair (e.g., Friederici 2011; Gunter, Friederici, and Schriefers 2000; Hahne and Friederici 1999; 2002).

However, findings from a number of morphosyntactic studies have challenged this modular-specific view. For example, while the processing of morphosyntactic violations is expected to elicit LAN and/or P600 effects, some studies have not observe LAN effects (e.g., Hagoort and Brown 2000; Kaan, Harris, Gibson, and Holcomb 2000; Kos et al. 2010; Osterhout et al. 1994). Others have reported N400 effects instead of the traditional LAN effects, e.g., aspect marking in Hindi (Choudhary, Schlesewsky, Roehm, and Bornkessel-Schlesewsky 2009), and gender marking in Spanish (Wicha, Moreno, and Kutas 2004). Still, others have observed different P600 latencies and amplitudes as a function of different morphological features (e.g., gender vs. number or person+gender) (e.g., Nevins, Dillon, Malhotra, and Phillips 2007). The presence/absence of the P600 has also been observed to vary as a function of whether the task was passive or active (e.g., Kolk and Chwilla 2007) or whether the violation was syntactically simple or complex (e.g., Kutas and Hillyard 1983; O'Rourke and Van Petten 2011).

In studies investigating S-V agreement the LAN and P600 effects have also been observed to vary as a function of modality of presentation and complexity of the violation, (see the brief outline of studies highlighted in **Table 1**). For example, some studies, which used the visual modality, reported a LAN with an onset latency around 300 ms (e.g., Osterhout and Mobley 1995) while others did not observe this negativity (e.g., Kaan et al. 2000). In contrast, studies that used the auditory modality reported ERP effects with earlier onset latencies. For example, Shen, Staub, and Sanders (2013) reported the LAN with an onset around 140 ms while Hasting and Kotz (2008) reported the LAN with an onset around 100 ms and a P600 with an onset latency around 300 ms. These differences in the latency of the negativity are generally assumed to reflect the ease of detecting the violation whereas those of the P600 reflect the speed of the revision or reanalysis of the violation.

Table 1: ERP studies on the processing of S-V agreement violation (*studies used inflectional agreement*).

Study (Language)	Modality	Type of agreement violation	Utterance Position	Example of stimuli	ERP Effect/ latency (ms)	
					Negativity	**P600**
Kutas and Hillyard 1983 (English)	visual	omission	medial	As a turtle grows its shell grows/*grow too.	LAN 300-600	Not reported
Osterhourt and Mobley 1995 (English)	visual	commission	medial	The elected officials hope/* hopes ….	LAN 300-500	Centro-posterior 500-800
(Osterhout et al. 1996) (English)	visual	commission	medial	The doctors believe/*believes …….	No negativity	Centro-posterior 500-800
(Coulson, King, and Kutas 1998) (English)	visual	omission & commission collapsed	medial	Every Monday he mows/*mow the…. They sun/*suns themselves on …….	LAN 300-500	Anterior-posterior 500 – 800
Kaan et al. 2000 (English)	visual	commission	medial	Emily wonders whether the performers in the concert imitate/* imitates a …..	No negativity	Central maximum 500-700 Posterior maximum 700-900
Shen et al. 2013 (English)	auditory	omission	medial	Larry pushes/*push his ……	AN 150-300	Posterior 700-900
(Hagoort and Brown 2000) (Dutch)	visual & auditory	substitution	medial	The spoilt child throws/* throw …… *(Het verwende kind gooit/*gooien …)*	No negativity	Anterior-posterior 500-700 Posterior 700-900
(Vincenzi et al. 2003) (Italian)	visual	omission & commission collapsed	medial	The old waiter serves/*serve with … *(Il cameriere anziano serve/*servono….)* The skilled butchers cut/*cuts …….. *(I macellai esperti tagliano/*taglia…)*	LAN 340-400	Posterior 500-700
(Kos et al. 2010) (Dutch)	visual	substitution	medial	The spoiled child *throw …… *(Het verwende kind gooit/*gooien …)*	No negativity	Centro-posterior 500-900
(Hasting and Kotz 2008) (German)	auditory	substitution	final	He bowls/* bowl. *(Er kegelt/*kegelst)* You bowl/* bowls. *(Du kegelst/*kegelt)*	LAN 100-300	Centro-posterior 300-800

Thus the different latencies between the visual and auditory modalities have been interpreted to reflect the differential effect of input modality on S-V agreement processing. However, Hasting and Kotz (2008) have further noted that the time-locking point used in S-V agreement studies also matters. This suggests that time-locking at the onset of morpho-syntactic violation instead of word onset may contribute to latency differences. Despite the interpretation of these variances, some researchers have questioned that the LAN reflects morphosyntactic processing (e.g., Tanner 2015) while others still maintain that there is generally a strong correlation between grammatical violations and the presence of the LAN and/or P600 in L1 adults (Molinaro et al. 2011).

Besides the latency differences, the scalp distribution and the duration of the P600 component have been reported to also differ as a function of syntactic complexity. For example, agreement violations that involved complex syntactic manipulations yielded longer P600 effects (500-900 ms) with a centro-posterior distribution (Kos et al. 2010) whereas those with less complex violations yielded shorter P600 effects (500-700 ms) with a posterior distribution (Vincenzi et al. 2003) the differences observed in the scalp distribution and size of the P600 components have led to different functional interpretations which include: i) syntactic reanalysis or costs associated with recovery from the ungrammatical parse (e.g., Osterhout and Holcomb 1992; Osterhout, McLaughlin, Kim, Greenwald, and Inoue 2004); ii) syntactic integration difficulty (e.g., Kaan et al. 2000); or iii) general strategic processes or reanalysis involved in the processing of the type of syntactic structure involved (e.g., Coulson, King, and Kutas 1998; Kolk and Chwilla 2007; Kuperberg 2007; Nevins et al. 2007; O'Rourke and Van Petten 2011). The variability of the P600 has also raised the old P600-as-P300 debate, in which it is argued whether the P600 reflects non-linguistic processes of stimulus classification and working memory updating or real linguistic processing (for discussions, see Sassenhagen, Schlesewsky, and Bornkessel-Schlesewsky 2014).

This review of previous ERPs studies shows that there are various factors that influence the processing of morphosyntactic information during online sentence comprehension. As a result, an alternative view to Friederici's (2002) was proposed—the internal models of sentence processing (e.g., Pickering and Garrord, 2013; Bornkessel-Schlesewsky et al. 2015). According to this alternative view, the variable realizations of the ERP components can be accounted for in terms of the nature of the incoming stimuli which may necessitate the engagement of different cognitive processes (e.g., predictive and decision certainty processes). Predictive processes involve anticipation of upcoming information whereby speakers may use contextual or previous experience to match incoming input the underlying abstract representations. On the other hand, decision certainty processes involve making decisions about whether the input matches the predicted outcome (for further discussion, see Bornkessel-Schlesewsky et al. 2015).

The engagement of these cognitive processes may thus result in quantitatively or qualitatively different ERP responses, despite similar underlying neural functions. For example, in processing S-V agreement violations that vary due to perceptual salience, different cognitive processes may be engaged for processing more perceptually salient versus less perceptually salient, yet the underlying morphosyntactic process remains the same. Thus, the question of whether different types of agreement violation and utterance position influence the processing of S-V agreement violations is important, given that these factors were used variably in previous studies highlighted in **Table 1**, above.

It is clear from the overview of previous studies in **Table 1,** that ERP responses may have been confounded due to the types of stimuli used. However, the variability of the LAN and P600 effects has never been considered in light of the *type of agreement violation* (errors of omission vs. errors of commission) and *utterance positions* (medial vs. final). For example, Osterhout and Mobley (1995) looked at errors of commission, i.e., superfluous addition of the 3SG, (e.g., *the officials* <u>*hope/*hopes*</u>*….*) occurring sentence medially, in a visual modality paradigm. They reported a left-anterior negativity (LAN) with an onset around 300 ms followed by a centro-posterior P600 with an onset around 500 ms. Similar biphasic LAN/P600 effects were observed in other studies that used the visual paradigm and sentence-medial position, although they looked at both errors of omission and commission that were collapsed together in the analysis (e.g., Coulson, King, and Kutas 1998).

In contrast, Shen, Staub, and Sanders (2013) looked at errors of omission, i.e., omission of the 3SG, (e.g., *Larry* <u>*pushes/*push*</u> *his …)* occurring utterance-medially in an auditory paradigm. They reported a bilateral anterior negativity (AN) with an onset around 150 ms followed by a posterior P600 with an onset around 700 ms. Similar early LAN effects were observed in Hasting and Kotz (2008), who investigated agreement violation processing in German, using auditory modality. However, the P600 effects observed in their study had an early onset latency around 300 ms. Importantly, Hasting and Kotz's (2008) study differed from Shen, Staub, and Sanders' (2013) in that it looked at S-V agreement violations involving substitution errors that occurred in utterance-final position. Thus, while it seems that modality of presentation modulated the ERP latencies in these studies, these effects are confounded with effects of errors of omission vs. commission. Moreover, it is not known if utterance-final S-V agreement violations in English will result in similar effects to those reported in Hasting and Kotz (2008) given that none of the previous ERP studies have investigated utterance position effects on the processing of S-V agreement violations during on-line auditory sentence comprehension.

Given these observations, it is therefore necessary to further investigate how auditory perceptual salience influences sentence processing and the underlying neural mechanisms involved in sentence processing. In this study, we assume that relative perceptual salience due to type of agreement violation and utterance position will influence the predictive processes underlying sentence comprehension, resulting in more sensitivity to more perceptually salient violations than the less perceptually salient counterparts. We used ERPs to systematically explore the effects of type of agreement violation and utterance position on listeners' sensitivity to S-V agreement violation in English. To achieve this, we recorded and compared listeners' ERP responses to grammatical and ungrammatical sentences in which the S-V agreement violations differed according to the type of agreement violation (errors of omission vs. commission) and utterance position (medial vs. final).

Based on previous findings from the traditional ERP studies that used a one-to-one mapping of linguistic processes with the underlying neural correlates, we hypothesized that the on-line computation of sentences with S-V agreement violations would evoke different neural responses relative to the grammatical sentences, resulting in a biphasic LAN/P600 (morpho-syntactic processing) response. However, if perceptual salience influenced the online processing of S-V agreement violations due to predictive processing, we expected that the LAN and/or P600 effects would vary in latency, amplitude or scalp distribution.

Therefore, in terms of processing S-V agreement violations that differed due to type of agreement violation, we hypothesized that listeners would be more sensitive to errors of commission (superfluous errors) than to errors of omission due to greater perceptual salience of the overt violation, based on (Dimitrova et al. 2012). We predicted that: (i) errors of commission would elicit earlier LAN/P600 effects compared to errors of omission as a result of quicker detection of the overt violation, (ii) the amplitude of the P600 would be larger for errors of commission compared to errors of omission as a result of greater sensitivity to the overt violation, and (iii) the scalp distribution of these effects would differ due to the underlying neural mechanisms involved in processing superfluous vs. missing information.

Furthermore, based on Sundara, Demuth, and Kuhl (2011), we expected that listeners' sensitivity to errors of omission and commission would also differ according to the utterance position in which the errors occurred. More specifically, we expected that errors in utterance-final position would be more perceptually salient compared to errors in utterance-medial position due to phrase-final lengthening. We therefore predicted that i) errors of omission and commission that occurred utterance-finally would elicit earlier LAN/P600 effects compared to errors utterance-medially, ii) the amplitude of the P600 would be more robust utterance-finally due to the greater perceptual salience resulting from phrase-final lengthening, and iii) that the scalp distribution of these effects would also differ.

Lastly, given that errors of commission and utterance-final position both enhance the perceptual salience of the violation, we expected that type of agreement violation and utterance position would have an additive effect. We therefore expected that the P600 elicited by errors of commission in utterance-final position would have the largest amplitude compared to other conditions. We hoped that findings from this study may shed light on the assumptions of the internal models of sentence processing which suggest that abstract features like perceptual salience influence predictive processes during online sentence comprehension.

Methods

Ethics statement

The Ethics committee for Human Research at Macquarie University approved the experimental methods used in this study. Written informed consent was obtained from all participants before the experiment began.

Participants

Twenty monolingual Australian-English speaking adults (age range: 18-25 years; mean: 22; 11 female, 9 male) participated in this study. Participants were recruited from the university student population. All completed a questionnaire on their developmental and linguistic history before participating in the study, and all were right-handed, with no clinical history of hearing or learning disorders. They received either course credits for participation or $20 if they did not require the course credits. Eight additional participants were excluded from the final analysis due to excessive ERP artefacts (e.g. sweating, or excessive movement).

Stimuli

The auditory stimuli included 50 CVC target verbs that could be used intransitively in both sentence medial and final positions (e.g., *The boy often cooks on the stove* vs. *The boy often cooks*). This ensured that the transitivity of the target verbs was balanced in both sentence conditions. Only those verbs with high-medium frequency were selected to ensure familiarity and to facilitate processing. The criteria for lexical frequency was that the verbs had between 1-3 counts on the SUBLEX Log10CD (Hofmann et al. 2007). In addition, only those verbs that ended with the voiceless coda stops /p/, /t/, /k/ were selected to make sure that the inflected–s morpheme was always realised in the same allophonic condition (e.g., as /s/). This facilitated subsequent splicing of the materials and ensured that all similar items had the same morpheme length (see below). As the stimuli were later paired with a picture to provide a visual context while listening to the sentence, the verbs also had to be highly imageable.

The verbs were inserted into carrier sentences that were composed of monosyllabic words, thereby controlling for utterance length and processing load. The carrier sentences had a singular vs. plural subject to enable manipulation of type of agreement violation (errors of omission vs. commission). The verbs appeared in the middle vs. end of the carrier sentence to create the utterance-medial vs. utterance-final conditions, respectively (see **Table 2** for examples). In the utterance-medial position, the verb was always followed by a preposition with a vowel onset to avoid masking of the morpheme in the preceding verb.

All sentence stimuli were accompanied by cartoon pictures that were designed by a professional cartoonist (see example in **Figure 1**). The drawings had a constant level of visual complexity to avoid distracting details. Since one of the aims for this study was to give a baseline for investigating sentence processing in children, we included these cartoon pictures in this study to later allow for a comparison between children and adults. Given that children have very low attention span, the purpose of the pictures therefore, was to sustain participants' attention, and keep their eyes focused on the computer display to minimize head movement (muscle movements introduce artefacts to the ERP data).

Table 2: Experimental conditions

Utterance position	Type of agreement Violation	Example
Medial	Omission	The boy often cooks/*cook on the stove
	Commission	The boys often cook/*cooks on the stove
Final	Omission	The boy often cooks/*cook
	Commission	The boys often cook/*cooks

*Ungrammatical verb forms are marked in asterisks

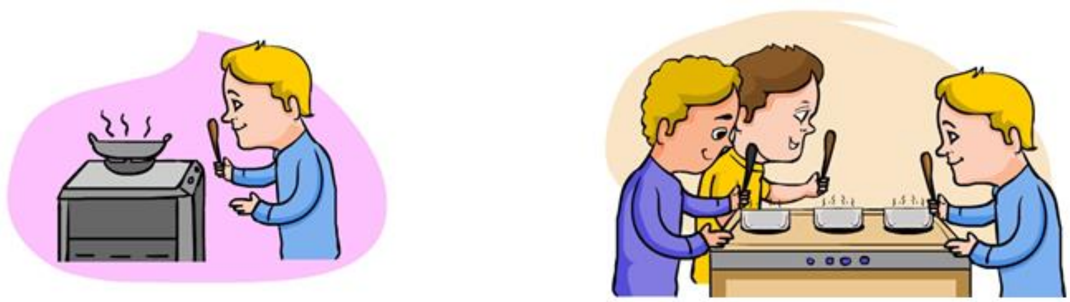

Figure 1: Example of images used for the verb *cook/cooks*.

As shown in **Table 2**, the study employed a 2x2x2 design by crossing type of agreement and utterance position with grammaticality. Each verb therefore appeared in a total of eight conditions which resulted in 50 test items per condition and a total of 400 test items. In addition to the test items, there were 44 catch trials. All catch trials were grammatical and had the same structure as that of the target carrier sentences, but the verbs were not fully controlled for CVC structure (e.g., *eat*). These catch trials were used as a probe task in order to maintain participants' attention during the experiment (see Task and procedure for further details).

Auditory Stimulus Preparation

All grammatical sentences were spoken by a female native speaker of Australian English who was trained in how to produce the sentences. To control for naturalness and intonational constancy, the sentences were read in response to a question and the accompanying picture. For example, all medial sentences were responses to a question like, "W*hat do the boys often do on the stove*? (Answer: *The boys often cook on the stove*). For the final conditions the question was "*What do the boys often do?* (Answer: *The boys often cook).* Medial and final conditions were separated into two lists and all sentences within the same list were recorded together. The sentences were recorded using Audacity (Audacity Team) in a sound-attenuated booth with a Behringer C2 microphone and a USBPre-2 amplifier. The recordings were digitized at a sampling rate of 44 KHz (16 bit; mono). Following the recording, the sentences were normalised using Audition C6 (Adobe Systems) and then extracted into individual sentences using Praat (Boersma and Weenink 2012).

Instead of recording ungrammatical sentences, we created the stimuli by cross-splicing the grammatical productions from the onset of the verb, as shown in **Table 3**. All sound files were spliced at the zero-crossing from the beginning of the verb using Audition C6 (Adobe Systems). This procedure was meant to minimise the possibility of listeners using any early acoustic cues to distinguish between the grammatical and the ungrammatical condition. Previous studies using the auditory EEG paradigm have observed that recording ungrammatical structures, even with a trained speaker, introduces subtle but systematic slowing in production as well as intonation modifications (Royle, Drury, and Steinhauer 2013; Hasting and Kotz 2008). Therefore the splicing procedure was used to avoid possible acoustic differences between grammatical and ungrammatical sentences before the point of violation. All stimuli were later rated for naturalness by a highly trained phonetician.

Table 3: Splicing points and procedure for creating ungrammatical stimuli.

<table>
<tr><th>Source</th><th>Result</th></tr>
<tr><td>The boys often |cook on the stove</td><td>The boys often *cooks on the stove</td></tr>
<tr><td>The boy often |cooks on the stove</td><td>The boy often *cook on the stove</td></tr>
<tr><td>The boys often |cook</td><td>The boys often *cooks</td></tr>
<tr><td>The boy often |cooks</td><td>The boy often *cook</td></tr>
</table>

After splicing the stimuli, we used Audition C6 (Adobe Systems) to examine the waveforms and insert triggers into the individual sound files. We systematically used the end of closure for the coda stops, instead of the end of burst release, as the time-locking point for all four conditions. This is because the burst release of some coda stops such as /t/ is not always clearly identifiable when followed by frication (i.e., the /s/ 3SG morpheme). By time-locking to the end of closure, we made sure that the time-locking points for grammatical and ungrammatical sentences were identical in all conditions. The spectrograms in **Figure 2** illustrate the time-locking points for grammatical and ungrammatical conditions that had inflected and uninflected verbs. Having the same time-locking point ensured that the grammatical and ungrammatical conditions were comparable in terms of where and when the ERP violation effects appeared in both medial and final contexts. For the analysis, we compared the target inflected vs. uninflected verbs within the singular and plural conditions. By doing so, we controlled for the context preceding the target agreement violation to make sure that the response to the violation was only influenced by the grammaticality manipulation on the target verb (see Steinhauer and Drury 2012 for discussion on effects of context/target manipulation on syntactic violation processing).

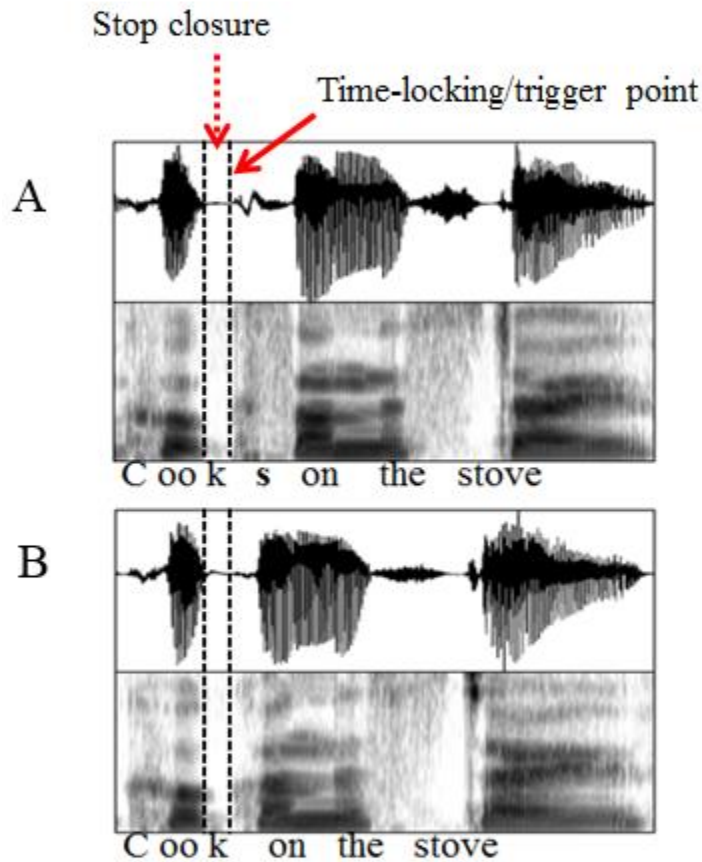

Figure 2: Representative waveforms and spectrograms illustrating the time-locking point used for ERP analysis; (A) illustrates the inflected verb (cooks) and (B) the uninflected verb (cook). The dotted arrow indicates the stop closure of the oral-stop coda /k/ and the solid arrow indicates the end of stop closure that was used as the time-locking point in grammatical and ungrammatical experimental conditions.

Recall that one of the aims of this study was to explore the effects of perceptual salience on the sensitivity to S-V agreement violations. Critical to this effect is the prediction that 3SG –s will be longer utterance-finally due to phrase-final lengthening. We used Praat to conduct acoustic measures of frication duration across all 50 tokens of 3SG –s. As expected, the –s in utterance-final position was twice as long as the morpheme utterance medially, with a mean duration of 238 ms (SD 28 ms) compared to 114 ms (SD 22 ms). Paired t-tests were used to compare the duration of the –s in medial and final position, and as expected, this difference was statistically significant, $t(49) = -5.989$, $p<.001$. This confirmed that the 3SG in utterance-final position was longer than that in utterance-medial condition.

Task and procedure

Participants were fitted with an electrode cap (Easycap, Brainworks GmbH) while seated in a comfortable plush chair at a distance of one meter from a CRT computer screen, in a dimly lit sound-attenuated and electromagnetically shielded room. EEG signals were recorded continuously as participants listened to sentences. They were instructed to listen attentively to all sentences and to immediately press a given response button when they heard the words "*cut/cuts'* or *'eat/eats"* in the sentence. As highlighted in the Materials section, these verbs were used as catch trials while the button-press task prevented participants from performing explicit grammaticality judgements. This probe task was used instead of a grammaticality-judgement task to distract participants from concentrating on the grammaticality of the sentences. Concentrating on grammaticality hinders natural comprehension processes (Dragoy et al. 2012). Besides, grammaticality judgement tasks introduce some other metalinguistic processes that could confound the observed responses to sentence processing. Thus the pseudo-passive task we used would make sure participants pay attention to probe task while passively comprehending all the experimental sentences, without pressure to make explicit judgements about the sentences. The sentences and their matching pictures were presented using Presentation (Neurobehavioral Systems) which also recorded responses (hits, misses and false alarms) for the probe task. Two audio speakers were positioned on the left and right of the computer screen while the matching images appeared on the screen.

The sentences were grouped into medial and final lists in which each list had two ten-minute blocks. Each block had 111 sentences with accompanying pictures. The lists were presented separately to avoid mixing the medial and final conditions as they were of different word lengths. Recall also that we used verbs that could be either transitive or intransitive, and could take an optional prepositional phrase. By blocking the presentation, we controlled for the possibility that the transitivity of the medial condition (verb + prepositional phrase) would influence participants' interpretation of final sentences, as they might then have expected a prepositional phrase in this condition as well. This was particularly important given that one of the aims of this study was to explore utterance position effects (target verb in utterance medial vs. final position), we had to minimize any possible confounds. To control for presentation list effects, the order of the blocks was counterbalanced among the participants so that half of the participants heard the medial-final order first, and the other half had the final-medial order first.

Within each block, the order of sentence/picture presentation was also pseudo-randomised with the constraint that the same verb did not occur consecutively. The picture was presented 500 ms before the onset of the sentence and remained on the screen until the end of the auditory stimulus. The same picture was used for both grammatical and ungrammatical sentence to avoid giving cues about the grammaticality of the upcoming stimuli. Two catch trials were presented at the beginning of the first block of each list and the presentation was pseudo-randomised with the constraint that they occur after five to eight consecutive target items within the block. A picture of an eye appeared on the screen ~1000 ms after the end of each sentence to control for eye blinks and remained on the screen for 1000 ms. Participants were asked to avoid blinking during the presentation of the sentences but to blink when the picture of an eye appeared on the screen. They were also asked to sit still during the presentation of the sentences to avoid movement artefacts during the EEG recording. The sentences had an inter-stimulus-interval of three seconds. A short break was taken at the end of each block. The duration of the break was determined by the participant. Altogether, the experiment lasted about 60 minutes.

EEG data recording

The continuous EEG was recorded from 64 Ag/AgCl scalp electrodes mounted onto an electrode cap (Easycap, Brainworks GmbH) in line with the International 10–20 system (Jasper, 1958: Fpz, Fz, FCz, Cz, CPz, Pz, POz, Oz, Fp1/2, F7/5/3/1/2/4/6/8, FT7/8, FC5/3/1/2/4/6, T7/8, C5/3/1/2/4/6, M1/2, TP7/8, CB1/2, CP5/3/1/2/4/6, P7/5/3/1/2/4/6/8, PO7/5/3/4/6/8, O1/2). Additional electrodes were placed above and below the left orbit and on the outer canthus of each eye to monitor electro-oculographic (EOG) activity with a bipolar recording. The ground electrode was positioned between Fpz and Fz. Electrode impedances were adjusted until they were below 10 kΩ. Electrical activity was recorded from both mastoids with the left mastoid (M1) serving as the online reference. The signal from the EEG was digitised at a sampling rate of 1000 Hz and filtered with a .05-100 Hz bandpass filter using a Neuroscan SynAmps2 DC Amplifier (Compumedics Ltd., USA).

EEG data processing

The digitised data were processed off-line in Matlab (Version R2013b: MathWorks, Massachusetts, U.S.A) using the Fieldtrip toolbox (Oostenveld et al. 2010,Version 2014-08-24). The data were epoched into trials of 1000 ms including a 100 ms pre-stimulus interval and then filtered with a Butterworth bandpass of 0.05-20 Hz for Independent Component Analysis (ICA) analysis. Extreme trials with amplitudes larger than ±300 μV were removed before entering all trials into the ICA. The purpose of the ICA was to identify any components resembling eye blinks, horizontal eye movements, noisy channels and other focal artefacts. The identified components were then mathematically removed from the data and signals were back projected to the original unfiltered data. After ICA, each channel was re-referenced to the mean mastoids and baseline corrected using the 100 ms pre-stimulus interval. Trials with artefacts that exceeded 100 μV, with trends greater than 75 μV, or with abnormal distributions or improbable data exceeding five *SD*s, were also rejected.

This procedure removed a total of 172 trials or (0.46% of all trials) from the eight experimental conditions: 21 medial-singular grammatical, 24 medial-singular ungrammatical (omission), 23 final-singular grammatical, 19 final-singular ungrammatical (omission), 21 medial-plural grammatical, 22 medial-plural ungrammatical (commission), 24 final-plural grammatical, and 18 final-plural ungrammatical (commission). There was no reliable difference between the numbers of rejected trials across conditions. The remaining trials in each of these conditions were averaged for each participant and grand averages were then computed for each of the conditions.

EEG data analysis

As discussed in the introduction section, different ERP latencies have been reported for studies using the visual and auditory modality (see literature review **Table 1**). Therefore analysing the grand ERP averages using standard time windows associated with LAN, N400 or P600 would not be ideal as we might miss out some effects that may fall outside of those time points. We therefore computed the subject grand averages using non-parametric cluster-based permutation tests (Maris and Oostenveld 2007). The statistical analysis sought to examine the differences between the overall grammatical and ungrammatical sentences (collapsing type of agreement and utterance position effects). We computed the cluster-based permutation test as described by Maris and Oostenveld (2007). The test first identifies sampling points with t-statistic exceeding a critical threshold ($p < .05$, two-tailed). Clusters are then formed by connecting significant sampling points on the basis of spatial and temporal adjacency. This is done separately for sampling points with positive and negative t-values. The maximum cluster-level test statistics (the sum of all individual t-values within a cluster) are then computed to generate permutation distributions, one for positive clusters and one for negative clusters, based on 1000 random partitions. The significance of a cluster is determined by whether it fell in the highest or the lowest 2.5^{th} percentile of the corresponding distribution.

The aim of this analysis was to test if and when the ERP responses to ungrammatical sentence differ from those to the grammatical ones. Given that this type of analysis cannot be used for testing interactions between conditions, we used it as a first step of data analysis. We then used these time windows to perform further analysis using repeated-measures multivariate analysis of variance (MANOVA) to statistically test the extent to which type of agreement violation and utterance position influence the on-line S-V agreement processing. We present the results from the cluster-based permutations first, and then the procedure and results for the MANOVAs. Note that the statistical analyses were performed on original unfiltered data, but for presentation purpose, the ERP waveforms presented in this paper were filtered using a 40 Hz low pass filter.

Results: Effects of grammaticality

One of the goals of this study was to test if adult speakers of English would be sensitive to S-V agreement violations as often reported in previous studies where there is generally a strong correlation between grammatical violations and the presence of the LAN and/or P600 in L1 adults (Molinaro et al. 2011). However, in this study, we sought to explore if these responses would be further modulated by the relative perceptual salience of the 3rd –s morpheme as a function of type of agreement violation (errors of omission vs. errors of commission) and utterance position (medial vs. final). We begin by reporting the results of the cluster-based permutation tests, which contrasted the grand average ERP waveforms of the grammatical condition with those of ungrammatical condition (collapsed over type of agreement and utterance position. The aim of this analysis was to examine if, and when, the ungrammatical condition yield a significantly different ERP response than the grammatical condition without a priori knowledge of the time-window. The grammaticality effects are shown at nine representative electrodes (corresponding to locations F3, Fz, F4; C3, Cz, C4 and P3, Pz, P4 in a standard 10–20 set-up) in **Figure 3**, which also shows the topographic maps highlighting the distribution and time course of the significant clusters.

Visual inspection of the waveforms indicated that, relative to the grammatical verbs, ungrammatical verbs elicited a bilateral negative-going waveform over the anterior-central electrodes followed by a positive-going waveform over the central-posterior electrodes. Statistical analysis using cluster-based permutation tests revealed that contrasts observed for grammatical vs. ungrammatical verbs yielded a significant *negative* cluster ($p = .036$) between 130 and 210 ms in the anterior-central electrodes and a significant *positive* cluster ($p < .0001$) between 350 and 590 ms with a centro-posterior distribution.

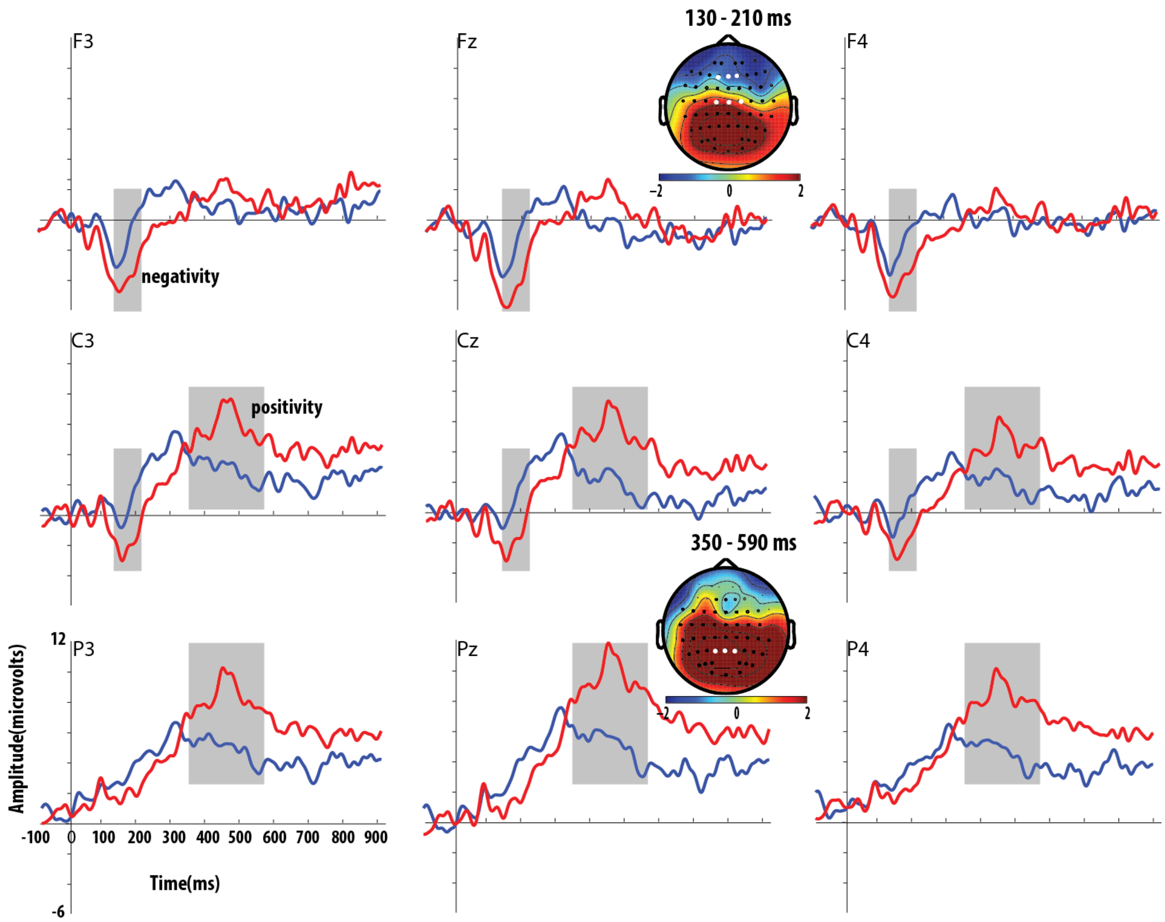

Figure 3: Grand average ERP waveforms for grammatical and ungrammatical conditions across positions and type of agreement violation at the F3, Fz, F4; C3, Cz, C4, P3, Pz, and P4 electrodes and the topographic maps of the significant ERP effects. The first row of the figure shows the anterior electrodes while the second row shows central electrodes and the third row shows the posterior electrodes. The ERPs are time-locked to the offset of the verb-stem (end of stop closure) and positivity is plotted upwards. The topographic maps show brain voltage distributions for the negative and positive clusters. These maps were obtained by interpolation from 64 electrodes and were computed by subtracting the grand averages of grammatical from the ungrammatical conditions. Electrodes in the significant clusters are highlighted with a black circle and the F3, Fz, F4; C3, Cz, C4, P3, Pz, and P4 electrodes are highlighted with a white circle. Time-windows for significant clusters is highlighted in grey over the waveforms.

Thus, ungrammatical sentences, in overall, elicited brain responses that were different from those of the grammatical sentences. However, Since the cluster-based permutation test cannot be used for testing the interactions between type of agreement violation, utterance position, and grammaticality, we therefore performed further analyses using repeated-measures multivariate analysis of variance (MANOVA) on the two time windows (130-210 ms and 350-590 ms) where the grammaticality effect yielded significant amplitude differences across all comparisons. The aim of this analysis was to statistically test the extent to which type of agreement violation and utterance-position effects contributed to the grammaticality effect.

MANOVA: Effects of type of agreement and utterance position

We performed MANOVA on mean amplitude measurements taken from 130-210 ms and 350-590 ms for all the eight experimental conditions. Within each time window, we performed MANOVAs with Type of agreement (singular, plural), Position (medial, final), Grammaticality (grammatical, ungrammatical) and Region of interest (nine regions of interest) [ROI] as repeated measures factors. The ROIs were computed from the means of electrodes in the parenthesis: (anterior midline [Fz, FCz], central midline [Cz, CPz], posterior midline [Pz, POz], anterior left [F7, F5, F3, FT7, FC5, FC3], central left [C3, C5, T7, CP3, CP5, TP7], posterior left [P7, P5, P3, PO7, PO5, PO3], anterior right [F4, F6, F8, FC4, FC6, FT8], central right [C4, C6, T8, CP4, CP6, TP8], posterior right [P8, P4, P6, PO4, PO6, PO8]). These electrode groupings are illustrated in **Figure 4.** The results of the MANOVA performed on the 130-210 ms and 570-770 ms time-windows are reported in **Table 4.**

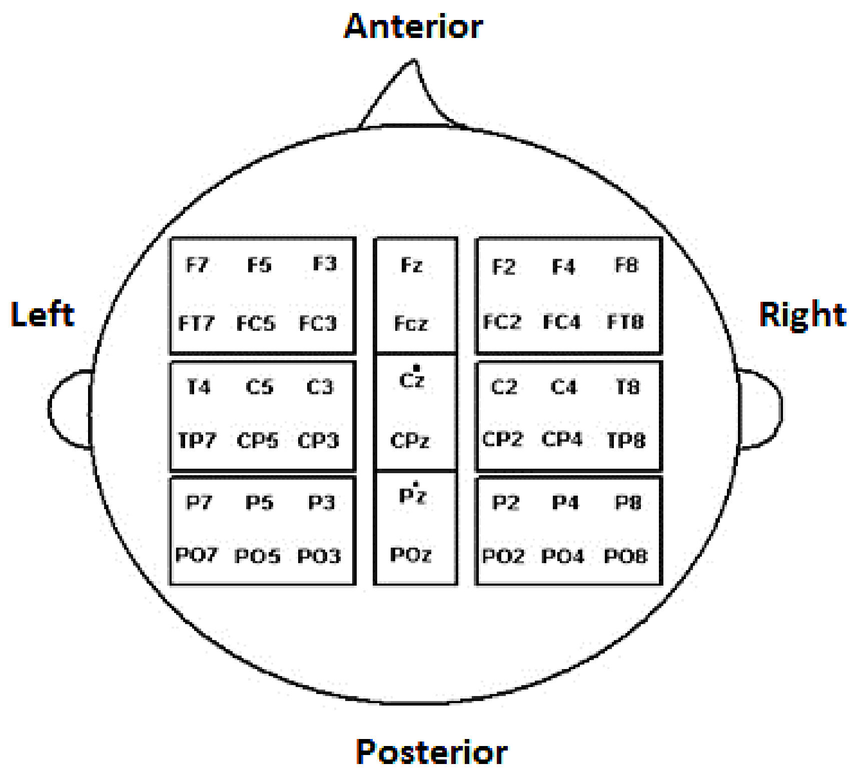

Figure 4: Approximate placement for the electrodes included in the regions of interests (ROI) analysis for MANOVA. The rectangles indicate the levels used to demacate the nine ROI (anterior midline (Fz, FCz), central midline (Cz, CPz), posterior midline (Pz, POz), anterior left (F7, F5, F3, FT7, FC5, FC3), central left (C3, C5, T7, CP3, CP5, TP7), posterior left (P7, P5, P3, PO7, PO5, PO3), anterior right (F4, F6, F8, FC4, FC6, FT8), central right (C4, C6, T8, CP4, CP6, TP8), posterior right (P8, P4, P6, PO4, PO6, PO8).

ERP results in the 130-210 ms time window

The statistical analysis for this time window showed a main effect of Grammaticality and interactions between Type of agreement and Grammaticality, between Position and ROI, and between Type of agreement, Grammaticality, and ROI (Pillai's trace and *F* values are given in **Table 4**). The interaction between Type and Grammaticality suggests that, in this time-window, the effect of Grammaticality differed depending on the type of agreement violation. Follow up pairwise t-tests revealed that the mean amplitude of the negativity for ungrammatical conditions was significantly greater for errors of omission (M = -0.314 μV, SE = 0.177) than errors of commission (M = -0.007 μV, SE = 0.188), t (19) = -2.543, p < .005. This shows that this interaction was driven by the negativity elicited by errors of omission

Table 4: **Omnibus MANOVA results across the 130-210 ms, and 350-590 ms time windows**

	130-210ms		**350-590ms**	
Effects	Pillai's trace	F-value	Pillai's trace	F-value
Type (1,19)	-	-	-	-
Pos. (1,19)	-	-	.236	5.860*
Gram (1,19)	.459	16.117***	.380	11.642**
Type. * Pos (1,19)	-	-	-	-
Type. * Gram (1,19)	.202	4.802*	.353	10.365**
Pos. * Gram (1,19)	-	-	-	-
Type.* Pos.*Gram (1,19)	-	-	.234	5.807*
Type.* ROI (8, 152)	-	-	-	-
Pos. *ROI (8, 152)	.686	3.280*		
Type.*Pos.*ROI (8, 152)	-	-	-	-
Gram. * ROI (8, 152)	-	-	-	-
Type. * Gram.* ROI (8, 152)	.710	3.672*		
Pos.*Gram.* ROI. (8, 152)	-	-	.705	3.593*
Type.*Pos.*Gram.*ROI (8, 152)	-	-	-	-

Degrees of freedom are reported in parentheses. Pos. = Position, Gram. = Grammaticality, ROI = Regions of interest. ***p < .001; **p < .05; *p = .05

In addition to the two-way interaction, the three-way interaction between Type, Grammaticality, and ROI suggests that the mean amplitudes of the electrodes differed depending on Grammaticality and Type. To test this, follow-up MANOVAS were performed on each ROI with Type and Grammaticality as within-subject factors. Results indicated that the interaction was significant in the central-mid region (Pillai's trace = .205, $F(1,19) = 4.904$, $p < .05$), posterior-left region, (Pillai's trace = .255, $F(1,19) = 6.505$, $p < .05$) posterior-mid region, (Pillai's trace = .301, $F(1,19) = 8.185$, $p < .05$) and the central right region (Pillai's trace = .279, $F(1,19) = 7.346$, $p < .05$). Further pairwise comparisons showed that the mean-amplitude differences for the ungrammatical conditions were only significant for errors of omission in the central-mid region ($M = 1.259$ µV, $SE = 0.400$), $t(19) = 3.143$, $p < .005$; and posterior-mid region ($M = 0.664$ µV, $SE = 0.292$), $t(19) = 2.274$, $p < .05$.

Finally, the interaction between Position and ROI suggests that the mean amplitude of the electrodes differed depending on Position. Follow up pairwise t-tests revealed that the mean amplitude of the negativity in the central-mid region was significantly greater for medial ($M = -.463$ µV, $SE = .274$) than final positions ($M = -.095$ µV, $SE = .230$), $t(19) = -2.543$, $p < .05$. This shows that the negativity observed in the cluster-based permutation was driven by type of violation (errors of omission) in the medial position. This is also reflected in the ERP the grand averaged ERP waveforms for grammatical and ungrammatical trials (errors of omission vs. commission) in the utterance-medial and utterance-final position in **Figure 5** and **Figure 6**. In overall, the interactions observed in this time window indicate a negativity for errors of omission in the medial condition.

ERP results in the 350-590 ms time window

The statistical analysis for this time window showed a main effects of Grammaticality and Position as well as interactions between Type and Grammaticality, and between Type, Position and Grammaticality, and between Position, Grammaticality, and ROI (Pillai's trace and F values are given in **Table 4**). The interaction between Type and Grammaticality suggests that, in this time-window, the effect of Grammaticality differed depending on the Type of agreement violation. Follow up pairwise t-tests revealed that the mean amplitude of the positivity for ungrammatical conditions was significantly greater for errors of commission (M = 1.372 µV, SE = 0.228) than errors of omission (M = 0.860 µV, SE = 0.244), t (19) = 3.152, $p < .005$. This shows that this interaction was driven by the positivity elicited by errors of commission.

In addition, the three-way interaction between Type, Position, and Grammaticality suggests that the effect of the Grammaticality also differed depending on Type of agreement violation and Position. To test this, follow-up MANOVAS were performed on grammatical and ungrammatical conditions with Type, Position and ROI as within-subject factors. The analysis showed main effects of Position and Type and a further three way interaction between Type, Position and ROI (Pillai's trace = .719, F(1,19) = 3.847, $p < .05$) in the ungrammatical condition. Further analysis performed on each ROI with Type and Positon as within factors revealed that the interaction was significant in the front-left region (Pillai's trace = .290, F(1,19) = 7.755, $p < .05$). Follow up pairwise t-tests revealed that the mean amplitude of the positivity for ungrammatical conditions was significantly greater for errors of commission in the utterance-final position (M = 1.520 µV, SE = 0.447) than in the utterance-medial position (M =0.684 µV, SE =*0 .286*), t (19) = -3.399, $p < .005$. This shows that in the 350-590 ms time window, errors of commission in the utterance-final position elicited a robust positivity. This indicates that the positivity observed in the overall cluster-based permutation was driven by the errors of commission in the utterance final position.

Furthermore, the other three-way interaction between Position, Grammaticality, and ROI suggests that the mean amplitude of the positivity also differed depending on Position and Grammaticality. To test this, follow-up MANOVAS were performed on each ROI with Position and Grammaticality as within-subject factors. Results indicated that the interaction was significant in the front-mid region (Pillai's trace = .296, $F(1,19) = 7.982$, $p < .05$), front-left region (Pillai's trace = .224, $F(1,19) = 5.343$, $p < .05$), central-mid region, (Pillai's trace = .190, $F(1,19) = 4.459$, $p < .05$) and posterior-mid region, (Pillai's trace = .279, $F(1,19) = 7.236$, $p < .05$). Further pairwise comparisons showed that the medial and final ungrammatical conditions were only significantly different for the errors of commission in the front-mid region ($M = 2.079$ µV, $SE = .657$), t (19) = 3.152, $p < .005$, central-mid region, ($M = 1.218$ µV, $SE = 0.529$), t (19) = 3. 038, $p < .05$, posterior-mid region, ($M = 1.027$ µV, $SE = .404$) (t (19) = 2.657, $p < .05$, and the front-left region ($M = 1.520$ µV, $SE = 0.444$) (t (19) = 3.399, $p < .005$. This shows that ungrammatical conditions in the final position elicited a broadly distributed positivity. This is pattern is reflected in the grand averaged ERP waveforms for grammatical and ungrammatical trials (errors of omission vs. commission) in the utterance-medial and utterance-final position in **Figure 5** and **Figure 6**. Overall, the interactions observed in this time window indicate that the amplitude and distribution of the positivity was influenced by the additive perceptual salience due to overtness of the violation and utterance-final lengthening.

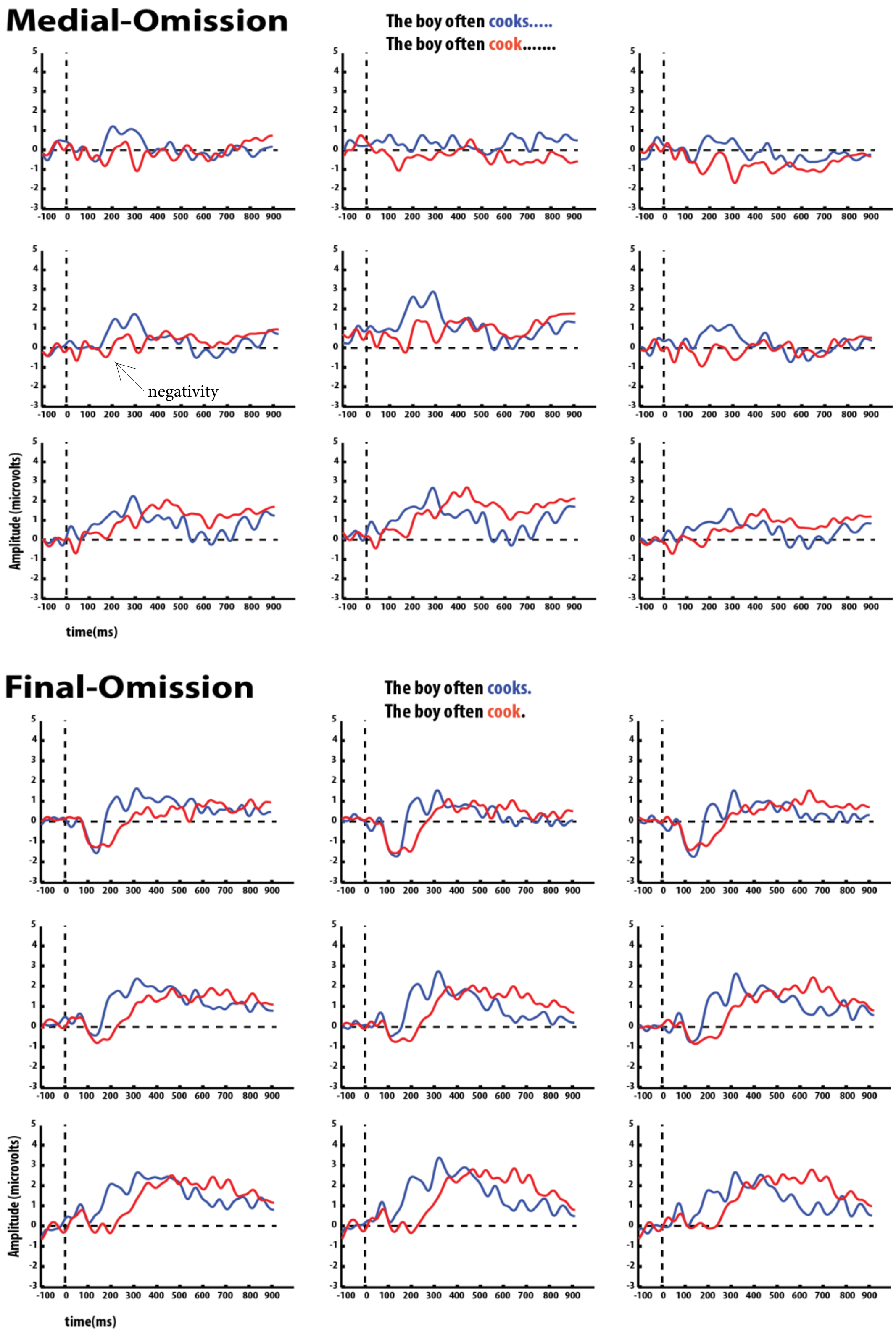

Figure 5: Grand average event-related potentials elicited by errors of omission (red) and correct verb (blue) in medial and final position.

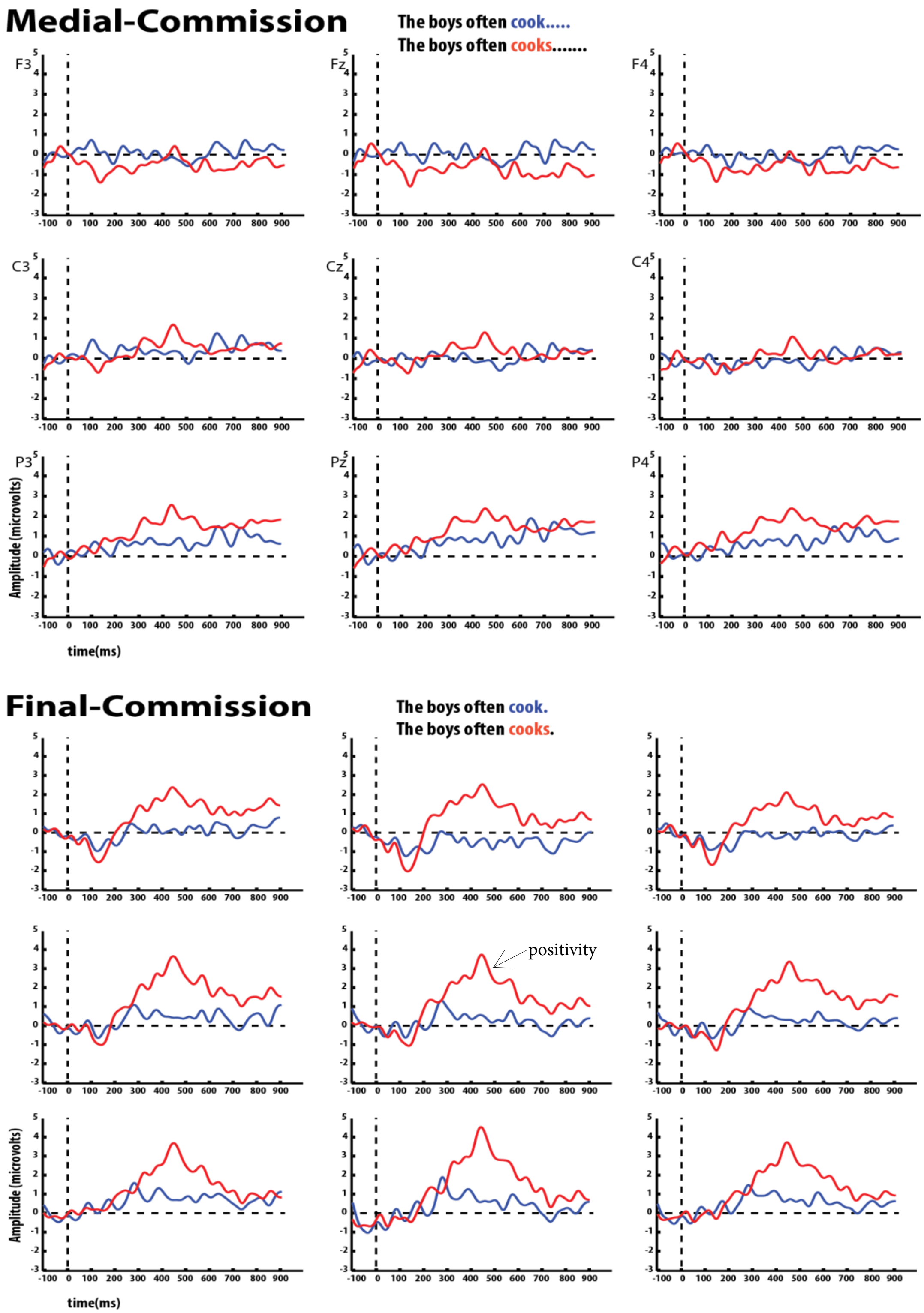

Figure 6: Grand average event-related potentials elicited by errors of commission (red) and correct verb (blue) in medial and final position.

Discussion

This study used ERPs to investigate how Australian-English speaking adults processed S-V agreement during auditory sentence comprehension. The aim of the study was to explore whether the LAN and P600 effects would vary as a function of perceptual salience associated with the type of agreement violation and utterance position. Previous ERP studies investigating the processing of agreement have shown that different aspects of experimental designs (e.g., the syntactic complexity of stimulus) influence the on-line computation of agreement information. However, the possibility that perceptual salience may influence the computation of S-V agreement has not yet been explored because most of the previous research has been carried out in the visual modality. Understanding how the different aspects of experimental designs influence the on-line computation of agreement information will enhance our knowledge of the processes that modulate sentence comprehension. This study is, therefore, the first to explore how these factors influence English-speakers' sensitivity to S-V agreement violation during auditory sentence comprehension.

Given the findings from previous S-V agreement studies, we predicted that both types of violation (errors of omission and commission) will elicit LAN and/or P600 effects due to morphosyntactic violation detection and sentence reanalysis. However, due to the stimuli manipulations used in this study, we predicted that these effects will be more robust for the more perceptually salient conditions (errors of commission and utterance-final positions) than for their less perceptually salient counterparts. The results are briefly summarized in the following paragraph, which is followed by a detailed discussion in the sub-sections below.

Results for the overall grammaticality effect, with all conditions collapsed, showed that S-V agreement violations evoked a bilateral negativity with an anterior-central distribution, in the early 130-210 ms time window. This is followed by a positivity in the 350-590 ms time window with a centro-posterior distribution. Based on the latency and scalp distribution of the negativity, we interpret it to be an anterior negativity (AN) which has been traditionally taken to reflect similar processes to those reflected by the LAN—i.e. detection of morphosyntactic violations (Friederici et al. 1993; Hagoort et al. 2003; Bornkessel and Schlesewsky 2006). As for the positivity, we interpret this to be a P600 effect, which has been traditionally taken to reflect repair, reanalysis or recovery from ungrammatical sentences (Osterhout and Holcomb 1992; Osterhout and Mobley 1995; Friederici, Hahne, and Mecklinger 1996; Kolk and Chwilla 2007). However, it is important to note that the latency of these effects is earlier than those usually reported, suggesting possible modality effects (auditory vs. visual) (Hasting and Kotz 2008).

Further analyses with MANOVAs, for investigating the interactions between Type of violation, Position, and Grammatically, revealed that the four experimental conditions contributed differently to the overall effects observed. For the early negativity time window (130-210 ms), MANOVAs revealed that the negativity observed in the cluster-based permutation test was elicited by errors of omission in utterance-medial position only. Furthermore, this negativity was strongest in the front-mid and central-mid region as shown by the three-way interaction between Type, Grammaticality and Region of interest (ROI). In the positivity time window (350-590 ms), MANOVAs revealed that the positivity observed in the cluster-based permutation test was elicited by the errors of commission in both utterance-medial and utterance-final position and errors of commission in utterance-medial position. This is demonstrated by the three-way interaction between Type, Position, and Grammaticality. These effects are illustrated in the grand averaged ERP waveforms in

Figures 5 and 6. Furthermore, the MANOVAs revealed that, errors of commission in the utterance-final position yielded larger mean amplitude than other conditions. The difference was strongest in the front, central, and posterior mid regions of the brain. These results show that, as predicted, the ERP effects manifest with broader scalp distribution and larger amplitude in contexts where the S-V agreement violation had higher perceptual salience. Thus, the results support our hypothesis that the type of agreement violation and utterance position modulated the processing of S-V agreement. Although this study does not allow us to resolve the debate on the processes underlying sentence comprehension, the findings that perceptual salience influenced S-V agreement processing are in line with the internal models for sentence comprehension (e.g., Bornkessel-Schlesewsky et al. 2015; Pickering and Gorrard, 2013). We discuss these issues in more detail below.

The role of perceptual salience in S-V agreement processing

Recall that in the introduction, that we mentioned two psycholinguistics views that have influenced sentence-processing research: The serial/syntactic-first view (Frazier & Fodor, 1978), and the parallel/interactive view (e.g., Trueswell, Tanenhaus, and Garnsey 1994; Trueswell, Tanenhaus, and Kello 1993), on which the internal models are based (e.g., (Pickering and Garrod 2013; Pickering and Garrod 2007; Trueswell, Tanenhaus, and Garnsey 1994; Trueswell, Tanenhaus, and Kello 1993), According to the former view, morphosyntactic processing, including S-V agreement processing, is not influenced by non-syntactic factors, such as the perceptual salience of the input. On the contrary, the latter assumes that perceptual salience of the input plays a role in sentence processing. There is increasing evidence from behavioural measures that support the latter view in the comprehension of S-V agreement (e.g., Song, Sundara, and Demuth 2009; Sundara, Demuth, and Kuhl 2011). However, these behavioural measures cannot inform us of the on-line processing of S-V agreement, and thus it remains unknown whether perceptual salience plays a role in the processing of S-V agreement.

To this end, in the present study, we tested whether the processing of S-V agreement violation can be affected by two types of perceptual salience of the violation: one associated with the type of agreement violation (errors of commission vs. errors of omission) and the other associated to the utterance position (utterance-final vs. utterance-medial). Also, given that previous studies on pitch accent (Dimitrova et al. 2012) have reported ERP responses with higher amplitude and broader scalp distribution to more perceptually salient violations (i.e. superfluous pitch accent) than less perceptually salient violations (i.e. missing pitch accent), we predicted the same would apply to the current study. That is, agreement violations that are more perceptually salient (i.e. errors of commission and errors at the utterance-final position) would elicit more robust ERP responses than the ones that are less perceptually salient (i.e. errors of omission and errors at the utterance-medial position). In particular, the errors of commission would elicit the most robust ERP effects amongst all four types.

In line with the predictions, our results showed that the more perceptually salient conditions yielded more robust ERP effects than the less perceptually salient conditions. The errors of commission in the utterance-final position evoked a larger P600 effect and broader scalp distribution compared with those at the utterance-medial position, and compared with the errors of omission at the utterance-final position. Another important finding of the present study is that perceptual salience related to the type of agreement violation appears to elicit different ERP effects. In particular, errors of omission in the utterance-medial position elicited only a bilateral anterior negativity while the errors of commission at the same position elicits only a P600 effect with a centro-posterior distribution. The presence of a P600 effect in the absence of a negativity has been argued to indicate an immediate reanalysis to check for processing error due to a strong conflict between the expected input and the actual stimuli (e.g., Kolk and Chwilla 2007; Kuperberg 2007; van de Meerendonk et al. 2010). This immediate reanalysis has an early onset and thus overrides the earlier anterior negativity, which signals the detection of a morphosyntactic error. In a similar vein, it has been argued that the presence of a negativity (LAN/N400) in the absence of a P600 effect reflects that listeners have detected a mismatch between the expected linguistic representation and the actual stimuli, however, the mismatch is resolvable and thus does not trigger a reanalysis (e.g., Kolk and Chwilla 2007; Kutas and Hillyard 1983; O'Rourke and Van Petten 2011).

This view is also in line with the internal models of sentence comprehension which that the nature of incoming stimuli may engage different general cognitive processes depending on the available cues (e.g., Dröge, Fleischer, Schlesewsky, and Bornkessel-Schlesewsky 2016). Thus, the additional acoustic cues found in the more perceptually salient errors seem to make the mismatch in the morphosyntactic error more pronounced and more difficult to process compared with the less perceptually salient errors. This in turns triggers different cognitive systems for the reanalysis of the sentence, in the less perceptually salient context, predictive processes are triggered whereas in the more perceptually salient context, syntactic certainty processes are triggered to check for processing error (we discuss the implications of these models below).

Taken together, the presence of a P600 effect in the absence of a negativity for the error of commission and the presence of an anterior negativity in the absence of a P600 effect points to the role of perceptual salience during the on-line speech processing of S-V agreement. These findings thus support the predictions we had for positional effects, that: i) S-V agreement violations in utterance-final position will elicit earlier LAN/P600 effects compared to errors in utterance-medial position, ii) that the amplitude of the P600 will be more robust in utterance-final position due to greater perceptual salience resulting from phrase-final lengthening, and iii) that the P600 elicited by errors of commission in utterance-final position will be more robust compared to that elicited in other conditions.

Implications for the interpretation of the LAN and P600 effects

The processing of agreement violations is traditionally assumed to elicit LAN/P600 effects in adult native speakers (e.g., Coulson, King, and Kutas 1998; Osterhout and Mobley 1995; Shen, Staub, and Sanders 2013). The LAN is often taken to reflect detection of morphosyntactic violations (e.g., Friederici, 2002), and the P600 to reflect syntactic reanalysis (Friederici, et al., 1993; Osterhout and Mobley 1985). However, this modular-specific approach to the functional interpretation of language related components has been challenged by reports from studies of S-V agreement violations processing where the LAN and P600 effects have been shown to vary in their presence, latency, amplitude or scalp distribution (Choudhary et al. 2009; Nevins et al. 2007; Kaan et al. 2000; O'Rourke and Van Petten 2011; Hasting and Kotz 2008). However, some researchers argue that the P600 is a more reliable index for the processing of S-V agreement violation than the LAN, which has been observed to vary within and across studies (Steinhauer and Drury, 2012; Tanner and Van Hell, 2014). In this study, the P600 effect was reliably observed in three of the four violation conditions whereas the negativity was only observed in one condition. Similar findings have been reported in previous ERP studies too (e.g., Osterhout et al. 1996; Hagoort and Brown 2000; Kaan et al. 2000; Nevins et al. 2007; Kos et al. 2010).

What is interesting, however, is that a number of explanations that have been previously given to account for the variability of the LAN do not apply to this study. For example, Hagoort and Brown (2000) only observed a negativity when they used the auditory modality but not the visual modality. As a result, they suggested that the presence of the LAN varied as a function of the modality of presentation. However in this study, we used the auditory modality but only observed a bilateral negativity in one of the four conditions that was the least perceptual salient. This finding suggests that the occurrence of the negativity is not modulated by the modality of presentation as previously argued by Friederici et al. (1993). Other factors that have been argued to modulate the presence of the negativity include the choice of mastoid referencing (Molinaro et al. 2011), the morphological richness of a language (Friederici and Weissenborn 2007), working memory load of the stimuli (Vos et al. 2001), and individual differences (Tanner and van Hell 2014; Tanner 2015). However, in this study, these explanations would not suffice given that the negativity was only observed in one of the four experimental conditions despite using the same mode of presentation, averaged mastoids, the same language, controlled utterance-length (until the point of violation) and the same participants, respectively.

Instead, results from our study seem to suggest that the presence of a negativity depends on how early the sentence reanalysis processes are implemented. This is because we only observed a P600 effect when the S-V agreement violation occurred in contexts that were more perceptually salient (e.g., errors of commission in utterance-final position) while we observed the negativity in the least perceptually salient context (errors of omission in utterance-medial position). When sentence reanalysis starts early, the early P600 may obscure the negativity resulting from morphosyntactic violation detection, thus, we did not observe any negativity in the more perceptually salient contexts. On the other hand, when the violation occurs in conditions with less perceptually salient cues, sentence reanalysis is not triggered, thus, we observe the negativity resulting from morphosyntactic violation detection.

This explanation is in line with the internal models of sentence comprehension which assume that the nature of incoming stimuli may engage different general cognitive processes depending on the available cues. (e.g., Dröge, Fleischer, Schlesewsky, and Bornkessel-Schlesewsky 2016). we thus assume that the perceptual salience of stimuli influenced how listeners predicted and matched incoming stimuli to the underlying linguistic representations (the predictive processes) and made decisions about the meaning of the sentence (decision certainty processes). The predictive processes are often associated with the elicitation of a negativity effect, whereas the decision certainty processes are associated with the P600 effect. It is, therefore, possible that the relative perceptual salience of the of the S-V agreement, influenced adults' detection of the violation, evoking different ERP responses even though the underlying linguistic process (morphosyntactic processing) was the same.

We, thus, propose that the presence of a negativity without a following P600 and the presence of a P600 without a preceding negativity were modulated by the perceptual salience of the S-V agreement violation. This suggests that the absence of LAN or AN does not necessarily mean a lack of morphosyntactic-violation detection, but rather indicates an overlap with the P600 due to early reanalysis processes of perceptually salient S-V agreement violations. A similar observation has been observed by (Kuperberg 2007) for the absence of an N400 effect in the presence of P600 effects for semantic violations.

Methodological Implications

As elaborated above, findings from this study suggest that perceptual salience associated with the type of agreement violation and utterance position influences the processing of S-V agreement during on-line comprehension. For example, listeners were more sensitive to errors of commission in utterance-final position (robust P600 effects) than errors of omission in utterance-medial position which are less perceptually salient. Previous studies have not been able to investigate such effects because they used the visual modality in which perceptual salience is irrelevant for S-V agreement. By using auditory stimuli, this study successfully explored how perceptual salience associated with the type of agreement violation and utterance position influence the computation of agreement during sentence comprehension. Besides demonstrating the effects of type of violation and utterance position, this study has also shown that the auditory modality is more ecologically valid than the visual modality for investigating the processing of S-V agreement. The auditory modality would be especially useful for research on younger populations or second-language learners who may not be efficient readers.

What is also clear from our study is that collapsing errors of omission and commission is not ideal as it confounds some of the processes that underlie the computation of agreement information. Our results show that errors of omission and commission are processed differently due to the degree of perceptual salience associated with the type of violation and utterance position. Errors of omission in utterance-medial position elicited an anterior negativity whereas errors of omission in utterance-final position and errors of commission in both medial and final positions elicited P600 effects. We interpret these findings to show that errors of omission and errors in utterance-medial position are less perceptually salient compared to errors of commission and errors in utterance-final position. It is, therefore, important for future studies investigating the processing of S-V agreement violations to avoid confounding type of agreement violation and utterance position given the different ERP effects. This has important theoretical implications for the functional interpretation of the LAN-like and P600 effects (see also Steinhauer and Drury 2009 on the discussion of experimental design effects on ERPs).

Conclusions

This study used ERPs to explore the possibility that perceptual salience related to type of agreement violation (errors of omission vs. commission) and utterance position (medial vs. final) influences the computation of S-V agreement violation during on-line speech comprehension. Previous studies have not systematically investigated how these factors individually impact on the on-line processing of S-V agreement violation. As a result, the perceptual salience associated with these factors has not been considered as an important factor when interpreting and generalizing the processes that modulate agreement processing. In this study, we observed that the ERP effects elicited by S-V agreement violations varied in terms of their presence, latency, distribution and amplitude due to type of agreement violation and positional effects. The P600 effect was only observed in contexts where the agreement violation had higher perceptual salience, e.g., errors of commission and utterance-final position, whereas the bilateral negativity was only observed in contexts with the least perceptual salience, e.g., errors of omission in utterance-medial position. These results support the internal models of sentence processing (e.g., Pickering and Garrod 2013) which proposed that the level of processing depends on the nature of stimuli. That is, stimuli that are perceptually more salient could engage more cognitive processes during sentence processing, and this in turns evoke more robust ERP responses. This study is, therefore, the first to show that perceptual salience related to type of agreement and utterance position influences listeners' sensitivity to agreement violation. These findings have important methodological and theoretical implications for understanding on-line sentence comprehension.

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CHAPTER 3

Perceptual Salience Matters for L2 Processing of Subject-Verb Agreement: ERP Evidence from Mandarin Learners of English

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Abstract

It has long been observed that grammatical morphemes are used variably by second-language (L2) learners of English. However, while this often subsides with increased proficiency, Mandarin L2 learners of English (MLEs) often persist in omission of inflectional morphemes such as 3rd person singular –s (3SG). Although this behaviour is often explained in terms of the degree of similarity between learners' first-language (L1) and L2 structures, there is now accumulating evidence suggesting that listeners' sensitivity to the presence of grammatical morphemes interacts with phonological/prosodic factors. To explore how perceptual salience might influence L2 morphosyntactic processing, we used ERPs to measure their brain activity while they listened to sentences in which the S-V agreement differed by *type of agreement violation* (errors of omission vs. errors of commission) and *utterance position* (verbal inflection in utterance-medial vs. utterance-final contexts). We observed an anterior P600 in response to errors of commission, and only in utterance-final position which had greater perceptual salience due to the overt violation and in utterance-final position. Further exploration of the data by length of exposure to English revealed different effects, only for participants with longer immersion: a late negativity with a posterior distribution for errors of omission and a P600 with a frontal distribution for errors of commission. These results suggest that, despite L1-L2 language structure differences, MLEs who have more experience listening to English are sensitive to grammatical morphemes, especially when these occur in more perceptually salient contexts. The findings hold important implication for experimental design and the interpretation of ERP components during L2 sentence processing.

Introduction

Learning a second language (L2) is difficult, particularly for adults. One of the language phenomena that has been long observed to be challenging for adult learners is L2 grammatical morphology (Flege, Munro, & MacKay, 1995). For Mandarin L2 learners of English (MLEs), this difficulty is most noticeable in speech-production errors involving omissions of inflectional morphology such as 3rd person singular –s (3SG) (Goad, White, & Steele, 2003; Lardiere, 2000, 2006), as shown in (1) below.

(1) *She get**s** dress**ed**….and then *make breakfast and *clean the dish**es**.* (Goad et al., 2003)

Of interest to this study is the observation that, while inconsistency in the use of grammatical morphology subsides over time for most L2 learners (e.g., Steinhauer, White, & Drury, 2009; McLaughlin et al., 2010; Bowden, Steinhauer, Sanz, & Ullman, 2013), it persists for MLEs (e.g., Laidere, 2006; 2007; Jia & Fuse, 2007; Chen, Shu, Liu, Zhao, & Li, 2007; Xue et al., 2013;Franceschina, 2001; Jia & Fuse, 2007; Lardiere, 2006, 2007). This raises the question of whether L2 learners have fully internalised the representations of the agreement morphemes in English, and if not, what the potential reasons could be. This study investigates two factors that have received relatively little attention in L2 speech comprehension studies: perceptual salience due to (i) the overtness of the violation (errors of omission vs. commission), and (ii) the prosodic context of the target word (utterance-medial vs. utterance-final). Although these factors have been shown to have an impact on L1 speaker's sensitivity to S-V agreement violations during sentence comprehension, it is not known whether MLEs are sensitive to such perceptual salience. Investigating these factors may shed light on our understanding of the factors underlying the persistent difficulty that MLEs have with S-V agreement. Furthermore, given the increasing numbers of MLEs working and studying in English-speaking countries, understanding how they process English grammatical morphemes may have important social and educational implications.

Explanations for L2 difficulties with grammatical morphology

The difficulties that L2 learners have with language have been commonly addressed in the framework of three L2 neurocognitive processing accounts which posit that L2 sentence comprehension may vary as function of L2 proficiency. While some researchers hold the view that the processes underlying L1 and L2 are the same (e.g., MacWhinney, 2012) others argue the processes are fundamentally different (Bley-Vroman, 1989) or that the processes gradually change from heavily relying on L1 to relying on L2 processes (e.g., (Ullman, 2001). Although these views have different implications for sentence processing, they all focus on rule-governed grammatical aspects and/or lexical-semantic processes. The roles of other mechanisms such as those involving the processing of phonological/prosodic information are not specified. As a result, very little is known about whether MLEs use other types of information to process grammatical morphemes during on-line sentence comprehension (e.g., Johnson & Newport, 1989; Jiang, 2004; Chen et al., 2007; Xue et al., 2013).

Besides the neurocognitive accounts, L2 learners' difficulties with grammatical morphology have also been explained in terms of the degree of similarity between the target L2 and the learners' native language (L1) (e.g., Hawkins, 2001;Franceschina, 2005;Tokowicz & MacWhinney, 2005). It is assumed that L2 linguistic structures, which do not occur in the learners' L1, will be challenging to learn. Thus, given that Mandarin and English have different phonological (phonotactic) and morphological structures, learning the 3rd person singular –s is expected to be difficult for MLEs. While English allows for a range of singleton and cluster codas, including fricatives, Mandarin only has nasal coda consonants and no fricative codas (Broselow, Chen, & Wang, 1998; Duanmu, 2007; Broselow & Xu, 2009). Furthermore, while English uses inflectional morphemes, Mandarin does not have inflectional morphemes at all (Liu, Bates, & Li, 1992). Thus, the challenge that MLEs have with the English inflectional 3SG morpheme –s is exacerbated by the difficulty of producing and/or perceiving coda consonants that are not permitted in Mandarin, e.g., word-final –s morphemes in cluster codas (Hout, Hulk, Kuiken, & Towell, 2003; Lardiere, 1998, 2000) 2006; Rattanasone & Demuth, 2014). Furthermore, challenges with comprehension are often associated with morphological-structure differences between the two languages (Chen, Shu, Liu, Zhao, & Li, 2007; Guo, Guo, Yan, Jiang, & Peng, 2009; Jiang, 2004; Xue et al., 2013). As a result of these differences between Mandarin and English, a major question being debated in this area is how MLEs compute subject-verb (S-V) agreement information given their prolonged challenge with the 3SG? This question is important given the role played by the 3SG in English—marking S-V agreement in the present tense.

Subject-verb agreement and sentence processing

Agreement is one of the phenomenon that enables speakers to compute grammatical relations between words to achieve successful sentence comprehension (Nicol, Forster, & Veres, 1997). For example, when presented with sentences such as *(*The boy often cook on the stove* or *The boys often cooks on the stove)*, English speakers will know that these sentences are ungrammatical because of the agreement mismatch between the subject noun-phrase and the verb. In the first sentence, the S-V agreement morpheme has been omitted, whereas in the second sentence a superfluous –s has been added. Although S-V-agreement may be considered less important in English compared to morphologically rich languages such as, Spanish or Italian (see MacWhinney & Bates, (1989); MacWhinney, Bates, & Kliegl, (1984) on this view), it has been shown that native English speakers are highly sensitive to inappropriate use of S-V agreement (e.g., Coulson, King, & Kutas, 1998; Dube, Kung, Peter, Brock & Demuth, submitted; Hagoort, Brown, & Groothusen, 1993; Kaan, 2002; Nicol, Forster, & Veres, 1997; Pearlmutter, Garnsey, & Bock 1999; Osterhout & Mobley, 1995; Wagers et al., 2009). Sensitivity to S-V agreement violations has therefore been considered to show that language users have internalised the representations of inflectional grammatical morphology.

According to Li et al. (2014), MLEs' failure to signal S-V agreement reflects that grammatical morphology is not integrated into their L2 syntactic representations. Thus it has therefore been argued that the morphological constraints of the Mandarin language hinder MLEs' acquisition and comprehension of L2 grammatical morphology. For example, Jiang (2004) examined MLEs' morphological competence through a self-paced reading comprehension task involving nominal subject-verb agreement violations (e.g., *The word/word*_**s**_ *on the screen* ------- (*was/were*) *difficult to recognize*). They did not observe any reading time differences between sentences with grammatical and ungrammatical agreement, but did observe differences when the violations involved pronoun subject-verb disagreement (e.g., *I told you I/*she am a professor of English*). They interpreted insensitivity to the plural morpheme –s on the subject noun, as an indication that MLEs' morphological knowledge is not integrated into their L2 grammatical competence due to L1-L2 differences. However, MLEs insensitivity to grammatical morphemes could be potentially influenced by factors other than syntactic knowledge.

The role of perceptual salience in L2 sentence comprehension

There is now accumulating evidence suggesting that the relative perceptual salience of the grammatical morpheme, as a function of the phonological/prosodic structure of English, impacts on listeners' sensitivity to the 3SG –s, (e.g., Sundara, Demuth, & Kuhl, 2011; Dube et al., submitted; Johnson & Newport, 1989; Peretokina, Best, Tyler, & Di Biase, 2014, 2015). For example, it has been observed that L1 children typically produce 3rd person singular morphemes more reliably when the verb occurs utterance-finally compared to utterance medially (Song, Sundara,& Demuth, 2009). This has been related to the fact that syllables (and morphemes) occurring utterance-finally are longer in duration than those that occur utterance medially (Hsieh, Leonard, & Swanson, 1999; Oller, 2005; Wagner &Watson, 2010; Wightman et al., 1992). This raised the possibility that children might perceive these longer utterance final morphemes better than those that occurred utterance medially. To test this hypothesis, Sundara et al. (2011) investigated 2-year-olds' sensitivity to grammatical (inflected) vs. ungrammatical (uninflected) 3rd person singular verbs in utterance-final versus utterance-medial position in an auditory visual-fixation task (e.g. *Now he <u>cries</u>* vs. **Now he <u>cry</u>*;. *He <u>cries</u> now* vs. **He <u>cry</u> now*).

As expected, infants showed a difference in looking times to the grammatical vs. ungrammatical sentences when the verb and morpheme occurred utterance finally, but not utterance medially. They interpreted these findings to suggest that the increased duration of the –s morpheme at the end of the utterance provides extra acoustic cues for listeners, enhancing infants' ability to detect its presence, and ungrammatical absence. That is, infants were more sensitive to the missing morpheme utterance-finally compared to utterance medially due to the greater perceptual salience of the morpheme in durationally longer utterance final position. These results have been corroborated by recent findings from an event-related potentials (ERPs) study in which Dube et al. (submitted) in L1 English-speaking adults (see below for details).

In line with these L1 perception studies, Peretokina et al. (2015) have also demonstrated that MLEs are sensitive to durational differences despite the different morphological structures of Mandarin and English. Using a phoneme-detection task, Peretokina et al. (2015) investigated whether utterance position affected MLEs' sensitivity to the plural morpheme –s (e.g., *Here the nights are cold* vs. *I don't like cold nights*). They observed that MLEs, like native-speakers of English, took longer to respond when the morpheme –s appeared utterance-medially than finally. However, the MLEs were also much slower than the English speakers. The authors interpreted their results to indicate that utterance position influences the perception of the plural –s in both MLEs and English speakers, but that the effects were more profound for MLEs in utterance-medial position. Therefore they argued that the perception of plural –s cannot be exclusively explained in terms of the presence or absence of plural morphology in Mandarin, but can be enhanced with extra acoustic cues utterance finally.

Although the reaction-time data from Peretokina et al. (2015) have provided useful insights on the role of perceptual salience in L2 perception of morphosyntactic information, it has been known that reaction-times provide 'after the effect' decision-making processes, and thus do not directly reflect on-line processing. It therefore remains unknown how perceptual salience modulates MLEs' processing of S-V agreement during on-line sentence comprehension (see recent reviews on L2 processing advocating for the need for more studies using fine-grained on-line measures e.g., Kotz, 2009; van Hell & Tokowicz, 2010).

The current study therefore examines whether perceptual salience influences how MLEs process S-V agreement during on-line sentence comprehension, using ERPs measures.

Subject-verb agreement processing and ERPs

ERPs have been shown to be sensitive to the dynamics of L1 and L2 sentence comprehension (e.g., Osterhout & Mobley, 1995; Weber-Fox & Neville, 1996, respectively). The ERPs measure scalp-recorded electrophysiological brain activity that is time-locked to the presentation of target stimuli and. Due to their excellent temporal resolution, they are ideally suited for exploring how different types of information are processed during on-line sentence comprehension (Luck, 2014). The traditional understanding behind the ERPs is that by observing the multidimensional data points of the ERP waveforms (e.g., their polarity, amplitude, latency, and scalp distribution); we can deduce the nature of the processes underlying language processing. For example, the processing of S-V agreement violations has been often shown to evoke two ERP components.

The LAN often occurs between 300 and 500 ms after the onset of the violation and has been observed to have either a left anterior scalp distribution. (e.g., Coulson, King, & Kutas, 1998; Friederici, Pfeifer, & Hahne, 1993; Gunter, Friederici, & Schriefers, 2000; Osterhout & Holcomb, 1992; Hahne & Friederici, 1999; Kaan, 2002). The P600 typically occurs between 500 and 1000 ms after violation onset and is often observed with a centro-posterior scalp distribution (e.g., Osterhout & Mobley, 1995) or with a broad scalp distribution (e.g., Molinaro et al., 2011). The P600 has been observed after the LAN (a biphasic LAN/P600 effect) or on its own (e.g., Coulson et al., 1998; Hagoort & Brown, 2000; Kaan et al., 2000; Osterhout & Mobley, 1995). Based on the evidence from previous studies, which reported evidence that correlated morphosyntactic processing to the L(AN) and the

P600, Friederici (2002) proposed a neuro-cognitive model of auditory sentence comprehension which instantiates the syntax-first view discussed above.

According to this model, the LAN observed from 300-500 ms is correlated with the second phase of syntactic processing, when lexical-semantic and morphosyntactic information are processed to assign thematic roles. It is also understood to reflect the detection of morpho-syntactic violations such as agreement mismatch (Batterink & Neville, 2013; Bornkessel & Schlesewsky, 2006; Friederici et al., 1993; Hagoort, Wassenaar, & Brown, 2003; Kos, Vosse, Van Den Brink, & Hagoort, 2010; Osterhout, Holcomb, & Swinney, 1994; Osterhout et al. 1996). On the other hand, the P600 effects observed from 500-1000 ms are correlated with the last phase of processing, when the different types of information are integrated. This effect is generally understood to reflect syntactic reanalysis or repair (e.g., Friederici, 2011; Gunter, Friederici, & Schriefers, 2000; Hahne & Friederici, 1999, 2002).

However, findings from a number of morphosyntactic studies have challenged this modular-specific view. For example, while the processing of morphosyntactic violations is expected to elicit LAN and/or P600 effects, some studies have not observe LAN effects (e.g., Hagoort & Brown, 2000; Kaan, Harris, Gibson, & Holcomb, 2000; Kos et al., 2010; Osterhout et al., 1994). Others have reported N400 effects instead of the traditional LAN effects, e.g., aspect marking in Hindi (Choudhary, Schlesewsky, Roehm, & Bornkessel-Schlesewsky, 2009), and gender marking in Spanish (Wicha, Moreno, & Kutas, 2004). Still, others have observed different P600 latencies and amplitudes as a function of different morphological features (e.g., gender vs. number or person+gender) (e.g., Nevins, Dillon, Malhotra, & Phillips, 2007). The presence/absence of the P600 has also been observed to vary as a function of whether the task was passive or active (e.g., Kolk & Chwilla, 2007) or whether the violation was syntactically simple or complex (e.g., Kutas & Hillyard, 1983; O'Rourke & Van Petten, 2011).

Nonetheless, it has been suggested that there is generally a strong correlation between grammatical violations and the presence of a L(AN) and/or P600 (Molinaro et al., 2011). The traditional view that L1 morpho-syntactic agreement violations elicit L(AN) and/or P600 components provides a background against which to compare L2 processing. However, it should also be noted that results from L1 research have shown that these components vary in latency, amplitude and scalp distribution due to other factors that interact with morpho-syntactic processing. As shown in the brief review of previous L1 studies in **Table 1**, the ERP components reported in these studies vary due to the different experimental paradigms used in these studies (e.g., presentation modality, complexity of stimuli, type of task, type of agreement violation and the position of the violation).

For example, **s**tudies that have used the visual modality report later LAN and P600 onset latencies (around 300 and 500 ms, respectively) (e.g., Coulson et al., 1998; Osterhout & Mobley, 1995) compared to studies that used the auditory modality (around 140-270 and 300-500 ms, respectively) (Shen et al., 2013). The latency differences of the negativity are generally assumed to reflect the ease of detecting the violation whereas those of the P600 reflect how fast the revision or reanalysis of the violation is implemented (Friederici, 1998). Given that the auditory modality has been generally been observed to yield earlier ERP latencies, it has been suggested that modality of presentation impacts on the processing of S-V agreement violations (Hasting & Kotz, 2008). This is one of the issues that the present study seeks to explore given that modality effects in MLEs L2 morphosyntactic processing have only been reported previously in one study that used off-line grammaticality measures (Johnson, 1992).

Also of interest to this study is the observation that the L(AN) and/or the P600 components reported in previous L1 studies varied due to the type of stimulus manipulation used (e.g., errors of omission vs. errors of commission) and utterance-position (medial vs final). Both types of manipulation have been shown to impact on the perceptual salience of the S-V agreement, influencing listeners' sensitivity to the morphosyntactic violations during on-line comprehension. For example, Dube et al. (submitted) showed that in utterance-medial position, agreement violations involving errors of omission (e.g., **the boy often* <u>*cook*</u> *on* ..) only elicited a bilateral anterior negativity (AN), whereas the more noticeable/more perceptually salient errors of commission (e.g., **the boys often* <u>*cooks*</u> *on …)* elicited a P600 effect. However, in the utterance-final condition, both types of errors (**the boy often* <u>*cook.*</u> vs. **the boys often* <u>*cooks.*</u>) elicited a P600. This was broadly distributed for the errors of commission, and centro-posteriorly distributed for errors of omission.

These results were interpreted to reflect the fact that agreement violations in contexts with higher perceptual salience (errors of commission and utterance-final position) elicited more robust effects compared to errors of omission and utterance-medial position. Thus, even though native speakers of English are expected to show robust sensitivity to all agreement violations due to excellent L1 grammatical knowledge, these results indicate that the perceptual salience of the grammatical morphemes influenced how they were perceived and processed during on-line auditory comprehension.

Table 1: L1 English ERP studies on the processing of S-V agreement violation (*studies used inflectional agreement*).

Study/Language	Modality	Type of agreement violation	Utterance Position	Example of stimuli	ERP Effect/ latency (ms)	
					Negativity	**P600**
Kutas & Hillyard, 1983 (English)	visual	omission	medial	As a turtle grows its shell grows/*grow too.	LAN 300-600	Not reported
Osterhourt & Mobley, 1995 (English)	visual	commission	medial	The elected officials hope/* hopes ….	LAN 300-500	Centro-posterior 500-800
Osterhout et al., 1996) (English)	visual	commission	medial	The doctors believe/*believes …….	No negativity	Centro-posterior 500-800
Coulson et al., 1998) (English)	visual	omission + commission	medial	Every Monday he mows/*mow the…. They sun/*suns themselves on …….	LAN 300-500	Anterior-posterior 500 – 800
Kaan et al., 2000 (English)	visual	commission	medial	Emily wonders whether the performers in the concert imitate/* imitates a …..	No negativity	Central maximum 500-700 Posterior maximum 700-900
Shen et al., 2013 (English)	auditory	omission	medial	Larry pushes/*push his ……	AN 150-300	Posterior 700-900
Dube et al., submitted (English)	auditory	omission	medial	The boy often cooks/*cook on …..	AN 270-340	No positivity
			final	The boy often cooks/*cook.	No negativity	Centro-posterior 470-570
		commission	medial	The boys often cook/*cooks on …..	No negativity	Centro-posterior 590-670
			final	The boys often cook/*cooks.	No negativity	Broad 310-770

It is therefore possible that MLEs' challenges with the comprehension of grammatical morphemes may be influenced by how they auditorily perceive the morphemes in continuous speech. Examining how *type of violation* and *utterance position* influence brain responses to S-V agreement violation will help us determine the extent to which perceptual salience is an important factor in L2 morphosyntactic processing.

The literature reviewed above demonstrates that L1 ERP research has explored several methodological issues that may influence morphosyntactic processing during on-line comprehension. However, the picture is not the same in L2 processing research. Most studies have focused on how L2 learners process syntactic information (phrase structure, word order), and how factors such as age of acquisition, L2 proficiency, and L1-L2 linguistic differences impact on syntactic processing (e.g., Friederici, Steinhauer, & Pfeifer, 2002; Hahne, 2001; Mueller, Hahne, Fujii, & Friederici, 2005; Weber-Fox & Neville, 1996). More findings from recent studies suggest that L2 proficiency plays a more important role in L2 learners' processing of syntactic information than L1-L2 linguistic differences (e.g., Foucart & Frenck-Mestre, 2012; McLaughlin et al., 2010; Ojima, Nakata, & Kakigi, 2005; Rossi, Gugler, Friederici, & Hahne, 2006; Tanner, Mclaughlin, Herschensohn, & Osterhout, 2013).

As shown in the brief review of previous L2 morphosyntactic processing studies in **Table 2**, the presence/absence of the L(AN) and/or P600 is modulated by the learners' proficiency levels (also correlated with type and length of exposure). In learners with low proficiency, neither LAN nor P600 effects are reported. Instead, N400 or N400-like effects with posterior distribution are observed (e.g., Rossi et al., 2006; Osterhout et al., 2006). The N400 is a negative-going wave that occurs between 300-500 ms with a centro-parietal distribution and has been argued to reflect lexical-semantic processing (e.g., Kutas &

Hillyard, 1980). Its presence in learners with low proficiency has been interpreted to reflect that learners have memorized the lexical probabilities of the verb forms but have not yet learned the syntactic rule of S-V agreement (e.g., Ullman, 2001). Thus, they use lexical/semantic processes instead.

While the absence of LAN-like effects has been considered a typical ERP pattern for L2 learners with low proficiency, learners with high proficiency have been reported to show native-like P600 or LAN/P600 effects. However, the presence of the LAN/P600 effects in highly proficient L2 learners can also vary due to the morphosyntactic-structure differences between L1 and L2. In particular, instead of a LAN/P600, an N400 effects were observed. For example, using the visual modality, Osterhout et al. (2006) examined how English-speaking learners of French processed S-V agreement violations (similar in L1 & L2) and article-noun number agreement (different in L1 & L2). They observed that learners' ERP responses to S-V agreement progressed from N400 to P600 effects as a function of increased proficiency over time. However, the article-noun number agreement continued to elicit N400 effects despite increased proficiency (see also Foucart & Frenck-Mestre, 2012; Tokowicz & MacWhinney, 2005). Similarly, Xue et al. (2013) used the visual modality to examine how advanced MLEs processed S-V agreement violations (different in L1 & L2) and subject-number agreement in collective nouns (similar in L1 & L2). They observed that ERP responses to S-V agreement violations elicited N400 effects while subject-number agreement violations elicited P600 effects. While the P600 effect is similar to that observed in L1 morphosyntactic processing, the N400 is not usually observed for morphosyntactic violations in L1 studies.

These results have been explained in terms of L1-L2 similarities, whereby MLEs are thought to rely more on lexical-semantic and contextual information (due to L1 influence) than L2 syntactic information for sentence comprehension (Li, Shu, & Liu, 2014). That is, the underlying representations of Mandarin syntax hinders these learners from learning the inflectional morphology in the target L2—a process known as forward transfer (Liu et al., 1992).

In addition to proficiency and L1-L2 differences, it has been proposed that the LAN/P600 effects vary due to type and/or length of L2 exposure. For example, Xue et al. (2013) speculated that lack of sensitivity (P600) to S-V agreement violations may also be due to the learners' type of exposure to English. Although the participants in their study were English majors in their third year of study, they had only been exposed to explicit-classroom training in China, without any form of immersion exposure. Evidence from previous L2 syntactic processing studies has shown that learners with classroom training plus immersion exposure are more sensitive to syntactic violations (e.g., word order) compared to learners with only classroom training (Bowden et al., 2013; Morgan-Short, Steinhauer, Sanz, & Ullman, 2011). It is however not known if immersion exposure may impact on the processing of S-V agreement violations in advanced MLEs.

Table 2: L2 English ERP studies on the processing of morphosyntactic violation (*studies used inflectional agreement*).

Reference	L1-L2 of interest	Participant variables		Modality	ERP effect/latency (ms)		
		Proficiency level	**Type of exposure**		**LAN**	**N400**	**P600**
Xue et al., (2013)	Mandarin-English	advanced	classroom & immersion	Visual	-	N400	-
Chen et al., (2007)	Mandarin-English	advanced	classroom learning	Visual	-	N600	-
Ojima et al., (2005)	Japanese-English Japanese-English	low high	classroom & immersion	Visual	- LAN	- -	- -
Osterhout et al., (2006)	French-English	low intermediate high	classroom learning	Visual	- -	N400 N400 -	- P600 P600
Dowens et al., (2011)	Mandarin-Spanish	advanced	classroom learning	Visual	-	-	P600
Dowens et al., (2010)	English-Spanish	advanced	classroom & immersion	Visual	LAN	-	P600
Rossi et al., (2006)	German-Italian Italian-German German-Italian Italian-German	low low high high	classroom learning	auditory	- - LAN LAN	- - - -	P600 (small) P600 (small) P600 P600

This review of previous ERPs studies shows that there are various factors that influence the processing of morphosyntactic information during online sentence comprehension. As a result, an alternative view to Friederici's (2002) was proposed—the internal models of sentence processing (e.g., Bornkessel-Schlesewsky & Schlesewsky, 2009; Bornkessel-Schlesewsky, Schlesewsky, Small, & Rauschecker, 2015; Pickering & Garrod, 2013). According to this view, the variable realizations of the ERP components can be accounted for in terms of the nature of the incoming stimuli and the speaker's ability to use predictive processes to match the stimuli to underlying representations. The predictions may be based on the available syntactic and non-syntactic information or the speakers's previous encounters with the given stimuli. All these factors may necessitate the engagement of different cognitive processes which may in turn result in quantitatively or qualitatively different ERP responses, despite similar underlying neural functions. For example, in processing S-V agreement violations that vary due to perceptual salience, different cognitive processes may be engaged for processing more perceptually salient versus less perceptually salient phenomena (predictive processing), yet the underlying morphosyntactic process remains the same. Thus, the question of whether different types of agreement violation and utterance position influence the processing of S-V agreement violations is important, given that these factors have been used variably in previous studies.

Taken together, the issues arising from previous L1 and L2 ERP research indicate that more research is needed to understand the factors that modulate S-V agreement processing in advanced MLEs. The need for more on-line studies of proficient L2 learners, with L1 backgrounds that are distant from the target L2, is also echoed by some recent reviews of L2 processing (e.g., Kotz, 2009; Steinhauer et al., 2009; Van Hell & Tokowicz, 2010). Such studies may help us understand the factors that play a more significant role in L2 sentence comprehension. The present study therefore seeks to contribute towards L2 morphosyntactic-processing research. To achieve this, we investigated whether MLEs immersed in an English-speaking country were sensitive to S-V agreement as a function of perceptual salience due to type of agreement violation and utterance-position.

Based on previous L2 studies, we hypothesized that MLEs who have been residing in Australia for 2-3 years would process S-V agreement violations in a native-like manner. We therefore expected that MLEs immersed in an English-speaking country will show native-like sensitivity to the S-V agreement violations and thus elicit P600 effects. However, if type of exposure (immersion) does not influence how MLEs process morphosyntactic information, we would expect the S-V agreement violations to evoke N400 effects (in line with Xue et al., 2013).

Based on previous L1 studies, we further hypothesized that MLEs' sensitivity to S-V agreement violations will be influenced by perceptual salience due to type of agreement violation and utterance position (Sundara et al., 2011; Dube et al., submitted). We therefore expected that the amplitude and latency of the P600 effect will further vary due to type of violation and utterance position. More specifically, we predicted that errors of omission and commission that occurred in utterance-final positions will elicit more robust P600 effects compared to errors in utterance-medial positions. Given that errors of commission and utterance-final positions both enhance the perceptual salience of the violation, we expected that type of agreement violation and utterance position will have an additive effect. We therefore expected that the P600 elicited by errors of commission in utterance-final position will be more robust compared to that elicited in other conditions.

Methods

Ethics statement

The Ethics committee for Human Research at Macquarie University approved the experimental methods used in this study. Written informed consent was obtained from all participants before the experiment began.

Participants

Thirty-two Mandarin-English L2 speaking adults were recruited from the university student population to participate in this study in exchange for course credits or $20. All completed a brief questionnaire which showed that they were right-handed and had no history of hearing or learning disorders, as well as a Language History Questionnaire: 2.0 (Li, Zhang, Tsai, & Puls, 2014). Participants were then screened for their comprehension and production of inflectional morphology through an elicited sentence imitation task comprising of 30 sentences. Ten of the sentences involved the 3rd person singular in utterance-medial, another ten in utterance-final positions, and another ten were filler sentences. Most of the participants performed well in this task, indicating that they were able to remember and reproduce the S-V agreement morpheme. However, four participants were excluded from the analysis as they made more than six out of twenty errors in the screening task. A further 12 participants were also excluded in the final analysis due to excessive ERP artifacts (e.g. sweating, or excessive movements). Compare to the previous L1 study, more participants were excluded in this study. A potential reason for the increase in exclusion rate is because most of our L2 participants were accounting students, who were not familiar with language experiments. As a result, they may not have been comfortable with the long language experiment, hence excessive movements and sweating. **Table 3** provides a summary of the information on the 16 participants included in the final analysis.

Table 3: Participant Information

	Mean (range)
No. of participants	16 (11 female)
Age	25.5 years (20-36)
Age of exposure to English	11.5 years (5-13)
Length of immersion (LOI)	27.4 months (22-36)
Self-rated English proficiency, scale 1-7 (range)	
Reading	5.1 (4-6)
Speaking	4.4 (3-5)
Writing	5 (4-6)
Listening	4.0 (3-5)
IELTS scores (range)	6.8 (5.5-7.5)
Articulation screener (% correct)	
Utterance-medial	90%
Utterance-final	94%

Stimuli

The stimuli used in this study were the same as those used by Dube et al. (submitted) with English speaking adults. The auditory stimuli included 50 CVC target verbs that could be used intransitively in both sentence medial and final positions (e.g., *The boy often cooks on the stove* vs. *The boy often cooks*). This ensured that the target verbs could be used in both utterance medial and utterance final conditions respectively. Only those verbs with high-medium frequency were selected to ensure familiarity and to facilitate processing. The criteria for lexical frequency was that the verbs had between 1 and 3 counts on the SUBLEX $Log_{10}CD$ (Hofmann, Stenneken, Conrad, & Jacobs, 2007). In addition, only those verbs that ended with the voiceless coda stops /p/, /t/, /k/ were selected to make sure that the inflected –s morpheme was always realized in the same allophonic condition (e.g., as /s/). This facilitated subsequent splicing of the materials and ensured that all morphemes in each condition had the same length (see below). As the stimuli were later paired with a picture to provide a visual context while listening to the sentence, the verbs also had to be highly imageable.

The verbs were inserted into carrier sentences that were composed of monosyllabic words, thereby controlling for utterance length and processing load. The carrier sentences had a singular vs. plural subject to enable manipulation of the type of agreement violation (errors of omission vs. commission). The verbs appeared in the middle vs. end of the carrier sentence to create the utterance-medial vs. utterance-final conditions, respectively (see **Table 4**). In utterance-medial position, the verb was always followed by a preposition with a vowel onset to avoid masking of verb-final -s. All sentence stimuli were accompanied by cartoon pictures that were designed by a professional cartoonist (see example in **Figure 1**). The drawings had a constant level of visual complexity to avoid distracting details. The purpose of the pictures was to sustain participants' attention, and keep their eyes focused on the computer display to minimize head movement (muscle movements introduce artefacts to the ERP data).

Table 1: Experimental conditions

Utterance position	**Type of agreement Violation**	**Example**
Medial	Omission	The boy often <u>cooks/*cook</u> on the stove
	Commission	The boys often <u>cook/*cooks</u> on the stove
Final	Omission	The boy often <u>cooks/*cook</u>
	Commission	The boys often <u>cook/*cooks</u>

*Ungrammatical verb forms are marked in asterisks

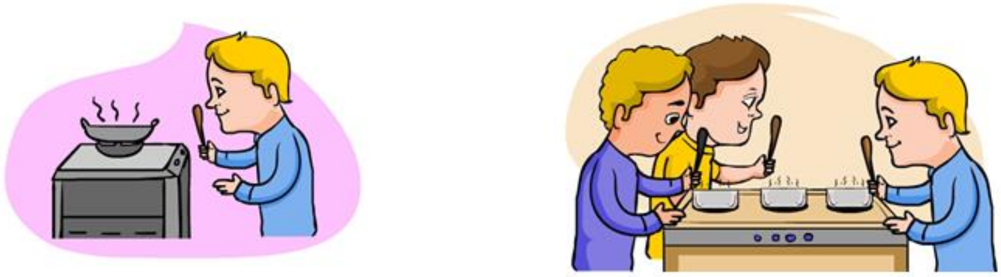

Figure 1: Example of images used for the verb *cook/cooks*.

As shown in **Table 4**, the study employed a 2x2x2 design by crossing Type of agreement, with Utterance position, and with Grammaticality. Each verb therefore appeared in a total of eight conditions, resulting in 50 test items per condition and a total of 400 test items. In addition to the test items, there were 44 catch trials. All catch trials were grammatical and had the same structure as that of the target carrier sentences, but the verbs were not fully controlled for CVC structure (e.g., *eat*). These catch trials were used as a probe task in order to maintain participants' attention during the experiment (see Task and procedure for further details).

Auditory Stimulus Preparation

All grammatical sentences were spoken by a female native speaker of Australian English who was trained in how to produce the sentences. To control for naturalness and intonational constancy, the sentences were read in response to a question and the accompanying picture. For example, all medial sentences were responses to a question like, "*What do the boys often do on the stove*? (Answer: *The boys often cook on the stove*). For the final conditions, the question was "*What do the boys often do?* (Answer: *The boys often cook).* Medial and final conditions were separated into two lists and all sentences within the same list were recorded together. The sentences were recorded using Audacity (Audacity Team) in a sound-attenuated booth with a Behringer C2 microphone and an USB Pre-2 amplifier. The recordings were digitized at a sampling rate of 44 KHz (16 bit; mono). Following the recording, the sentences were normalised using Audition C6 (Adobe Systems) and then extracted into individual sentences using Praat (Boersma & Weenink, 2012).

Instead of recording ungrammatical sentences, we created the ungrammatical stimuli by cross-splicing the grammatical productions from the onset of the verb, as shown in **Table 5**. All sound files were spliced at the zero-crossing from the beginning of the verb using Audition C6 (Adobe Systems). This procedure was meant to minimize the possibility of listeners using any early acoustic cues to distinguish between the grammatical and the ungrammatical condition. Previous studies using the auditory EEG paradigm have observed that recording ungrammatical structures, even with a trained speaker, introduces subtle but systematic slowing in production as well as intonation modifications (Royle, Drury, & Steinhauer, 2013; Hasting & Kotz, 2008). Therefore the splicing procedure was used to avoid possible acoustic differences between grammatical and ungrammatical sentences before the point of violation. All stimuli were later rated for naturalness by a highly trained phonetician.

Table 5: Splicing points and procedure for creating ungrammatical stimuli.

<table>
<tr><th>Source</th><th>Result</th></tr>
<tr><td>The boys often |cook on the stove</td><td>The boys often *cooks on the stove</td></tr>
<tr><td>The boy often |cooks on the stove</td><td>The boy often *cook on the stove</td></tr>
<tr><td>The boys often |cook</td><td>The boys often *cooks</td></tr>
<tr><td>The boy often |cooks</td><td>The boy often *cook</td></tr>
</table>

After splicing the stimuli, we used Audition C6 (Adobe Systems) to examine the waveforms and insert triggers into the individual sound files. We used the end of closure for the coda stops as the time-locking point for all four conditions. This insured the time-locking points for grammatical and ungrammatical sentences were identical in all conditions. The spectrograms in **Figure 2** illustrate the time-locking points for grammatical and ungrammatical conditions respectively. For the analysis, we compared the same verb in grammatical and ungrammatical inflected and uninflected forms across all conditions. By so doing, we controlled for the context preceding the target agreement violation to make sure that the response to the violation was only influenced by the grammaticality manipulation on the target verb (see Steinhauer & Drury, 2012).

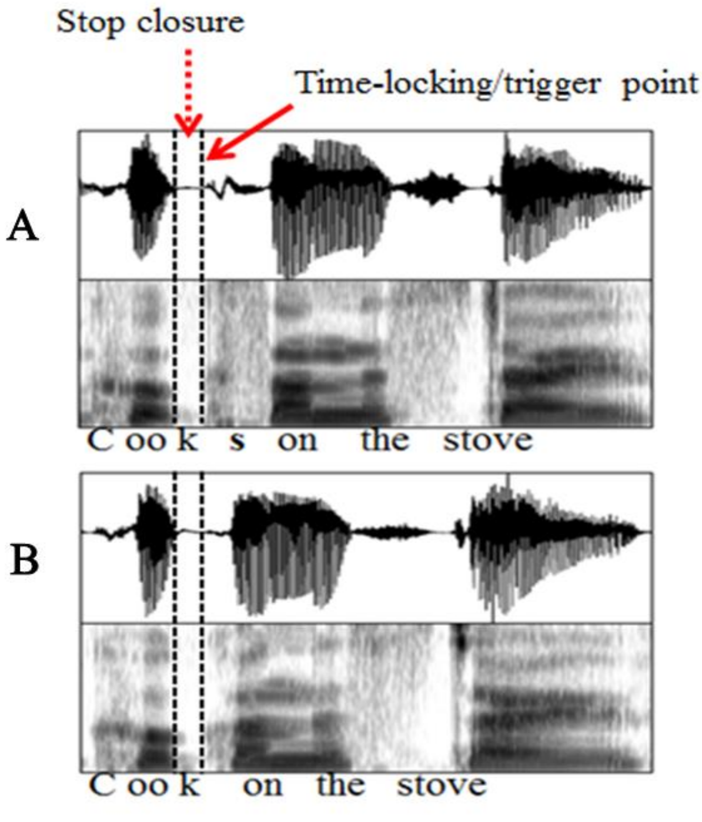

Figure 2: Representative waveforms and spectrograms illustrating the inflected verb (cooks) in (A) and the uninflected verb (cook) in (B). The dotted lines indicate the beginning and end of stop closure, the arrow indicates the time-locking point in both conditions.

Recall that one of the aims of this study was to explore the effects of perceptual salience on the sensitivity to S-V agreement violations. Critical to this effect is the prediction that 3SG –s will be longer utterance-finally due to phrase-final lengthening. We used Praat to conduct acoustic measures of frication duration across all 50 tokens of 3SG –s. In utterance-final position, the 3SG –s was twice as long as the morpheme in utterance-medial position, with a mean duration of 238 ms (SD 28 ms) compared to 114 ms (SD 22 ms). Paired t-tests were used to compare the duration of the –s in medial and final position, and as expected, this difference was statistically significant, $t(49) = -5.989$, $p<.001$. This confirmed that the 3SG in utterance-final position was longer than that in utterance-medial condition.

Task and procedure

Participants were fitted with an electrode cap (Easycap, Brainworks GmbH) while seated in a comfortable chair at a distance of one meter from a CRT computer screen, in a dimly lit sound-attenuated and electromagnetically shielded room. Two audio speakers were positioned on the left and right of the computer screen while the matching images appeared on the screen. EEG signals were recorded continuously as participants listened to sentences. Participants were instructed to listen attentively and to immediately press a response button when they heard the words *cut/cuts* or *eat/eats*. This probe task was used instead of a grammaticality-judgement task to distract participants from concentrating on the grammaticality of the sentences (Dragoy, Stowe, Bos, & Bastiaanse, 2012). The sentences and matching pictures were presented using Presentation (Neurobehavioral Systems) which also recorded responses (hits, misses and false alarms) for the probe task.

The sentences were grouped into medial and final lists where each list had two ten-minute blocks. Each block had 111 sentences with accompanying pictures. The lists were presented separately to avoid mixing the medial and final conditions as they were of different lengths. Recall also that we used verbs that could be either transitive or intransitive, and could take an optional prepositional phrase. By blocking the presentation we controlled for the possibility that the transitivity of the medial condition (verb + prepositional phrase) would influence participants' interpretation of final sentences, as they might then have expected a prepositional phrase in this condition as well. This was particularly important given that one of the aims of this study was to explore utterance position effects (target verb in utterance medial vs. final position), we had to minimize any possible confounds. To control for presentation list effects, the order of the blocks was counterbalanced among the participants so that half of the participants heard the medial-final order first, and the other half had the final-medial order first.

Within each block, the order of sentence/picture presentation was also pseudo-randomised with the constraint that the same verb did not occur consecutively. The picture was presented 500 ms before the onset of the sentence and remained on the screen until the end of the auditory stimulus. The same picture was used for both grammatical and ungrammatical sentence to avoid giving cues about the grammaticality of the upcoming stimuli. Two catch trials were presented at the beginning of the first block of each list, and then occurred after every five to eight target items within the block. A picture of an eye was programmed to appear on the screen ~1000 ms after the end of each sentence to control for eye blinks and remained on the screen for 1000 ms. The sentences had an inter-stimulus-interval of three seconds. Participants were asked to avoid blinking during the presentation of the sentences but to blink when the picture of an eye appeared. They were also asked to sit still during the task to avoid movement artifacts during the EEG recording. A short break was taken at the end of each block. Altogether, the experiment lasted about 60 minutes.

EEG data recording

The continuous EEG was recorded from 64 Ag/AgCl scalp electrodes mounted onto an electrode cap in line with the International 10–20 system (Jasper, 1958: Fpz, Fz, FCz, Cz, CPz, Pz, POz, Oz, Fp1/2, F7/5/3/1/2/4/6/8, FT7/8, FC5/3/1/2/4/6, T7/8, C5/3/1/2/4/6, M1/2, TP7/8, CB1/2, CP5/3/1/2/4/6, P7/5/3/1/2/4/6/8, PO7/5/3/4/6/8, O1/2; see **Figure 3** for an illustration of electrode positions). Additional electrodes were placed above and below the left orbit and on the outer canthus of each eye to monitor electro-oculographic (EOG) activity with a bipolar recording. The ground electrode was positioned between Fpz and Fz. Electrode impedances were adjusted until they were below 10 kΩ. Electrical activity was recorded from both mastoids with the left mastoid (M1) serving as the online reference. The signal from the EEG was digitised at a sampling rate of 1000 Hz and filtered with a .05-100 Hz bandpass filter using a Neuroscan SynAmps2 DC Amplifier (Compumedics Ltd., USA).

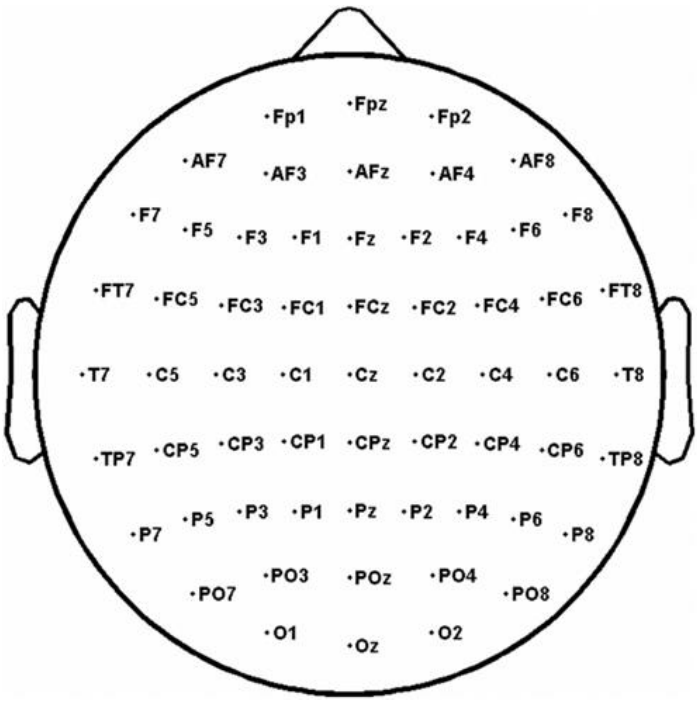

Figure 3: Approximate placement of the 64 electrodes according to the 10-20 system.

EEG data processing

The digitised data were further processed off-line in Matlab (Version R2013b: MathWorks, Massachusetts, U.S.A) using the Fieldtrip toolbox (Oostenveld, Fries, Maris, & Schoffelen, 2010; Version 2014-08-24). The data were epoched into trials of 1000 ms including a 100 ms pre-stimulus interval and then filtered with a Butterworth bandpass of 0.05-20 Hz for the Independent Component Analysis (ICA). Extreme trials with amplitudes larger than ±300 µV were removed before entering all trials into the ICA. The purpose of the ICA was to identify any components resembling eye blinks, horizontal eye movements, noisy channels and other focal artefacts. The identified components were then mathematically removed from the data and signals were back projected to the original unfiltered data. After ICA, each channel was re-referenced to the mean mastoids and low-pass filtered with a 4th-order low-pass Butterworth filter with a cutoff frequency of 30 Hz and roll-off slope of 12 dB/octave. (Note that unlike in the Dube et al's. (submitted) L1 study where we did not use any filter, we had to use a low pass filter for the L2 data because the data was noisy. This might have been due to the fact that most L2 participants were not familiar with language experiments and therefore fidgeted a lot during the experiment).

After filtering, the data were segmented and time-locked to the end of stop closure preceding the critical target morpheme/omission (as illustrated in **Figure 2** above) from 100 ms before to 900 ms after the onset of the critical target and baseline corrected using the 100 ms pre-stimulus interval. Trials with artefacts that exceeded 100 µV, with trends greater than 75 µV, or with abnormal distributions or improbable data exceeding five *SD*s, were also rejected. This procedure removed a total of 166 trials or (0.41% of all trials across participants) from the eight experimental conditions: 21 medial-singular grammatical, 25 medial-singular ungrammatical (omission), 18 final-singular grammatical, 23 final-singular ungrammatical (omission), 17 medial-plural grammatical, 20 medial-plural ungrammatical (commission), 19 final-plural grammatical, and 23 final-plural ungrammatical (commission). There was no reliable difference between the numbers of rejected trials across conditions. The remaining trials in each of these conditions were averaged for each participant and grand averages were then computed for each of the conditions.

EEG data analysis

As discussed in the introduction, different ERP latencies have been reported for studies using the visual vs. auditory modality, and different ERP components have also been observed between L1 and L2 speakers (see literature review **Table 1 & 2**). Therefore, analysing the grand ERP averages using standard time windows associated with LAN, N400 or P600 would not be ideal, as we might miss some effects that falling outside of those time windows. We therefore computed the subject grand averages using non-parametric cluster-based permutation tests (Maris & Oostenveld, 2007). The statistical analysis sought to establish the differences between the overall grammatical and ungrammatical sentences (collapsing type of agreement and utterance position effects). We computed the cluster-based permutation test as described by Maris and Oostenveld (2007). The test first identifies sampling points with t-statistic exceeding a critical threshold ($p < .05$, two-tailed). Clusters are then formed by connecting significant sampling points on the basis of spatial and temporal adjacency. This is done separately for sampling points with positive and negative t-values. The maximum cluster-level test statistics (the sum of all individual t-values within a cluster) are then computed to generate permutation distributions, one for positive clusters and one for negative clusters, based on 1000 random partitions. The significance of a cluster is determined by whether it fell in the highest or the lowest 2.5th percentile of the corresponding distribution.

The aim of this analysis was to test if and when the ERP responses to ungrammatical sentence differ from those to the grammatical ones. Given that this type of analysis d cannot be used for testing interactions between conditions, we used it as a first step of data analysis. We then used these time windows to perform further analysis using repeated-measures multivariate analysis of variance (MANOVA) to statistically test the extent to which type of agreement violation and utterance position influence the on-line S-V agreement processing. However, because we did not observe any significant clusters, we could not get a baseline time window for performing statistics using MANOVA. Instead, we split the data according to the four experimental conditions and computed separate cluster based permutation tests.

The aim of the second analysis was to further explore if there were any differences in time-course between the grammatical and ungrammatical sentences as a function of error type (omission vs. commission) and utterance position (medial vs. final). We assumed that lack of overall grammaticality effects could have been due to differences in individuals' sensitivities to the S-V agreement the manipulations. We present the results from the cluster-based permutations for the different experimental manipulations. Note that the statistical analyses were performed on data that were filtered using a 30 Hz low pass filter.

Results

Effects of type of agreement violation: utterance-medial position

Recall that one of the goals of this study was to test if S-V agreement errors of omission would exhibit the same or somewhat different responses compared to errors of commission. We predicted that both types of errors might be small in utterance-medial position compared to the more perceptually salience utterance-final position. If there were any utterance-medial effects in these MLE participants, we predicted these would occur for the more perceptually salient errors of commission. Here, we report findings from the comparisons of the grand average ERP waveforms for grammatical and ungrammatical trials (errors of omission vs. commission) in utterance-medial position as shown in **Figure 4 and Figure 5.** These figures display the type of agreement effects at representative electrodes (corresponding to locations F3, Fz, F4; C3, Cz, C4, P3, Pz, and P4 in a standard 10–20). Visual inspection of the waveforms indicated that, relative to the grammatical verbs, ungrammatical verbs with *errors of omission* did not elicit different responses. On the other hand, visual inspection shows that errors of commission elicited a negative-going waveform in the Fz electrode followed by a positive-going wave in the Pz electrode. However, cluster-based permutation tests revealed that errors of commission did not yield any significant clusters.

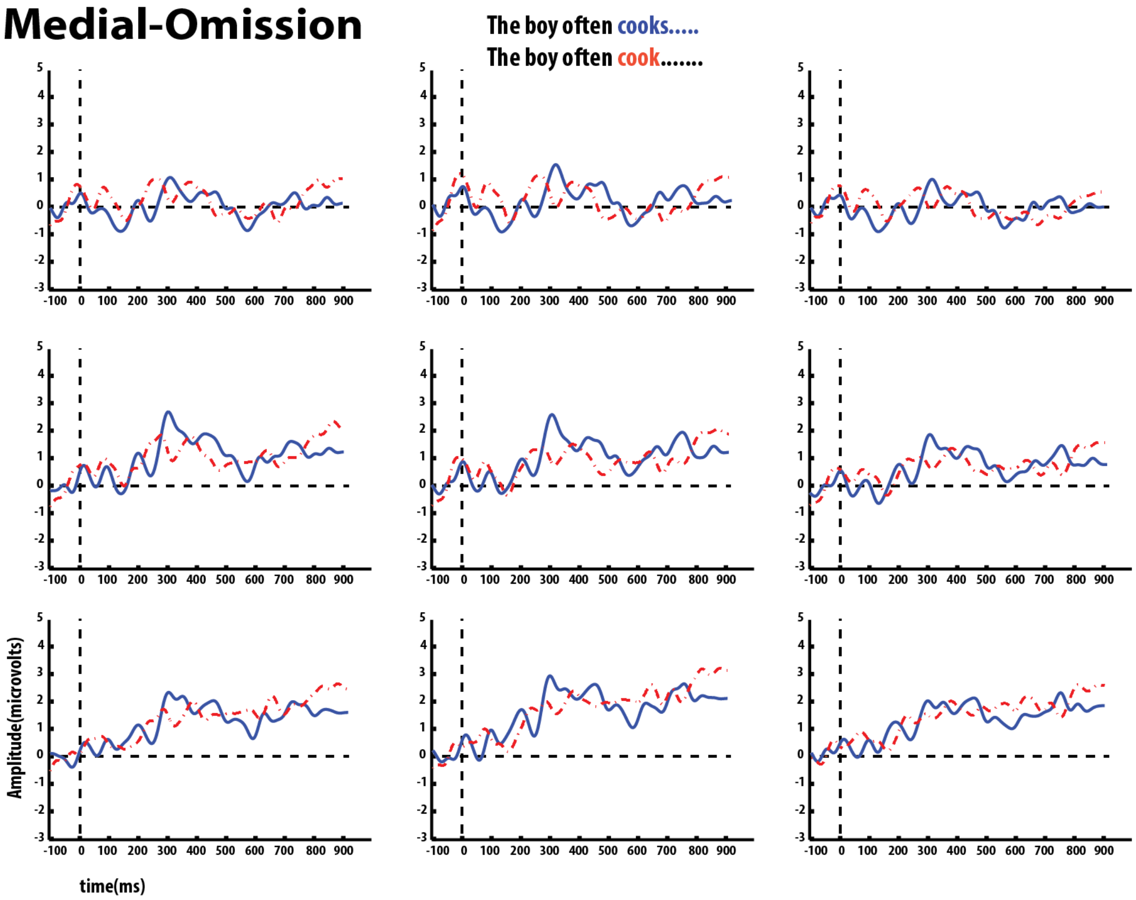

Figure 4: Grand average ERP waveforms for errors of omission in the utterance-medial position at the F3, Fz, F4; C3, Cz, C4, P3, Pz, and P4 electrodes. The first row of the figure shows the anterior electrodes while the second row shows central electrodes and the third row shows the posterior electrodes. The ERPs are time-locked to the offset of the verb-stem (end of stop closure) and positivity is plotted upwards.

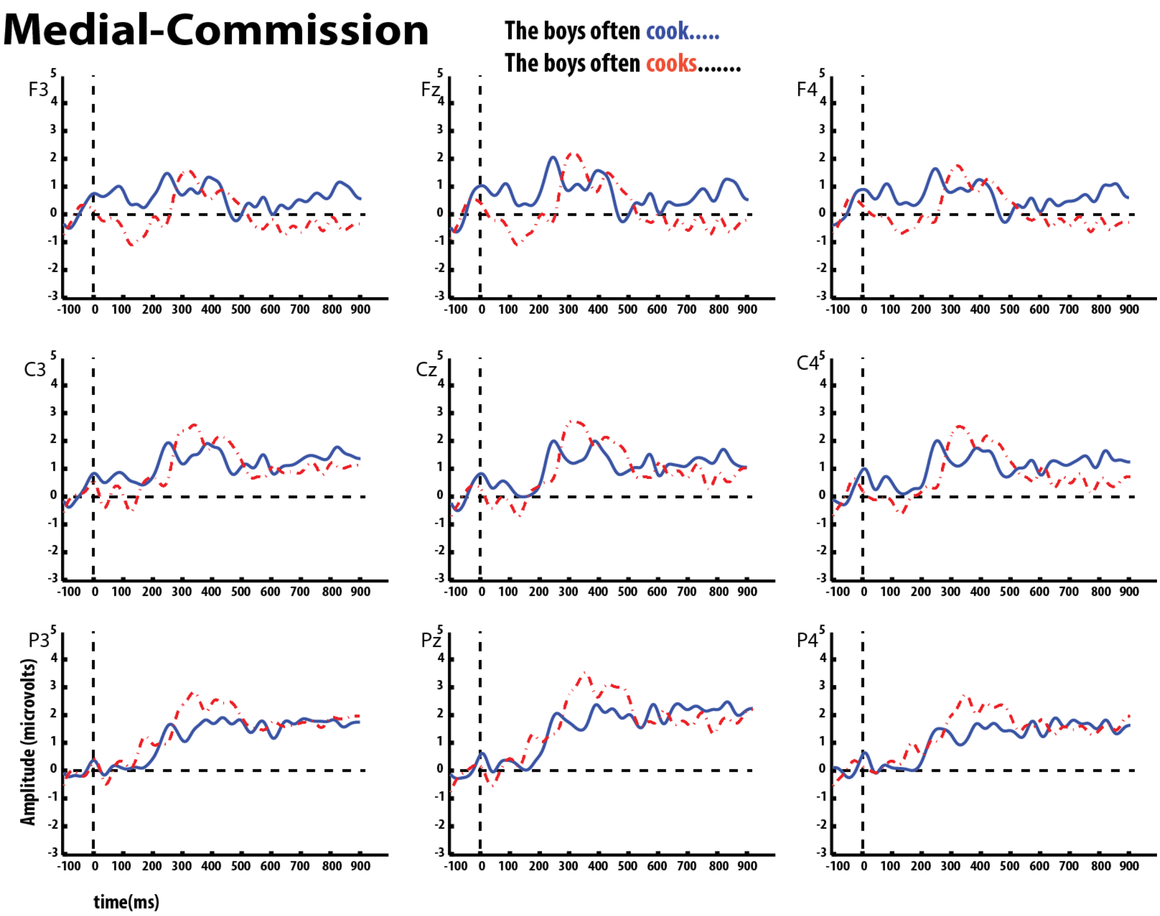

Figure 5: Grand average ERP waveforms for errors of commission in the utterance-medial position at the F3, Fz, F4; C3, Cz, C4, P3, Pz, and P4 electrodes. The first row of the figure shows the anterior electrodes while the second row shows central electrodes and the third row shows the posterior electrodes. The ERPs are time-locked to the offset of the verb-stem (end of stop closure) and positivity is plotted upwards.

We turn now to examine the effects found when the verb occurred utterance-finally, where we anticipated more robust effects due to phrase-final lengthening resulting in greater perceptual salience.

Effects of type of agreement violation: utterance-final position

The grand-average ERP waveforms for grammatical and ungrammatical trials (omission vs. commission) in the utterance-final condition are shown in **Figure 6** and **Figure 7**. Visual inspection of the waveforms showed that, relative to grammatical verbs, ungrammatical verbs with *errors of omission* elicited a negative-going waveform over the posterior electrodes (represented by the Pz electrode). On the other hand, *errors of commission* elicited a positive-going waveform over the fronto-central electrodes. However, cluster-based permutation tests revealed that the contrast between grammatical and ungrammatical verbs with *errors of omission* did not yield any significant cluster. On the contrary, the differences for *errors of commission* yielded a significant positive cluster (p=.020) between 677 and 866 ms in the fronto-central electrode (see topographic maps in **Figure 7** for the significant clusters).

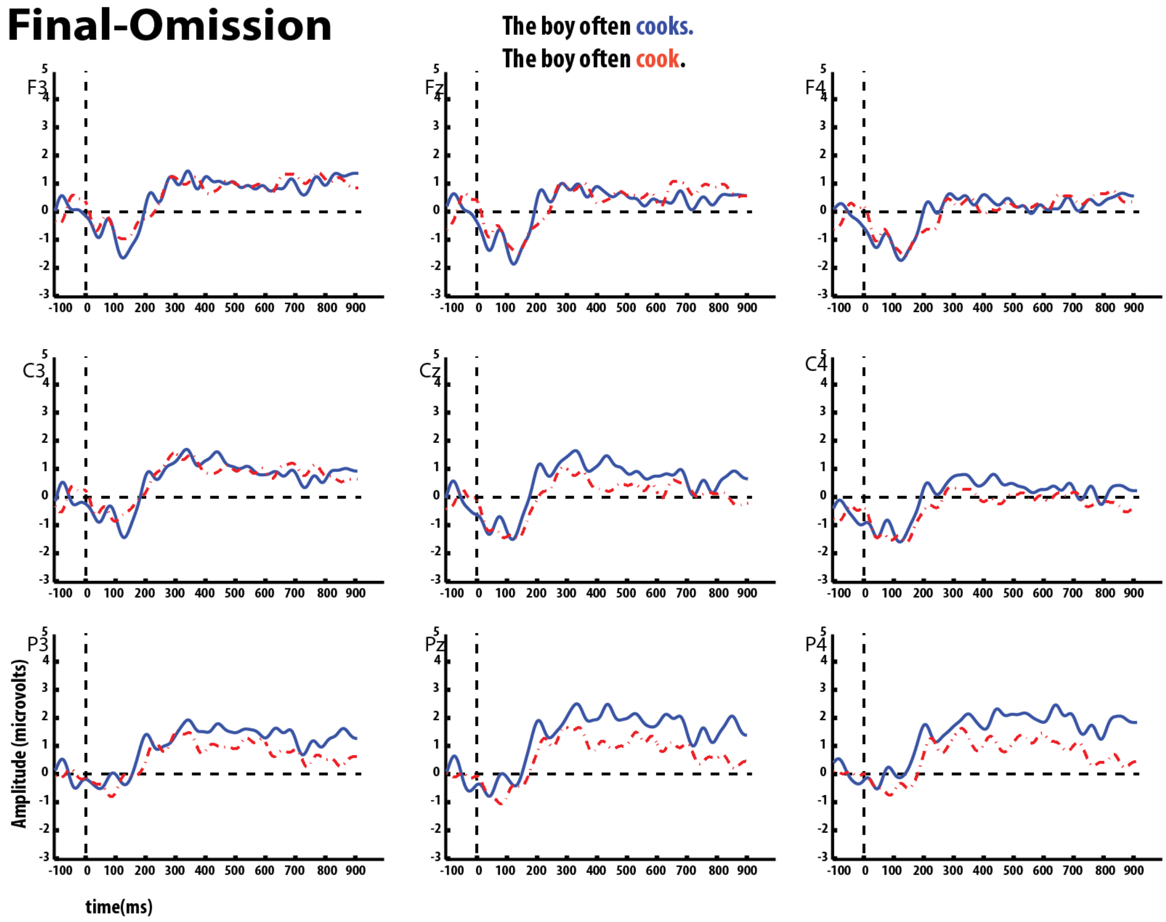

Figure 6: Grand average ERP waveforms for errors of omission in the utterance-final position at the F3, Fz, F4; C3, Cz, C4, P3, Pz, and P4 electrodes. The first row of the figure shows the anterior electrodes while the second row shows central electrodes and the third row shows the posterior electrodes. The ERPs are time-locked to the offset of the verb-stem (end of stop closure) and positivity is plotted upwards.

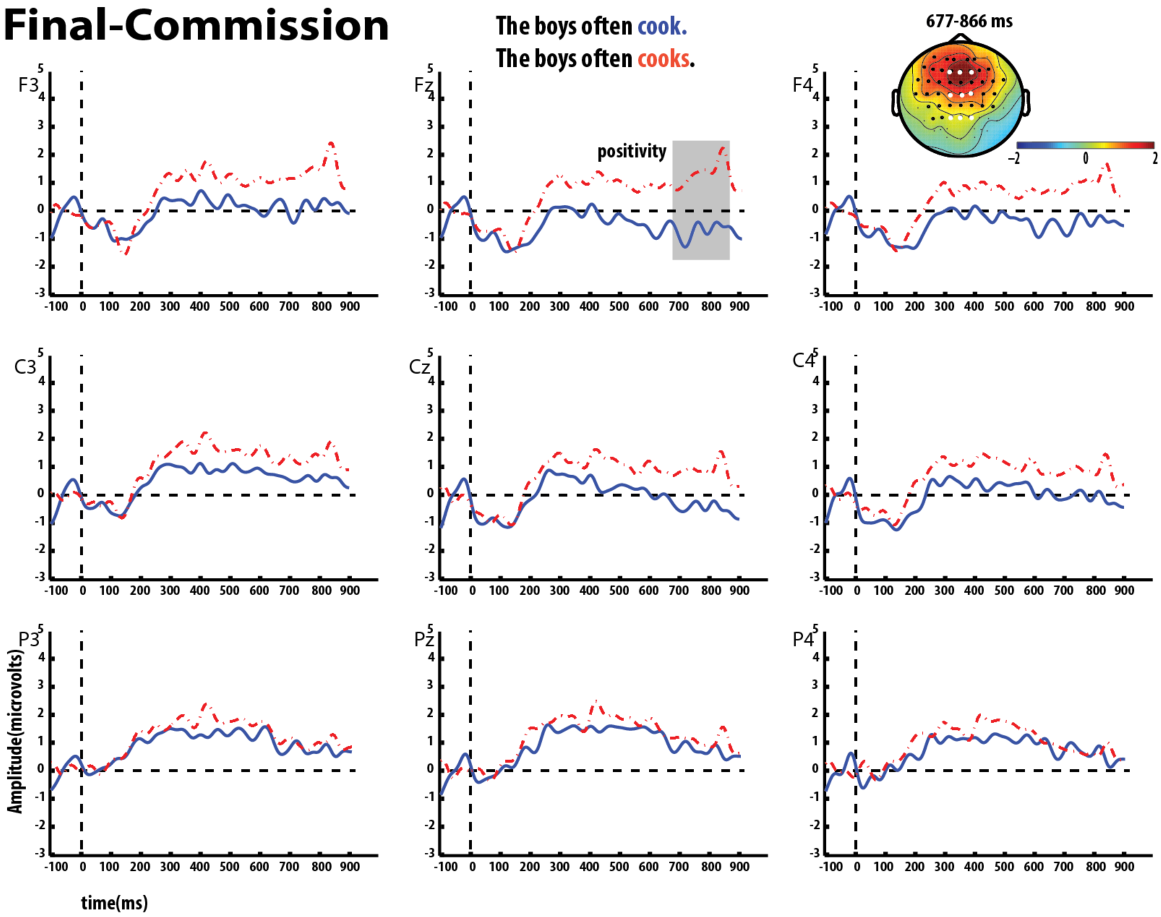

Figure 7: Grand average ERP waveforms for errors of commission in the utterance-final position at the F3, Fz, F4; C3, Cz, C4, P3, Pz, and P4 electrodes and the topographic maps of the significant ERP effects. The first row of the figure shows the anterior electrodes while the second row shows central electrodes and the third row shows the posterior electrodes. The ERPs are time-locked to the offset of the verb-stem (end of stop closure) and positivity is plotted upwards. The topographic maps show brain voltage distributions for the negative and positive clusters. These maps were obtained by interpolation from 64 electrodes and were computed by subtracting the grand averages of grammatical from the ungrammatical conditions. Electrodes in the significant clusters are highlighted with a black circle and the F3, Fz, F4; C3, Cz, C4, P3, Pz, and P4 electrodes are highlighted with a white circle. Time-windows for significant clusters is highlighted in grey over the waveforms.

Previous studies have suggested, however, that a lack of effects in grand mean ERPs could be due to the cancellation of opposite effects elicited by different individuals (e.g., Tanner et al., 2013). This might be especially true in the case of L2 learners, where issues of proficiency may influence results. Therefore, we performed further analysis to examine if there were any individual differences masking sensitivity to perceptual salience in these conditions, and if this might be driven by differences in proficiency, despite the overall homogeneity of these listeners.

Effects of proficiency

Computing the median-split: There are multiple factors that might correlate with grammatical proficiency, e.g., type of language exposure, length of exposure/immersion, self-rating proficiency scores, and performance on Standard English tests. Since we collected information on all of these factors (see **Table 3)**, we could correlate each of these factors with participants' performance on the elicited imitation production screener. The strongest correlation was that between length of immersion and the screener-test scores (*r(16)* = 0.475, *p* = .003; see **Figure 8**). We therefore used this correlation to calculate a proficiency median split for further explorations of the data.

As shown in **Figure 8**, participants were split into high and low proficiency groups using the intersection quotient between the length of immersion (28-36 months) and screener scores (18-20; see figure caption for details). This enabled us to explore if longer length of immersion (and resulting higher proficiency) would correlate with more robust ERP responses to S-V agreement violations. If so, we again expect to find these effects in those conditions that were more perceptually salient, i.e. those with errors of commission and/or those occurring utterance finally. In contrast, we might expect to find smaller and/or fewer effects (i.e. less sensitivity) for those participants with lower grammatical proficiency.

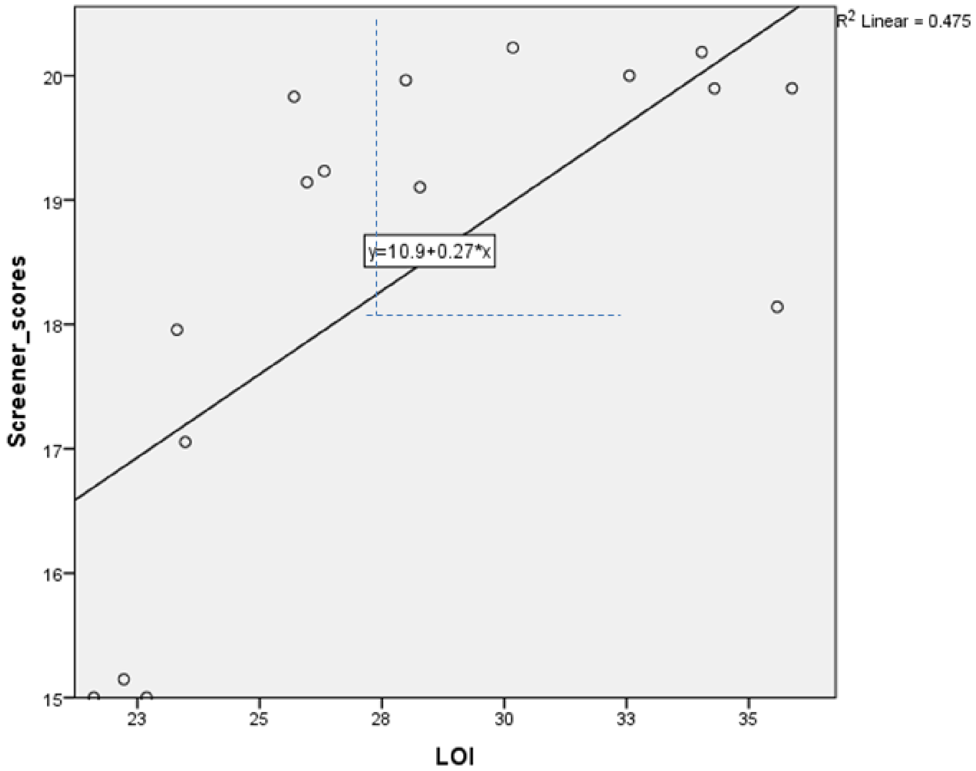

Figure 8: Scatter plot showing the relationship between length of immersion (LOI) and responses to the elicited-imitation production screener task. Small circles represent the distribution of the participants. Dotted line represents the median split by LOI and screener scores. Participants above the horizontal dotted line and to the right of the vertical dotted line fell within the intersection of longer immersion (28-36 months) and high screener scores (18-20), forming the group with higher proficiency (HP). Those outside of the intersection formed the group with lower proficiency (LP).

ERP results for the HP and LP groups: The comparisons of grand-average ERP waveforms from the LP group did not show any differences between grammatical and ungrammatical trials in both utterance-medial and -final positions. In contrast, the high proficiency group showed significant differences for both types of agreement violation in the utterance-final position, but not in the less perceptually salient utterance-medial position (see summary of results in **Table 7**). So we only report in detail the results from the HP group in the utterance-final position.

The grand-average ERP waveforms of the utterance-final grammatical and ungrammatical conditions of the HP group are shown in **Figure 9** and **Figure 10**. Visual inspection of the waveforms indicated that, relative to the grammatical verbs, ungrammatical verbs with *errors of omission* elicited a negative-going waveform over the frontal and posterior electrodes, represented by the Pz electrode. On the other hand, *errors of commission* elicited a positive-going waveform over the fronto-central electrodes represented by the Fz electrode. Cluster-based permutation tests revealed that the contrast between grammatical and ungrammatical verbs with *errors of omission* yielded a significant broad negative cluster (p = .027) between 745 and 900 ms. The contrast observed for *errors of commission* also yielded a significant positive cluster (p = .022) between 765 and 855 ms in the fronto-central electrodes.

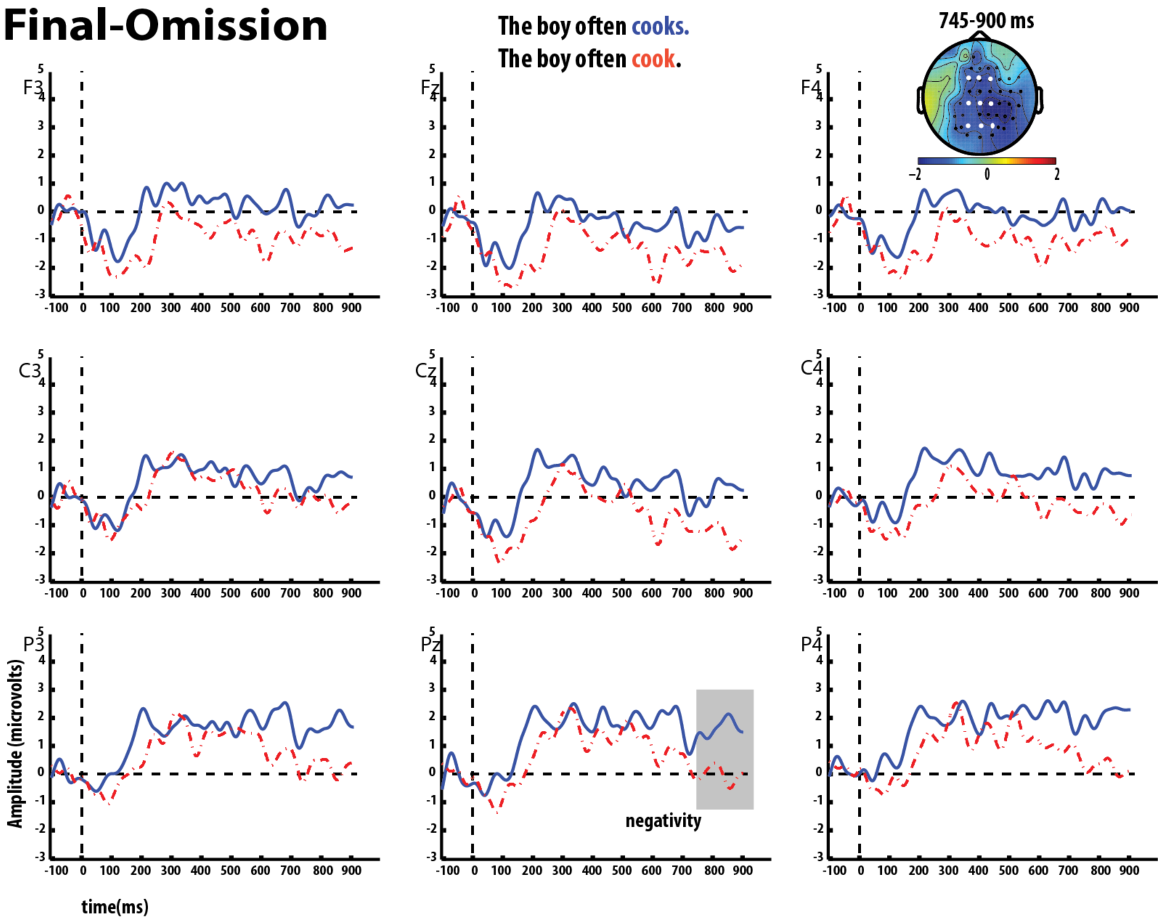

Figure 9: Grand average ERP waveforms for errors of omission in the utterance-final position for the HP group, at the F3, Fz, F4; C3, Cz, C4, P3, Pz, and P4 electrodes and the topographic maps of the significant ERP effects. The first row of the figure shows the anterior electrodes while the second row shows central electrodes and the third row shows the posterior electrodes. The ERPs are time-locked to the offset of the verb-stem (end of stop closure) and positivity is plotted upwards. Time-window for significant clusters is highlighted in grey over the waveforms. The topographic maps next to the ERP waveforms show the voltage distribution of the respective significant cluster. These maps were obtained by interpolation from 64 electrodes and were computed by subtracting the grand averages of grammatical from the ungrammatical conditions. Electrodes in the significant clusters are highlighted with a black circle and the Fz and Pz electrodes are highlighted with a white circle.

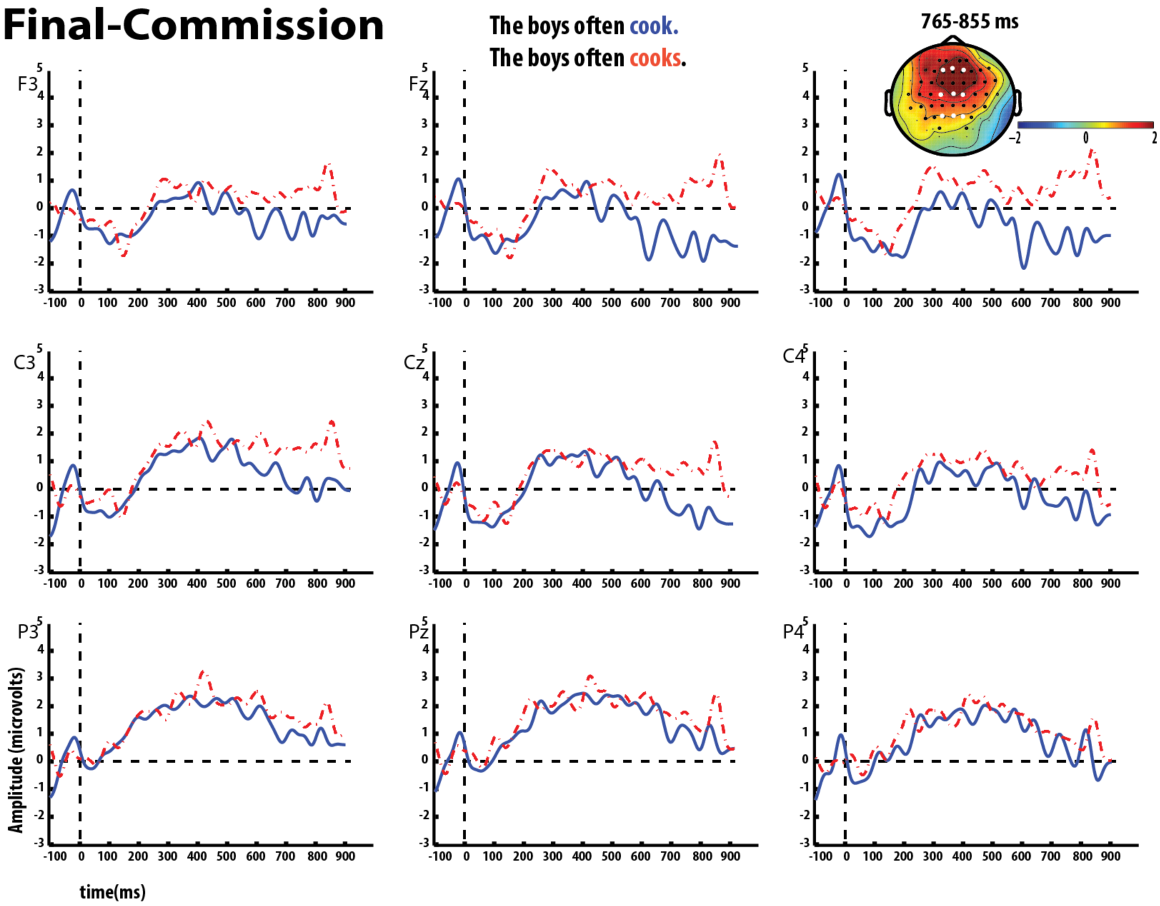

Figure 10: Grand average ERP waveforms for errors of commission in the utterance-final position for the HP group, at the F3, Fz, F4; C3, Cz, C4, P3, Pz, and P4 electrodes and the topographic maps of the significant ERP effects. The first row of the figure shows the anterior electrodes while the second row shows central electrodes and the third row shows the posterior electrodes. The ERPs are time-locked to the offset of the verb-stem (end of stop closure) and positivity is plotted upwards. Time-window for significant clusters is highlighted in grey over the waveforms. The topographic maps next to the ERP waveforms show the voltage distribution of the respective significant cluster. These maps were obtained by interpolation from 64 electrodes and were computed by subtracting the grand averages of grammatical from the ungrammatical conditions. Electrodes in the significant clusters are highlighted with a black circle and the Fz and Pz electrodes are highlighted with a white circle.

Table 7: Summary of finding from the cluster-based permutation tests by proficiency

Proficiency level	Utterance position	Type of agreement violation	Polarity	Latency (ms)	Distribution	*p*-value
HP	Medial	Errors of omission	Negative Positive	---------- ----------	------------ ------------	n.s n.s
		Errors of commission	Negative Positive	---------- ----------	------------ ------------	n.s n.s
	Final	Errors of omission	Negative Positive	745-900 ---------	Centro-posterior ------------	0.027 n.s
		Errors of commission	Negative Positive	---------- 765-855	------------ Fronto-central	n.s 0.022
LP	Medial	Errors of omission	Negative Positive	---------- ----------	-------------- -------------	n.s n.s
		Errors of commission	Negative Positive	---------- ----------	------------ ------------	n.s n.s
	Final	Errors of omission	Negative Positive	---------- ----------	------------ ------------	n.s n.s
		Errors of commission	Negative Positive	---------- ----------	------------ ------------	n.s n.s

Discussion

This study used ERPs to investigate whether Mandarin L2 learners of English (MLEs) immersed in an English-speaking country show native-like brain responses to S-V agreement violations, especially when the violations occurred in contexts considered to be more perceptual salient. Recent L1 ERP studies investigating the processing of S-V agreement have shown that higher perceptual salience of the violation (e.g., errors of commission vs. errors of omission; errors occurring utterance-finally vs. utterance medially) influences on-line computation of agreement information during sentence comprehension (Dube et al., submitted). However, it has remained unknown whether perceptual salience can influence MLEs sensitivity to grammatical morphemes during on-line sentence comprehension. This is in part due to the fact that most of the previous L2 processing research has been carried out using the visual modality which does not reveal the auditory perceptual salience of the stimuli. This study is therefore the first to explore the possibility that perceptual salience can enhance MLEs' sensitivity to S-V agreement violations, despite the phonotactic and morphological differences between Mandarin and English. The study will enhance our understanding of the factors that are important for successful sentence comprehension in advanced MLEs.

Based on findings from recent L1 ERP studies, we predicted that S-V agreement violation in more perceptually salient contexts (errors of commission and utterance-final position) will evoke robust P600 effects compared to the less perceptually salient context (errors of omission and utterance-medial position). The results showed that MLEs were sensitive to S-V agreement, but only for errors of commission in utterance-final position. This yielded a positive cluster from 765 to 855 ms with a fronto-central distribution. Based on the latency and scalp distribution of this positive cluster, we interpret this response to be a frontally distributed P600 taken to reflect syntactic reanalysis processes (Osterhout & Holcomb, 1992). It has been argued that syntactic reanalysis processes are susceptible to non-linguistic factors such as experimental manipulations or participant variability, which may in turn necessitate the engagement of attention processes as well (e.g., Vos, Gunter, Kolk, & Mulder, 2001). Recall we had predicted additive perceptual salience for errors of commission in utterance-final position, thus we interpret the frontal distribution of the P600 to indicate the involvement of attentional processes as a result of enhanced perceptual salience.

However, further analysis of data revealed that participants' responses to S-V agreement violation also varied as a function of L2 proficiency (indexed by length of immersion [LOI] and production accuracy). MLEs with lower proficiency (shorter LOI and lower production accuracy) did not show any sensitivity to violations of S-V agreement. In contrast, those with higher proficiency (longer LOI and higher production accuracy) showed sensitivity to S-V agreement violations in (some) of the contexts where the grammatical violation was more perceptually salient, i.e. in utterance-final position. For the errors of commission, we observed a positive cluster from 755 to 855 ms with a fronto-central distribution similar to that observed in the overall analysis for all participants, indicating that the overall result was driven by responses from learners with higher proficiency. However, for the errors of omission in utterance-final position, we observed a late negative cluster from 745 to 900 ms with a right-lateralized centro-posterior distribution, which was not observed in the overall analysis (see summary of results in **Table 7** above). The sensitivity displayed by MLEs with higher proficiency is not surprising given that longer LOI entails more exposure to speech input which sharpens their listening skills.

There are two important observations arising from these results. The first is that the S-V agreement violations in the utterance-final position elicited qualitatively different ERP components (a late frontal P600 and a late posterior negativity). The second is that the late posterior negativity was not observed in the grand-averaged ERPs for MLEs with lower and greater proficiency. We discuss these two observations below.

Recall that one of our predictions was that MLEs will be more sensitive to S-V violations in contexts with more perceptual salience (errors of commission and utterance-final position). While the overall results of the study show that MLEs were only sensitive to errors of commission in utterance-final position, further analysis revealed that MLEs with greater proficiency were sensitive to both errors of omission and commission in utterance-final position. However the sensitivity manifest in qualitatively different ERP components: a late posterior negativity for errors of omission and a late frontal P600 for errors of commission. According to Rugg and Coles (1995), scalp distribution differences in the ERP effects suggest that different neuronal structures were involved during language processing. Differential sensitivity due to utterance-position has been found in previous L1 studies of both child and adult English (Sundara et al., 2011; Dube et al., submitted) and for MLEs (Johnson & Newport, 1989). Our results therefore support that perceptual salience, especially due to utterance-position, influences how MLEs' process S-V agreement, despite the differences in the phonotactic and morphological structures of Mandarin and English.

Furthermore, two observations can be made from the observed different brain responses. The first is that MLEs were not just sensitive to presence (errors of commission) or absence (errors of omission) of –s, but did process the agreement violations during on-line comprehension. However, this was only possible when the violations occurred in more perceptually salient utterance-final context. The second is that, only those MLEs with greater proficiency (longer immersion in an English-speaking environment) showed sensitivity to errors of omission which had a lesser-extent of perceptual salience. This suggests that, despite lack of consistent use of such grammatical morphemes in everyday speech, MLEs may have some (emerging) awareness of the grammatical contexts in which these verbal inflections should be used. This awareness may be influenced by the perceptual salience of the context in which the morphemes occur.

Another interesting observation from our results is that the late posterior negativity observed in MLEs with greater proficiency was not observed in the grand-averaged ERPs for all participants. Previous research has shown that a lack of effects in grand mean ERPs could be due to the cancellation of opposite effects elicited by different individuals (e.g., Tanner et al., 2013). It is therefore possible that the late posterior negativity effect was cancelled out or masked by grand averaging brain responses from

MLEs with greater proficiency with those for MLEs with less proficiency. This result underscores the importance of investigating how individual differences within L2 participants impact on the overall ERP results before drawing any conclusions on how learners process grammatical information. Furthermore, this result suggests that proficiency associated with length of immersion may be a good predictor for sensitivity to L2 speech input, including perceptual cues in the speech stream.

Besides revealing the potential proficiency effects on S-V agreement processing, the late posterior negativity observed in MLEs with higher proficiency is also interesting given that it has not been reported before for L2 morphosyntactic processing. Previous ERP studies of MLEs have instead reported late negativities with a frontal distribution (Chen et al., 2007), or N400 effects (Xue et al., 2013). However, Xue et al., (2013) also reported a P600 However, a similar posterior negativity referred to as the LPN has been observed in memory processing studies (Johansson & Mecklinger, 2003). This component is associated with successful recall of information and is thought to reflect memory processing.

However, given that the latency and distribution of this negativity is similar to that observed for the P600, reflecting syntactic repair processes (Friederici et al., 2002), it is possible that syntactic processes underlying MLEs' processing of S-V agreement violations interact with memory processes. This is in line with observations that L2 processing is less automatic than L1 processing, sometimes relying on declarative memory (Ullman, 2001). This suggests that MLEs with longer length of immersion, and thus higher proficiency, were sensitive to S-V agreement violations involving errors of omission, but that the underlying processing mechanisms they use are somewhat different from those of native speakers, where errors of omission in utterance final position for L1 speakers elicited a P600 from 590 to 670 ms with a centro-posterior distribution. Dube et al. (submitted).

Our results are therefore fundamentally different from previous ERP studies investigating the processing of S-V agreement violations in advanced MLEs (Xue et al., 2013a). We propose that the lack of morphosyntactic sensitivity reported in previous studies of MLEs with advanced proficiency could be due to three interrelated factors. The first is that the difficulty that MLEs have with grammatical inflection is often considered in terms of L1-L2 differences in phonotactic and underlying morphological representations that might influence MLE production (Broselow & Xu, 2009; Jiang, 2004; Li, Shu, et al., 2014; Liu et al., 1992). The second is that most studies have used the visual modality, whereas this study used the auditory modality to investigate the impact of perceptual salience due to the type of agreement violation and utterance position. The third is that the only two studies to date that have investigated S-V agreement processing in MLEs were based on advanced learners living in China (without immersion exposure). The present study was conducted on MLEs immersed in an English-speaking environment where they were exposed to speech input with varying degrees of perceptual salience. Another possible difference may relate to the experimental tasks used in previous studies, e.g., Xue et al., (2013) used a grammaticality judgement task whereas our study used a listening task. Grammaticality judgements tend to also involve some metalinguistic processes that may constrain the responses to S-V agreement processes. Besides that, we have already argues that the auditory modality gives a more natural environment for investigating how speakers comprehend sentences.

However, given that this study is the first to report effects of auditory perceptual salience on the processing of S-V agreement violations involving errors of omission and commission in utterance-medial and -final positions, there is need for future research to replicate this study. Such studies will further enhance our understanding of how the nature of speech input can potentially influence MLEs acquisition and processing of grammatical inflection, as well as the broader social and educational implications this entails.

Taken together, the present study demonstrates that, despite L1-L2 differences, MLEs show sensitivity to S-V agreement violations when the violation is perceptually salient, at least when they have a few years of immersion in an English speaking environment. These findings suggest that, while perceptual salience facilitates MLEs' processing of S-V agreement violations, length of immersion facilitates overall sensitivity to grammatical contrasts in on-line sentence comprehension. These findings have important methodological and theoretical implications for L2 acquisition and processing research.

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CHAPTER 4

Perceptual Salience Matters for the Processing of Subject-Verb Agreement in 8-11 years-old English-speaking Children: Evidence from ERPs

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Abstract

Approaches to how children process language are often formulated with reference to maturational (syntactic and neurological) limitations. However, there is now accumulating evidence suggesting that the perceptual salience of linguistic information influences children's sensitivity to grammatical violations during sentence comprehension. However, this evidence has come from studies using off-line measures, thus it is not known, for example, how perceptual salience due to phonological/prosodic cues impacts on children's online sentence processing. In this study, we used event-related potentials (ERPs), to explore whether 8-11-year-old English speaking children will show different brain responses to subject-verb (S-V) agreement violations that varied as a function of perceptual salience due to the overtness of type of agreement violation (errors of omission vs. commission) and utterance position (medial vs final).

We observed that children only displayed sensitivity to errors of omission, as shown by the N400 effect. However, this effect was more sustained and broadly distributed in the utterance-final position compared to the utterance-medial position. These results suggest that perceptual salience, due to utterance position, enhanced children's sensitivity to S-V agreement violations during online sentence processing. However, a lack of sensitivity to errors of commission could suggest that perceptual salience due to superfluous errors may be redundant information for S-V agreement processing in 8-11-year-olds. Furthermore, we interpret the absence of the P600 effect to indicate that the cognitive processes underlying decision certainty are not yet fully developed in 8-11-year-olds. These findings provide interesting insights into sentence processing theories and have great implications for language acquisition and the functional interpretations of the ERP components.

Introduction

A key aspect of successful sentence comprehension is figuring out the relations between the various elements in a sentence. Like adults, one of the relations that children need to figure out is whether the subject (noun-phrase) and the verb agree. For example, when presented with sentences such as "*The boy often cooks on the stove*" and "*The boys often cook on the stove"*, they must keep track of the grammatical information (i.e., number) of the subject noun phrase in order to determine which verb-form qualifies as a suitable continuation of the sentence. Thus, in the first sentence, the verb-form takes the 3rd person singular –s (3SG) inflection, whereas in the second sentence, the verb remains uninflected. Failure to use the appropriate verb-form results in ungrammatical forms, as in "**The boy often cook on the stove*" and "**The boys often cooks on the stove"*. This phenomenon of establishing grammatical relations between the subject and the verb is known as subject-verb (S-V) agreement (Nicol, Forster, & Veres, 1997).

Children have been observed to demonstrate receptive knowledge of morphosyntactic aspects of language such as S-V agreement by the age of three (e.g., Brandt-Kobele & Höhle, 2014; Nazzi, Barrière, Goyet, Kresh, & Legendre, 2011; Soderstrom, 2008; Sundara, Demuth, & Kuhl, 2011). Sentence-comprehension research has also shown that children are sensitive to ungrammatical sentences involving S-V agreement mismatches. Such sensitivity is often considered to be driven by children's underlying knowledge of inflectional grammatical morphology (e.g., Brandt-Kobele & Höhle, 2014). However, recent findings from language acquisition research suggest that there are a number of other factors that may interact with grammatical knowledge to influence children's sensitivity to the grammatical morphemes during sentence comprehension.

One of these factors is the phonological context (e.g., utterance position) in which the grammatical morpheme occurs (Song, Sundara, & Demuth, 2009; Sundara et al., 2011). It has been observed that L1 children typically produce 3rd person singular morphemes more reliably when the verb occurs utterance-finally compared to that occurs utterance medially (Song, Sundara, & Demuth, 2009). This behaviour is thought to be due to the fact that syllables (and morphemes) occurring utterance-finally are longer in duration than those that occur utterance medially (Hsieh, Leonard, & Swanson, 1999; Oller, 2005; Wagner & Watson, 2010; Wightman et al., 1992). This raised the possibility that children might perceive these longer utterance-final morphemes better than the utterance-medial ones. To test this hypothesis, Sundara, Demuth, & Kuhl (2011) investigated 2-year-olds' sensitivity to grammatical (inflected) vs. ungrammatical (uninflected) 3rd person singular verbs in utterance-final versus utterance-medial position in an auditory visual-fixation task (e.g. *Now he <u>cries</u>* vs. **Now he <u>cry</u>*;. *He <u>cries</u> now* vs. **He <u>cry</u> now*).

As expected, infants showed a difference in looking times to the grammatical vs. ungrammatical sentences when the verb and morpheme occurred utterance finally, but not utterance medially. They interpreted these findings to suggest that the increased duration of the –s morpheme at the end of the utterance provides extra acoustic cues for listeners, enhancing infants' ability to detect its presence, and ungrammatical absence. That is, infants were more sensitive to the missing morpheme utterance-finally compared to utterance medially due to the greater perceptual salience of the morpheme in the durationally longer utterance-final position. These results have been corroborated by recent findings from an event-related potentials (ERPs) study involving L1 English-speaking adults (Dube, Kung, Peter, Brock & Demuth, submitted). They observed different brain responses to S-V agreement violations due to perceptual salience that varied as a function of type of violation and utterance position in (see below for details). However, despite the accumulating evidence for the role of perceptual salience in grammatical-morpheme comprehension, it is not yet known how this might influence on-line processing of S-V agreement in children. This question is addressed in the present study.

To this end, we investigate how 8-11-year-olds English-speaking children process sentences involving S-V agreement violations manipulated for perceptual salience, i.e. violations in which perceptual salience differed due to their overtness (e.g., errors of omission vs. commission) and the prosodic context of the target word (utterance-medial vs. utterance-final). Exploring the kinds of information and processes that facilitate successful on-line sentence comprehension in children may enhance our understanding of the factors important for the acquisition and processing grammatical morphology. We explore how the relative perceptual salience of grammatical morphemes impacts on the on-line sentence processing of spoken sentences using event-related potentials (ERPs). ERPs have been shown to be a suitable paradigm for examining how children process morphosyntactic information during on-line sentence comprehension (Courteau et al., 2013; Hahne, Eckstein, & Friederici, 2004; Royle & Courteau, 2014; Silva-Pereyra, Rivera-Gaxiola, & Kuhl, 2005).

Subject-verb agreement processing and ERPs

The ERPs measure scalp-recorded electrophysiological brain activity that is time-locked to the presentation of target stimuli. Due to their excellent temporal resolution, they are ideally suited for exploring how different types of information are processed during on-line sentence comprehension (Luck, 2014). By observing the multidimensional data points of the ERP waveforms (e.g., their polarity, amplitude, latency, and scalp distribution), one can deduce the nature of the processes underlying language processing.

For example, the processing of S-V agreement violations has been often shown to evoke two ERP components.

The LAN often occurs between 300 and 500 ms after the onset of the violation and has been observed to have either a left anterior scalp distribution. (e.g., Coulson, King, & Kutas, 1998; Friederici, Pfeifer, & Hahne, 1993; Gunter, Friederici, & Schriefers, 2000; Osterhout & Holcomb, 1992; Hahne & Friederici, 1999; Kaan, 2002). The P600 typically occurs between 500 and 1000 ms after violation onset and is often observed with a centro-posterior scalp distribution (e.g., Osterhout & Mobley, 1995) or with a broad scalp distribution (e.g., Molinaro et al. 2011). The P600 has been observed after the LAN (a biphasic LAN/P600 effect) or on its own (e.g., Coulson et al., 1998; Hagoort & Brown, 2000; Kaan et al., 2000; Osterhout & Mobley, 1995). Based on the evidence from previous studies, which reported evidence that correlated morphosyntactic processing to the L(AN) and the P600, Friederici (2002) proposed a neuro-cognitive model of auditory sentence comprehension which instantiates the syntax-first view discussed above.

According to this model, the LAN observed from 300-500 ms is correlated with the second phase of syntactic processing, when lexical-semantic and morphosyntactic information are processed to assign thematic roles. It is also understood to reflect the detection of morpho-syntactic violations such as agreement mismatch (Batterink & Neville, 2013; Bornkessel & Schlesewsky, 2006; Friederici et al., 1993; Hagoort, Wassenaar, & Brown, 2003; Kos, Vosse, Van Den Brink, & Hagoort, 2010; Osterhout, Holcomb, & Swinney, 1994; Osterhout et al., 1996). On the other hand, the P600 effects observed from 500-1000 ms are correlated with the last phase of processing, when the different types of information are integrated. This effect is generally understood to reflect syntactic reanalysis or repair (e.g., Friederici, 2011; Gunter, Friederici, & Schriefers 2000; Hahne & Friederici, 1999, 2002).

However, findings from a number of morphosyntactic studies have challenged this modular-specific view, raising a debate about the functional interpretation of these components (e.g., Dröge, Fleischer, Schlesewsky, & Bornkessel-Schlesewsky, 2016; Fiebach, Schlesewsky, & Friederici, 2002; Kuperberg, 2007; Kolk & Chwilla, 2007; Luck & Kappenman, 2011; Steinhauer & Drury, 2012) . For example, while the processing of morphosyntactic violations is expected to elicit LAN and/or P600 effects, some studies have not observe LAN effects (e.g., Hagoort & Brown, 2000; Kaan, Harris, Gibson, & Holcomb, 2000; Kos et al., 2010; Osterhout et al., 1994). Others have reported N400 effects instead of the traditional LAN effects, e.g., aspect marking in Hindi (Choudhary, Schlesewsky, Roehm, & Bornkessel-Schlesewsky, 2009) and gender marking in Spanish (Wicha, Moreno, & Kutas, 2004). Still, others have observed different P600 latencies and amplitudes as a function of different morphological features (e.g., gender vs. number or person+gender) (e.g., Nevins, Dillon, Malhotra, & Phillips, 2007). The presence/absence of the P600 has also been observed to vary as a function of whether the task was passive or active (e.g., Kolk & Chwilla, 2007), or whether the violation was syntactically simple or complex (e.g., Kutas & Hillyard, 1983; O'Rourke & Van Petten, 2011).

This review of previous ERPs studies shows that there are various factors that influence the processing of morphosyntactic information during online sentence comprehension. As a result, an alternative view to that proposed by Friederici (2002) was proposed—the internal models of sentence processing (e.g., Pickering & Garrord, 2013; Bornkessel-Schlesewsky, et al. 2015). According to this view, the variable realizations of the ERP components can be accounted for in terms of the nature of the incoming stimuli which may necessitate the engagement of different cognitive processes. These cognitive processes may result in quantitatively or qualitatively different ERP responses, despite similar underlying neural functions. For example, in processing S-V agreement violations that vary due to perceptual salience, different cognitive processes may be engaged for processing more perceptually salient versus less perceptually salient phenomena, yet the underlying morphosyntactic process remains the same. Thus, the question of whether different types of agreement violation and utterance position influence the processing of S-V agreement violations is important, given that these factors were used variably in previous ERP studies investigating S-V agreement violation processing.

There is recent evidence from L1 adult online processing of S-V agreement indicating that the nature of stimulus manipulation used (e.g., errors of omission vs. errors of commission) and utterance-position (medial vs final), enhances the perceptual salience of the S-V agreement violation during on-line comprehension (e.g., Dube et al., submitted). Dube et al. (submitted) observed that in utterance-medial position, agreement violations involving errors of omission (e.g., *the boy often <u>cook</u> on* ..) only elicited a bilateral anterior negativity (AN), whereas the more noticeable/more perceptually salient errors of commission (e.g., *the boys often <u>cooks</u> on …)* elicited a P600 effect. However, in the utterance-final condition, both types of errors (*the boy often <u>cook.</u>* vs. *the boys often <u>cooks.</u>*) elicited a P600 effect, which was broadly distributed for the errors of commission, and centro-posteriorly distributed for errors of omission.

These results were interpreted to reflect that agreement violations in contexts with higher perceptual salience (errors of commission and utterance-final position) elicited more robust effects compared to errors of omission and errors in utterance-medial position. Thus, even though native adult speakers of English are expected to show robust sensitivity to all realizations of agreement due to their grammatical knowledge, their sensitivity to S-V agreement violations during on-line auditory sentence processing differed as a result of the perceptual salience of the error. These findings provide a basis against which to compare children's processing of the same grammatical construction. It is possible that 8-11-year-olds s' sensitivity to S-V agreement violations during on-line comprehension may also be influenced by the perceptual salience of the agreement errors. However, no ERP study has investigated this issue in children.

Instead, most of the ERP studies in children have focused on how maturational effects impact on syntactic processing (e.g., Friederici & Oberecker, 2008; Meier, 2008; Oberecker, Friedrich, & Friederici, 2005; Hahne, Eckstein, & Friederici, 2004; Friederici, 2002; Clahsen, Lück, & Hahne, 2007). The general finding is that, although children show sensitivity to syntactic violations during on-line sentence comprehension, the presence, latency and amplitude of the LAN and/or P600 effects vary with age. For example, Clahsen et al. (2007) investigated how 6-7, 8-9, and 11-12 year-olds processed morphosyntactic errors involving plural overregulisation in German (e.g., *Ein Vertreter besucht die grossen <u>Apotheken/*Apothekes</u> in unserer Stadt –A salesman visits the large pharmacies in our town.* They did not observe any P600 effects in 6 and 7 year-olds. Instead, a broadly distributed negativity was observed. This negativity was however not observed in 8-9 year-olds who showed an anterior negativity followed by a late positivity at 1000 ms in the occipital regions. In the 11-12 year-olds, they observed a slightly left-lateralised anterior negativity followed by a P600. The distribution of these effects was similar to that observed in adults, except that the P600 had a longer latency. According to Clahsen et al. (2007), these results suggest that children begin to show adult-like ERP responses above the age of 8 and that the latencies and topography of these ERP components changes with age.

Further evidence for maturational developments is shown in Meier (2008) who investigated the processing of morphosyntactic violation involving agreement violations in English-speaking adolescents between the ages of 14-17 years and adults. She observed that in both groups, violations involving errors of omission in utterance-final position (e.g., *Everyday, the musicians tune their *<u>instrument</u>*) elicited a slight anterior negativity that did not reach significance. However this negativity was followed by a positivity that occurred from 880-1440 ms in adolescents, in contrast to the adults who showed positivity a from 700-1500 ms. This result, along with that from Clahsen et al. (2007), suggests that ERP effects observed in children's processing of morphosyntactic violations differ from those of adults due to maturational effects.

From a physiological perspective, these differences are not surprising given that syntactic processes are instantiated in the frontal brain regions which continue to experience developmental changes until adulthood (Paus et al., 1999; Friederici, 2002; 2006; Brauer, Anwander, & Friederici, 2011). As a result of brain maturation, smaller P600 amplitudes observed in children's brain responses have been associated with reduced capacity for deep syntactic processing mechanism due to immaturity of the inferior frontal cortex and the anterior parts of the temporal cortex which are involved in syntactic analysis (Friederici, 2002; also see, Thompson-Schill, Bedny, & Goldberg, 2005 for alternative view for brain regions involved in syntactic processing). Furthermore, greater latencies observed in children's ERP components are thought to reflect slowed syntactic processing due to limited fibre tracts of the arcuate fasciculus which mediates syntactic processes by transmitting information from anterior to posterior brain regions (Paus et al., 1999).

While these physiological constraints explain why ERP responses from children manifest in longer latencies and smaller amplitudes compared to those of adults, it is not clear what modulates the presence or absence of the LAN and P600 components. Results from the aforementioned studies are inconsistent on this matter. These effects could be the due to the different linguistic structures investigated (plural over-regularisation vs. morpheme omission), the different utterance positions in which the violations occurred (utterance-medial vs. utterance-final), or differences in the languages investigated (German vs. English). It is therefore possible that the different stimuli manipulations used in sentence processing studies may influence the nature of the ERP components observed. The internal models of sentence processing propose that the qualitative and quantitative differences of the ERPs may reflect different cognitive processes involved (e.g., predictive or decision making) as a result of the nature of the input rather than different underlying linguistic processes. Therefore, exploring how perceptual salience influences children's online processing of S-V agreement violation may enhance our understanding of the factors that facilitate successful sentence comprehension in children. Findings from such research will have great implications for language processing in bilingual children and children with language impairment.

Therefore, the aim of the present study was to contribute to sentence processing research in children by using ERPs to investigate how perceptual salience of grammatical morphemes influences the processing of S-V agreement violations during on-line sentence comprehension in 8-11-year-olds s. A secondary aim was to determine whether the underlying processes differ from those observed in the previous adult studies. To achieve this, we recorded and compared children's ERP responses to grammatical and ungrammatical sentences in which the subject-verb agreement violations differed according to the type of agreement violation (errors of omission vs. commission) and utterance position (medial vs. final).

Based on previous ERP findings from 8-11-year-old German-speaking children, we hypothesised that children in our study will show sensitivity to S-V agreement, showing an adult-like LAN/P600 (Clahsen et al., 2007). Alternatively, we anticipated we might find that the children would show robust P600 effects in more perceptually salient contexts, replicating the findings with adults in Dube et al. (submitted). We therefore expected more robust ERP effects for errors of commission due to the greater perceptual salience of the overt violation, and that the effect would be more robust in utterance-final position due to durational cues. Finally, we expected that the ERP effects would have greater latency and reduced amplitude due to maturational effects (Friederici, 2002; Brauer et al., 2011).

Methods

Ethics statement

The Ethics committee for Human Research at Macquarie University approved the experimental methods used in this study. Written informed consent was obtained from all participants' parents or guardians before the experiment began.

Participants

The participants were 17 monolingual Australian-English speaking children (10 female, 7 male) aged 8-11-years (mean: 9.8) who were all right-handed and had no clinical history of hearing or learning disorders. They were recruited via Neuronuts, an online recruitment website administered by the Center for Cognition and its Disorders (CCD) at Macquarie University. Prior to the experiment, parents/guardians completed a questionnaire on the developmental and linguistic history of the children. We excluded an additional 15 participants from the final analysis due to excessive ERP artefacts (e.g., as a result of sweating, or too much movement). The reason for the high exclusion rate can be related to children's difficulty to sit still throughout the entire ERP experiment.

To confirm that children had no language related problems, they were all administered with a quick language screener—the Grammar and Phonology Screening (GAPS) test (Gardner, Froud, McClelland, & van der Lely, 2006). The GAPS is a reliable assessment for young children's language abilities. It consists of sentence and non-word repetitions tasks which test young children's knowledge of grammatical constructions and phonotactic abilities, respectively. All children included in this study performed at ceiling, with a percentile score of 100% in both components. Given that these children were above the age of 6, and had no history of language-related problems, these scores were expected. We also administered the children with the Test of Non-verbal Intelligence (TONI) to confirm that their non-verbal cognitive skills were also within the normal range. Results of the TONI showed that the children had a normal non-verbal IQ falling within 108-150 points of the deviation quotient (mean: 129. 2; SD 32.4).

Stimuli

The stimuli used in this study were the same as those used by Dube et al., (submitted) with English speaking adults. The auditory stimuli included 50 CVC target verbs that could be used intransitively in both sentence medial and final positions (e.g., *The boy often cooks on the stove* vs. *The boy often cooks*). This ensured that the target verbs could be used in both utterance medial and utterance final conditions respectively. Only those verbs with high-medium frequency were selected to ensure familiarity and to facilitate processing. The criteria for lexical frequency was that the verbs had between 1-3 counts on the SUBLEX Log10CD (Hofmann, Stenneken, Conrad, & Jacobs, 2007). In addition, only those verbs that ended with the voiceless coda stops /p/, /t/, /k/ were selected to make sure that the inflected –s morpheme was always realised as [s]. This facilitated subsequent splicing of the materials and ensured that all morphemes had the same duration (see below). As the stimuli were later paired with a picture to provide a visual context while listening to the sentence, the verbs also had to be highly imageable.

The verbs were inserted into carrier sentences that were composed of monosyllabic words, thereby controlling for utterance length and processing load. The carrier sentences had a singular vs. plural subject to enable manipulation of type of agreement violation (errors of omission vs. commission). The verbs appeared in the middle vs. end of the carrier sentence to create the utterance-medial vs. utterance-final conditions, respectively (see **Table 1** for examples). In the utterance-medial position, the verb was always followed by a preposition with a vowel onset to avoid masking of the morpheme in the preceding verb. All sentence stimuli were accompanied by cartoon pictures that were designed by a professional cartoonist (see example in **Figure 1**). The drawings had a constant level of visual complexity to avoid distracting details. Given the reduced attention span of children, the purpose of the pictures was to sustain their attention, and keep their eyes focused on the computer display to minimize head movement (muscle movements introduce artefacts to the ERP data).

Table 1: Experimental conditions

Utterance position	**Type of agreement Violation**	**Example**
Medial	Omission	The boy often <u>cooks/*cook</u> on the stove
	Commission	The boys often <u>cook/*cooks</u> on the stove
Final	Omission	The boy often <u>cooks/*cook</u>
	Commission	The boys often <u>cook/*cooks</u>

*Ungrammatical verb forms are marked in asterisks

Figure 1: Example of images used for the verb *cook/cooks*.

As shown in **Table 2**, the study employed a 2x2x2 design by crossing Type of agreement violation and Utterance position with Grammaticality. Each verb therefore appeared in a total of eight conditions, which resulted in 50 test items per condition and a total of 400 test items. In addition to the test items, there were 44 catch trials. All catch trials were grammatical and had the same structure as that of the target carrier sentences, but the verbs were not fully controlled for CVC structure (e.g., *eat*). These catch trials were used as a probe task in order to maintain participants' attention during the experiment (see Task and procedure for further details).

Auditory Stimulus Preparation

All grammatical sentences were spoken by a female native speaker of Australian English who was trained in how to produce the sentences. To control for naturalness and intonational constancy, the sentences were read in response to a question and the accompanying picture. For example, all medial sentences were responses to a question like, "W*hat do the boys often do on the stove*? (Answer: *The boys often cook on the stove*). For the final conditions the question was "*What do the boys often do?* (Answer: *The boys often cook).* Medial and final conditions were separated into two lists and all sentences within the same list were recorded together. The sentences were recorded using

Audacity (Audacity Team) in a sound-attenuated booth with a Behringer C2 microphone and a USB Pre-2 amplifier. The recordings were digitized at a sampling rate of 44 KHz (16 bit; mono). Following the recording, the sentences were normalised using Audition C6 (Adobe Systems) and then extracted into individual sentences using Praat (Boersma &Weenink, 2012).

Instead of recording ungrammatical sentences, we created the stimuli by cross-splicing the grammatical productions from the onset of the verb, as shown in **Table 3**. All sound files were spliced at the zero-crossing from the beginning of the verb using Audition C6 (Adobe Systems). This procedure was meant to minimise the possibility of listeners using any early acoustic cues to distinguish between the grammatical and the ungrammatical condition. Previous studies using the auditory EEG paradigm have observed that recording ungrammatical structures, even with a trained speaker, introduces subtle but systematic slowing in production as well as intonation modifications (Royle, Drury, & Steinhauer 2014; Hasting & Kotz, 2008). Therefore the splicing procedure was used to avoid possible acoustic differences between grammatical and ungrammatical sentences before the point of grammatical violation. All stimuli were later rated for naturalness by a highly trained phonetician.

Table 3: Splicing points and procedure for creating ungrammatical stimuli.

<table>
<tr><th>Source</th><th>Result</th></tr>
<tr><td>The boys often |cook on the stove</td><td>The boys often *cooks on the stove</td></tr>
<tr><td>The boy often |cooks on the stove</td><td>The boy often *cook on the stove</td></tr>
<tr><td>The boys often |cook</td><td>The boys often *cooks</td></tr>
<tr><td>The boy often |cooks</td><td>The boy often *cook</td></tr>
</table>

After splicing the stimuli, we used Audition C6 (Adobe Systems) to examine the waveforms and insert triggers into the individual sound files. We systematically used the end of closure for the coda stops, instead of the end of burst release, as the time-locking point for all four conditions. This is because the burst release of some coda stops such as /t/ is not always clearly identifiable when followed by frication (i.e., the /s/ 3SG morpheme). By time-locking to the end of closure, we made sure that the time-locking points for grammatical and ungrammatical sentences were identical in all conditions. The spectrograms in **Figure 2** illustrate the time-locking points for grammatical and ungrammatical conditions that had inflected and uninflected verbs.

Having the same time-locking point thus ensured that the grammatical and ungrammatical conditions were comparable in terms of where and when the ERP violation effects appeared in both medial and final contexts. For the analysis, we compared the target inflected vs. uninflected verbs within the singular and plural conditions. By doing so, we controlled for the context preceding the target agreement violation to make sure that the response to the violation was only influenced by the grammaticality manipulation on the target verb (see Steinhauer & Drury 2012 for discussion on effects of context/target manipulation on syntactic-violation processing).

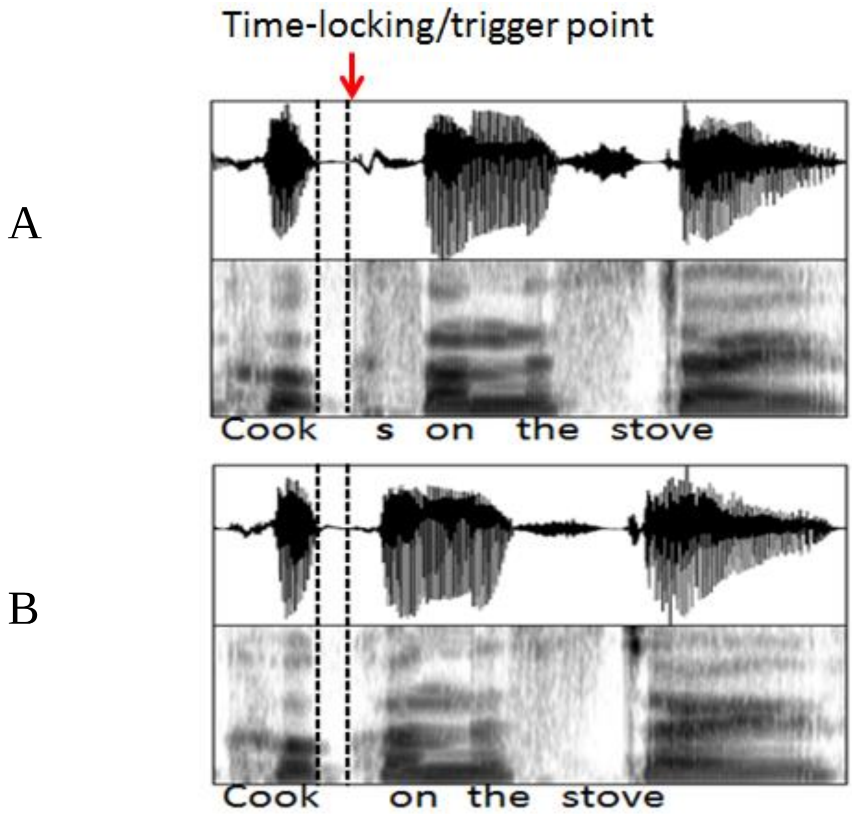

Figure 2: Representative waveforms and spectrograms illustrating the inflected verb (cooks) in (A) and the uninflected verb (cook) in (B). The dotted lines indicate the beginning and end of stop closure, the arrow indicates the time-locking point in both conditions.

Recall that one of the aims of this study was to explore the effects of phrase-final lengthening on the processing of S-V agreement violations. We used acoustic measures to confirm the duration of the 3SG in utterance-medial and utterance-final position. As expected, the 3SG morpheme in utterance-final position had a mean duration of 238 ms (SD = 28) compared to 114 ms (SD = 22) in utterance-medial position. Paired t-tests confirmed that this difference was statistically significant, $t(49) = -5.989$, $p < .001$. This ensured that the 3SG morpheme in the utterance-final stimuli was significantly longer than that in utterance-medial condition.

Task and procedure

Participants were fitted with an electrode cap (Easycap, Brainworks GmbH) while seated in a comfortable plush chair at a distance of one meter from a CRT computer screen, in a dimly lit sound-attenuated and electromagnetically shielded room. EEG signals were recorded continuously as participants listened to sentences. They were instructed to listen attentively to all sentences and to immediately press a given response button when they heard the words "*cut/cuts'* or *'eat/eats"* in the sentence. As highlighted in the Materials section, these verbs were used as catch trials while the button-press task prevented participants from performing explicit grammaticality judgments. This probe task was used instead of a grammaticality-judgement task to distract participants from concentrating on the grammaticality of the sentences, which hinders natural comprehension processes (Dragoy, Stowe, Bos, & Bastiaanse, 2012).

The sentences and their matching pictures were presented using Presentation (Neurobehavioral Systems) which also recorded responses (hits, misses and false alarms) for the probe task. Two audio speakers were positioned on the left and right of the computer screen while the matching images appeared on the screen. Sentences were grouped into medial and final lists in which each list had two ten-minute blocks. Each block had 111 sentences with accompanying pictures. The lists were presented separately to avoid mixing the medial and final conditions as they were of different word lengths.

Recall also that we used verbs that could be either transitive or intransitive, and could take an optional prepositional phrase. By blocking the presentation we controlled for the possibility that the transitivity of the medial condition (verb + prepositional phrase) would influence participants' interpretation of final sentences, as they might then have expected a prepositional phrase in this condition as well. This was particularly important given that one of the aims of this study was to explore utterance position effects (target verb in utterance medial vs. final position), we had to minimize any possible confounds. To control for presentation list effects, the order of the blocks was counterbalanced among the participants so that half of the participants heard the medial-final order first, and the other half had the final-medial order first.

Within each block, the order of sentence/picture presentation was also pseudo-randomised with the constraint that the same verb did not occur consecutively. The picture was presented 500 ms before the onset of the sentence and remained on the screen until the end of the auditory stimulus. The same picture was used for both grammatical and ungrammatical sentence to avoid giving cues about the grammaticality of the upcoming stimuli. Two catch trials were presented at the beginning of the first block of each list and the presentation was pseudo-randomised with the constraint that they occur after five to eight consecutive target items within the block. A picture of an eye appeared on the screen ~1000 ms after the end of each sentence to control for eye blinks and remained on the screen for 1000 ms. Participants were asked to avoid blinking during the presentation of the sentences but to blink when the picture of an eye appeared on the screen. They were also asked to sit still during the presentation of the sentences to avoid movement artifacts during the EEG recording. The sentences had an inter-stimulus-interval of three seconds. A short break was taken at the end of each block. The duration of the break was determined by the participant. Altogether, the experiment lasted about 60 minutes.

EEG recording

The continuous EEG was recorded from 64 Ag/AgCl scalp electrodes mounted onto an electrode cap (Easycap, Brainworks GmbH) in line with the International 10–20 system (Jasper, 1958: Fpz, Fz, FCz, Cz, CPz, Pz, POz, Oz, Fp1/2, F7/5/3/1/2/4/6/8, FT7/8, FC5/3/1/2/4/6, T7/8, C5/3/1/2/4/6, M1/2, TP7/8, CB1/2, CP5/3/1/2/4/6, P7/5/3/1/2/4/6/8, PO7/5/3/4/6/8, O1/2; see **Figure 3** for an illustration of electrode positions). Additional electrodes were placed above and below the left orbit and on the outer canthus of each eye to monitor electro-oculographic (EOG) activity with a bipolar recording. The ground electrode was positioned between Fpz and Fz. Electrode impedances were adjusted until they were below 10 kΩ. Electrical activity was recorded from both mastoids with the left mastoid (M1) serving as the online reference. The signal from the EEG was digitised at a sampling rate of 1000 Hz and filtered with a .05-100 Hz bandpass filter using a Neuroscan SynAmps2 DC Amplifier (Compumedics Ltd., USA).

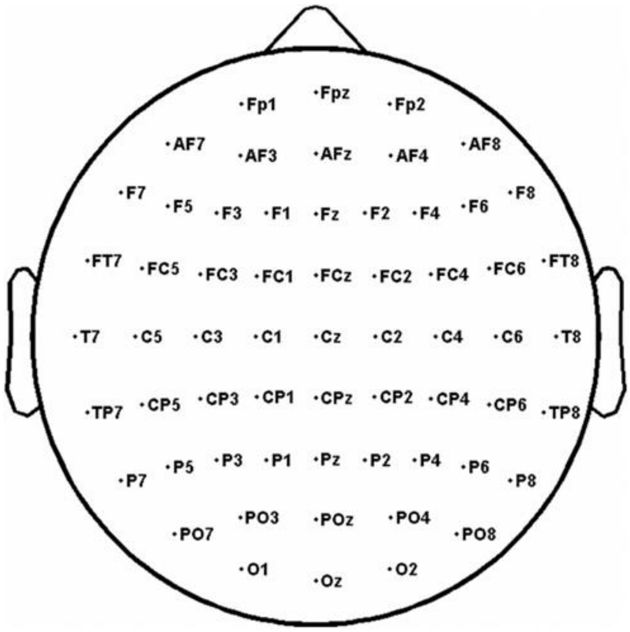

Figure 3: Approximate location of the electrode recording sites according to the 10-20 system.

EEG data processing

The digitised data were processed off-line in Matlab (Version R2013b: MathWorks, Massachusetts, U.S.A) using the Fieldtrip toolbox (Oostenveld, Fries, Maris, & Schoffelen, 2010; Version 2014-08-24). The data were epoched into trials of 1000 ms including a 100 ms pre-stimulus interval and then filtered with a Butterworth bandpass of 0.05-20 Hz for Independent Component Analysis (ICA) analysis. Extreme trials with amplitudes larger than ±300 μV were removed before entering all trials into the ICA. The purpose of the ICA was to identify any components resembling eye blinks, horizontal eye movements, noisy channels and other focal artefacts. The identified components were then mathematically removed from the data and signals were back projected to the original unfiltered data. After ICA, each channel was re-referenced to the mean mastoids and band-pass filtered at 0.5 to 30 Hz using a Butterworth IIR zero-phase filter 4-order pass with 12 dB/octave slope. (We used this band pass filter because the data contains a large number of drifts which could be due to the fact that the child participants were not able to be as attentive and be as still as adult participants). After that, the data were segmented and time-locked to the end of stop closure preceding the critical target morpheme/omission (as illustrated in Figure 2 above) from 100 ms before to 900 ms after the onset of the critical target and baseline corrected using the 100 ms pre-stimulus interval. Trials with artifacts that exceeded 100 μV, with trends greater than 75 μV, or with abnormal distributions or improbable data exceeding five *SD*s, were also rejected.

This procedure removed a total of 231 trials (0.33% of all trials across all participants) from the eight experimental conditions: 30 medial-singular grammatical, 33 medial-singular ungrammatical (omission), 27 final-singular grammatical, 32 final-singular ungrammatical (omission), 24 medial-plural grammatical, 33 medial-plural ungrammatical (commission), 30 final-plural grammatical, and 22 final-plural ungrammatical (commission). There was no reliable difference between the numbers of rejected trials across conditions. The remaining trials in each of these conditions were averaged for each participant and grand averages were then computed for each of the conditions.

EEG data analysis

As discussed in the Introduction, different ERP latencies have been reported in previous studies of morphosyntactic processing in children. Therefore analyzing the grand ERP averages using standard time windows associated with LAN or P600 would not be ideal as we might miss effects that fall outside of those time points. We therefore performed non-parametric cluster-based permutation tests to test for a difference between the overall grammatical and ungrammatical sentences (collapsing type of agreement and utterance position effects; Maris & Oostenveld 2007).

We computed the cluster-based permutation test as described by Maris and Oostenveld (2007). The test first identifies sampling points with t-statistic exceeding a critical threshold ($p < .05$, two-tailed). Clusters are then formed by connecting significant sampling points on the basis of spatial and temporal adjacency. This is done separately for sampling points with positive and negative t-values. The maximum cluster-level test statistics (the sum of all individual t-values within a cluster) are then computed to generate permutation distributions, one for positive clusters and one for negative clusters, based on 1000 random partitions. The significance of a cluster is determined by whether it fell in the highest or the lowest 2.5th percentile of the corresponding distribution.

The aim of this analysis was to test if, and when, the ERP responses to ungrammatical sentence differ from those of grammatical sentences. Given that this type of analysis cannot be used for examining interactions between conditions, we used it as a first step of data analysis to identify the time-window for further analyses. We then used these time windows to perform further analyses using repeated-measures multivariate analysis of variance (MANOVA) to test the extent to which type of agreement violation and utterance position effects influence S-V agreement processing during online sentence comprehension. We present the results from the cluster-based permutations first, and then the procedure and results for the MANOVAs.

Results

Effects of grammaticality

One of the goals of this study was to test if 8-11-year-old English speaking children would show sensitivity to S-V agreement violations and whether that sensitivity will evoke LAN and/or P600 effects similar to adults or not. Furthermore, we sought to explore if these responses would vary due to the relative perceptual salience of the 3rd –s morpheme as a function of type of agreement violation (errors of omission vs. errors of commission) and utterance position (medial vs. final). We begin by reporting the results of the cluster-based permutation tests, which contrasted the grand average ERP waveforms of the grammatical condition with those of ungrammatical condition (collapsed over type of agreement and utterance position. The grammaticality effects are shown at nine representative electrodes (corresponding to locations F3, Fz, F4; C3, Cz, C4 and P3, Pz, P4 in a standard 10–20 set-up) in **Figure 4**, which also shows the topographic maps highlighting the distribution and time course of the significant clusters.

Visual inspection of the waveforms indicated that, relative to the grammatical verbs, ungrammatical verbs elicited a broad negative-going waveform. Statistical analysis using cluster-based permutation tests revealed that contrasts observed for grammatical vs. ungrammatical verbs yielded a significant *negative* cluster (p = .007) between 170 and 690 ms in the anterior-central electrodes. Thus, ungrammatical sentences, in overall, elicited brain responses that were different from those of the grammatical sentences.

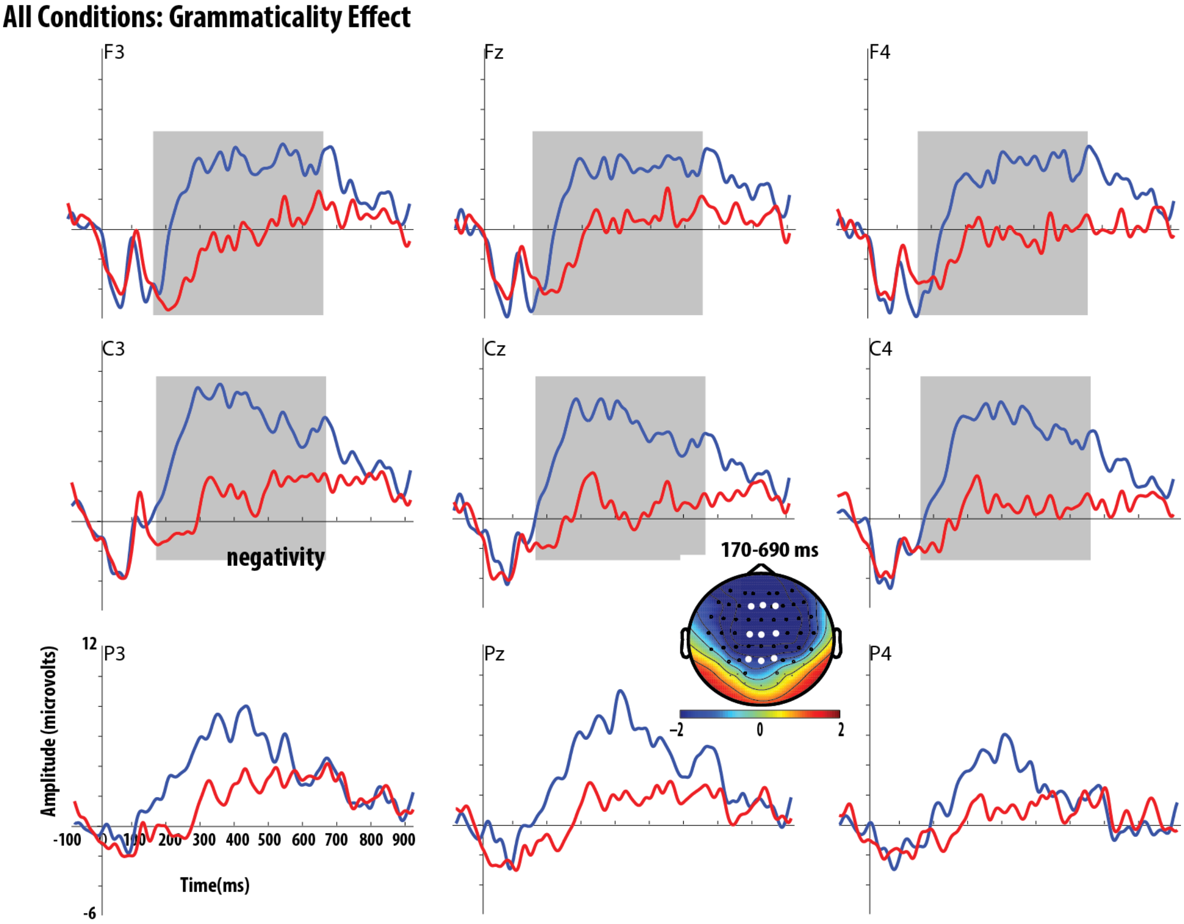

Figure 4: Grand average ERP waveforms for grammatical and ungrammatical conditions across positions and type of agreement violation at the F3, Fz, F4; C3, Cz, C4, P3, Pz, and P4 electrodes and the topographic maps of the significant ERP effects. The first row of the figure shows the anterior electrodes while the second row shows central electrodes and the third row shows the posterior electrodes. The ERPs are time-locked to the offset of the verb-stem (end of stop closure) and positivity is plotted upwards. The topographic maps show brain voltage distributions for the negative and positive clusters. These maps were obtained by interpolation from 64 electrodes and were computed by subtracting the grand averages of grammatical from the ungrammatical conditions. Electrodes in the significant clusters are highlighted with a black circle and the F3, Fz, F4; C3, Cz, C4, P3, Pz, and P4 electrodes are highlighted with a white circle. Time-windows for significant clusters is highlighted in grey over the waveforms.

However, since the cluster-based permutation test cannot be used for testing the interactions between type of agreement violation, utterance position, and grammaticality, we therefore performed further analyses using repeated-measures multivariate analysis of variance (MANOVA) on the time windows (170-690 ms) where the grammaticality effect yielded significant amplitude differences across all comparisons. The aim of this analysis was to statistically test the extent to which type of agreement violation and utterance-position effects contributed to the grammaticality effect.

MANOVA: Effects of type of agreement violation and utterance position

We performed MANOVA on mean amplitude measurements taken from 170 to 690 ms for all the eight experimental conditions. The within-subject factors were Type of agreement (singular, plural), Position (medial, final), Grammaticality (grammatical, ungrammatical) and Region of interest (nine regions of interest) [ROI]. The ROIs were computed from the means of electrodes in the parenthesis: (anterior midline [Fz, FCz], central midline [Cz, CPz], posterior midline [Pz, POz], anterior left [F7, F5, F3, FT7, FC5, FC3], central left [C3, C5, T7, CP3, CP5, TP7], posterior left [P7, P5, P3, PO7, PO5, PO3], anterior right [F4, F6, F8, FC4, FC6, FT8], central right [C4, C6, T8, CP4, CP6, TP8], posterior right [P8, P4, P6, PO4, PO6, PO8]). These electrode groupings are illustrated in **Figure 5.** The results of the MANOVA performed on the 170-690 ms time-window are reported in **Table 4.**

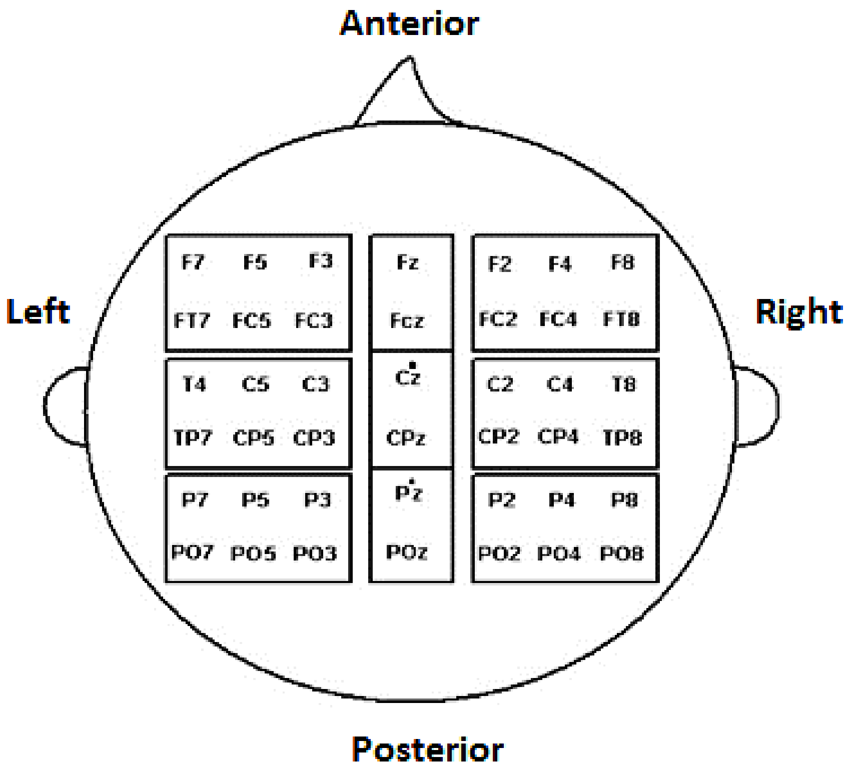

Figure 5: Approximate placement for the electrodes included in the regions of interests (ROI) analysis for MANOVA. The rectangles indicate the levels used to demacate the nine ROI (anterior midline (Fz, FCz), central midline (Cz, CPz), posterior midline (Pz, POz), anterior left (F7, F5, F3, FT7, FC5, FC3), central left (C3, C5, T7, CP3, CP5, TP7), posterior left (P7, P5, P3, PO7, PO5, PO3), anterior right (F4, F6, F8, FC4, FC6, FT8), central right (C4, C6, T8, CP4, CP6, TP8), posterior right (P8, P4, P6, PO4, PO6, PO8).

ERP results in the 170-690 ms time window

The statistical analysis for this time window showed main effects of Position (Pillai's trace = .528, $F(1,16) = 17.915$, $p < .005$) and Grammaticality (Pillai's trace = .271, $F(1,16) = 5.950$, $p < .05$) and a three way interactions between Type, Position and Grammaticality (Pillai's trace = .230, $F(1,16) = 4.773$, $p < .05$). The three-way interaction between suggests that the effect of the Grammaticality differed depending on type of agreement violation and utterance position. To test this, follow-up MANOVAS were performed on grammatical and ungrammatical conditions with Type, Position and ROI as within-subject factors. The analysis showed main effects of Position for both Grammatical (Pillai's trace = .364, $F(1,16) = 9.167$, $p < .05$) and Ungrammatical (Pillai's trace = .416, $F(1,16) = 11.385$, $p < .005$) conditions. However, the Ungrammatical condition showed a further two way interaction between Type, Position (Pillai's trace = .230, $F(1,16) = 4.774$, $p < .05$). Further analysis performed on each ROI with Type and Positon as within-subject factors revealed that the interaction was significant in the front-left region (Pillai's trace = .233, $F(1,16) = 4.605$, $p < .05$), front-right region (Pillai's trace = .385, $F(1,16) = 10.028$, $p < .005$) and central-mid region (Pillai's trace = .254, $F(1,16) = 5.441$, $p < .05$).

Follow up pairwise t-tests revealed that the mean amplitude of the negativity for ungrammatical conditions was significantly greater for errors of omission in the utterance-final position (M =-.868 µV, $SE =0\ .441$) than in the utterance-medial position (M = 2.408 µV, SE = 0.773), $t\ (16) = -3.642$, $p < .002$, in the central-mid region. This indicates that the negativity evoked by errors of omission in the utterance-final position was strongest in the central-mid regions of the scalp. This pattern is reflected in the grand averaged ERP waveforms for grammatical and ungrammatical trials (errors of omission vs. commission) in the utterance-medial and utterance-final position shown in **Figures 6** and **7.** Overall, the interactions indicate that the amplitude and distribution of the negativity varied as a function of type of violation and utterance position. Thus, the negativity observed in the overall cluster-based permutation was driven by the errors of omission in the utterance final position.

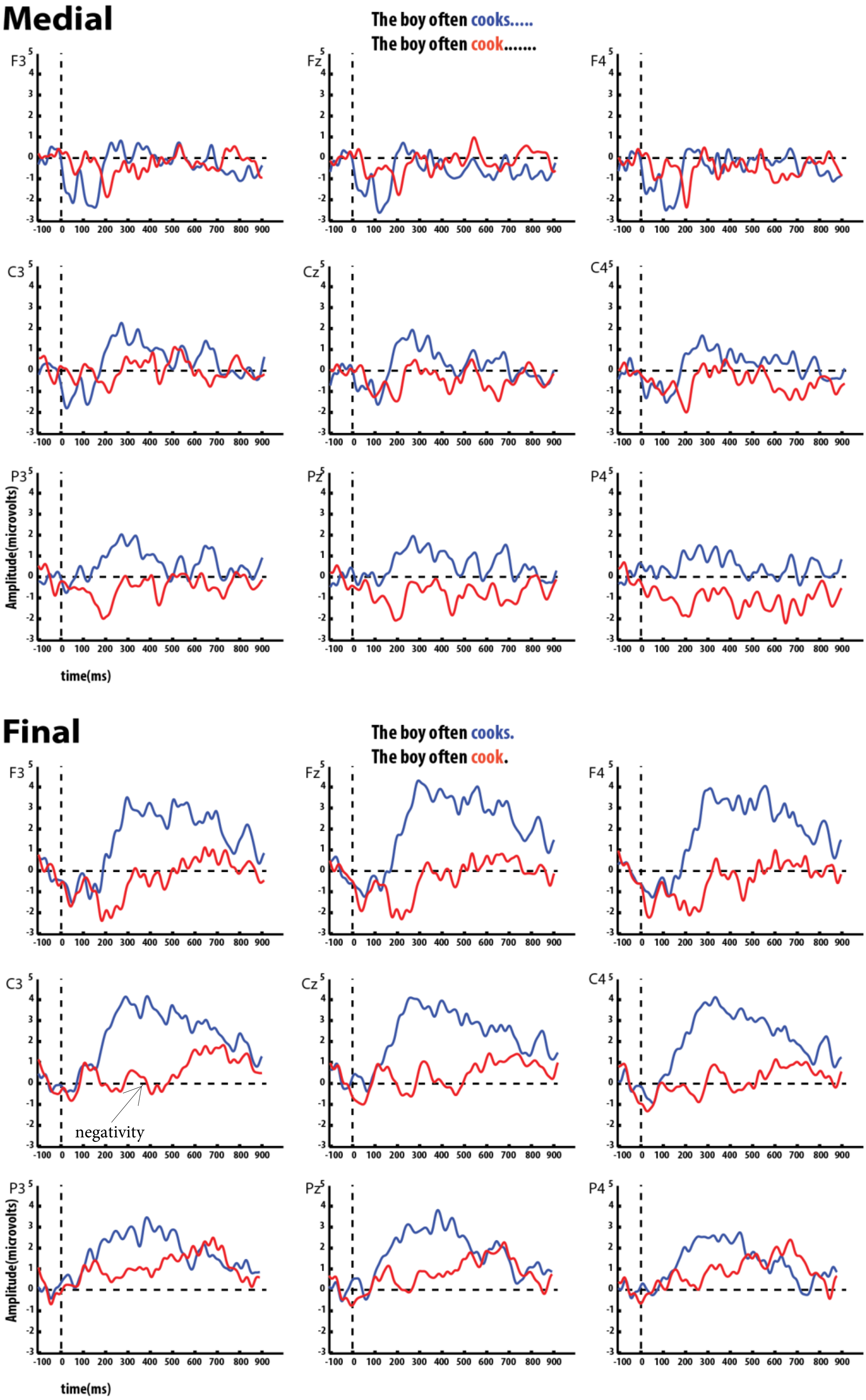

Figure 6: Grand average event-related potentials elicited by errors of omission (red) and correct verb (blue) in medial and final position.

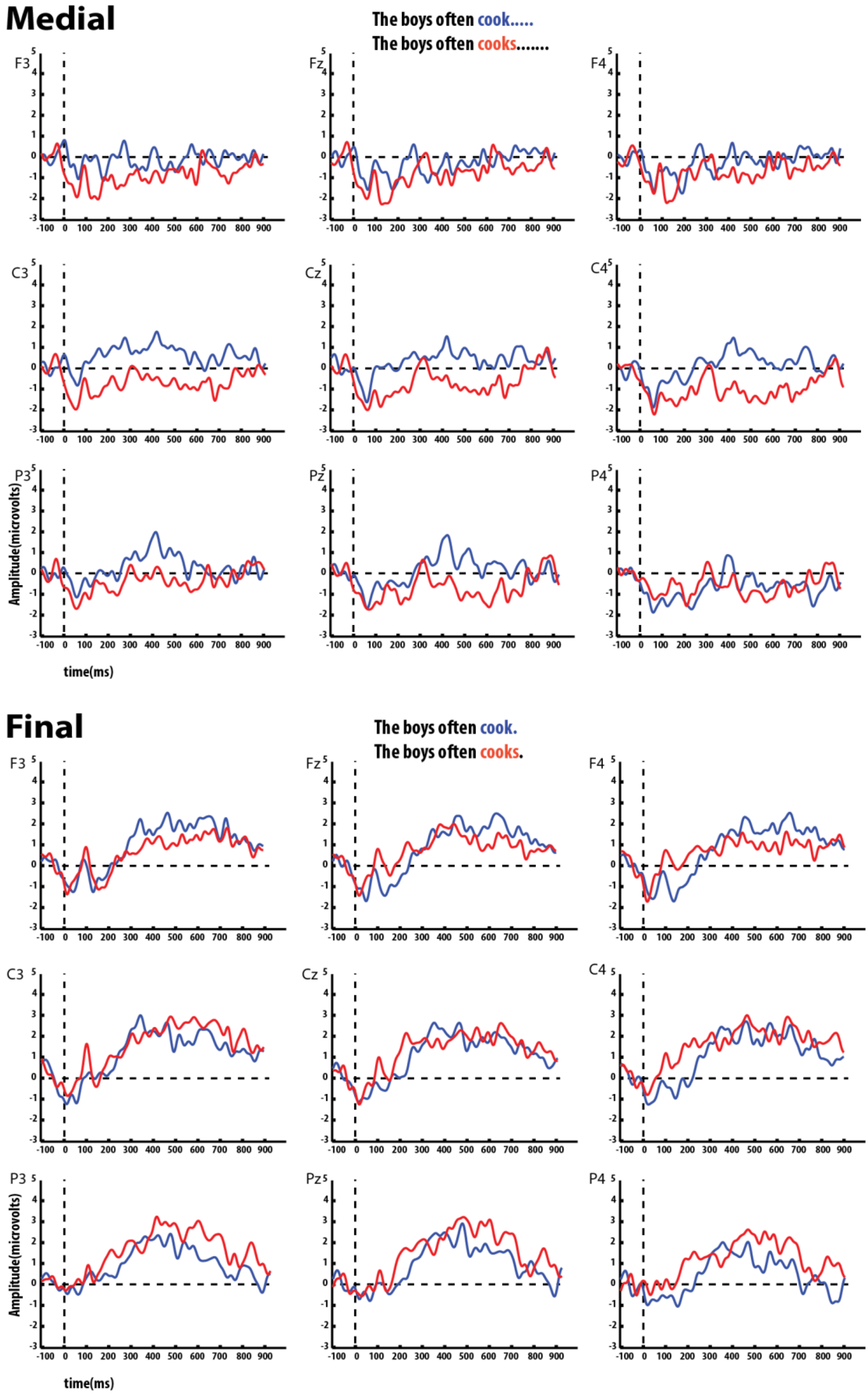

Figure 7: Grand average event-related potentials elicited by errors of commission (red) and correct verb (blue) in medial and final position.

Discussion

This study investigated ERP responses to S-V agreement violations during auditory sentence comprehension in children aged 8-11-years-old. The aim of the study was to explore whether the LAN and/or P600 effects would vary as a function of relative perceptual salience of S-V agreement due to type of agreement violation (errors of omission vs. commission) and utterance position (medial vs. final). Previous child ERP studies investigating the processing of agreement have shown that maturational factors influence the on-line computation of agreement information, as indicated by decrease in latencies and focalisation of ERP effects with age. However, the possibility that other factors inherent in the speech stimuli, e.g., perceptual salience, may influence the computation of S-V agreement has not yet been explored. Understanding how the different properties of speech influence the on-line computation of agreement information will enhance our knowledge of the factors that modulate sentence comprehension. This study is therefore the first to explore whether the perceptual salience of the type of agreement violation and the utterance position influence 8-11-year-olds s' sensitivity to S-V agreement violation during on-line speech comprehension.

Previous studies investigating morphosyntactic processing in children have reported that 8-11-year-olds s show adult-like LAN/P600 effects (Clahsen et al., 2007), which indicate morphosyntactic violation detection and sentence reanalysis (Friederici, 1993). Based on this, we predicted that children in our study will show sensitivity to both types of S-V agreement (errors of omission and commission). However, due to the stimulus manipulations used in this study, we predicted that these effects will be more robust for the more perceptually salient conditions (errors of commission and utterance-final positions) than their counterparts, thus, replicating the results of Dube et al. (submitted).

Results for the overall grammaticality effect, with all conditions collapsed, showed that S-V agreement violations evoked a sustained negativity that was broadly distributed over the scalp. This indicated that children were sensitive to the violation. However, this effect differs from that previously observed in adults. This difference can be related to maturational effects. Further analyses with MANOVA revealed that this negativity was elicited by errors of omission, in both utterance-medial and final positions. However, errors of omission in the utterance-final position elicited a more robust negativity compared to errors of omission in the utterance-final position. These results support the prediction of an utterance-position effect. Furthermore, the results from the MANOVAs revealed that the negativity observed for errors of omission in the utterance-final position was strongest in the central regions of the scalp. Based on its scalp distribution, we interpreted this negativity to be an N400 effect, taken to reflect lexical/semantic processes associated with failure to integrating the input stimuli with the predicted word form or thematic assignment (Kolk & Chwilla, 2007). However, based on the sustained latency of the effect, 170-690 ms, we interpret this to be an extended N400 effect, possibly overlapping with an anterior negativity (AN) (Clahsen et al., 2007).

Contrary to our predictions that 8-11-year-olds would elicit type of violation effects as observed in adults (Dube et al., submitted), the negativity was only observed for S-V agreement violations involving errors of omission but not errors of commission. Furthermore, no positivity was observed. In summary, these results support the prediction that 8-11-year-olds' sensitivity to S-V agreement violations was modulated by perceptual salience (utterance-final lengthening). However it is important to note that the ERP components differed from those observed in adults due to neural maturation. We discuss these factors in more detail below.

ERP of S-V agreement and maturational effects

Results from previous studies suggest that children begin to show adult-like brain responses (LAN and/ or P600 effects) to syntactic violations by the age of 8 (e.g., Hahne et al., 2004; Clahsen et al., 2007). Contrary to these studies and to our prediction, our results show that the processing of S-V agreement violation by 8-11-year-old English-speaking children evoked N400-like effects, instead of LAN or P600 effects. The present results suggest that these children did not engage in similar processing mechanisms as those previously observed in English speaking adults (e.g., Dube et al., submitted), or in other children of similar age (e.g., Clahsen et al., 2007).

The differences observed between the present results and the results from previous L1 adult studies can be accounted for in terms of maturational development, which has been previously argued in other studies (e.g., Meier, 2008). In her study of English speaking adolescents, Meier (2008) also observed an N400 effect in adolescent English-speakers and interpreted it to index that the adolescence is still undergoing neural development, and thus their language processing is not yet adult-like. As a result, language tasks that require children to process complex tasks like syntactic violations tend to increase processing load which children may not handle due to their immature brain structures underlying syntactic processes (see also, Friederici, 2002, 2006). However, given that other previous studies of S-V agreement in children reported LAN/P600 like effects for agreement violations, it is possible that the differences in the observed ERP components could be due to the syntactic structures investigated (e.g., noun over-regularisation vs. subject-verb agreement violation) or languages thereof (English vs. German). The processing of agreement violations with different morphosyntactic features has been shown to elicit ERP components in adult studies

(Molinaro, Barber, & Carreiras, 2011). Furthermore, S-V agreement violations manipulated for relative perceptual salience (Sundara et al., 2011; Dube et al., submitted).

Perceptual salience effects

Recall that besides maturational effects, we had predicted that ERP effects would vary due to perceptual salience associated with the overtness of the violation (type of agreement violation) and phrase-final lengthening (utterance position effects). However, the results only showed an N400-like effect to a missing 3SG -s (errors of omission), but not the superfluous counterpart (errors of commission). We interpret the absence of ERP effects for errors of commission to suggest that 8-11-year-olds in this study were not influenced by the overtness of error. In contrast, children showed different sensitivity to errors of omission as a function of utterance position, which manifest in scalp distribution and mean amplitude differences of the negativity.

Errors of omission in utterance-final position evoked an N400 effect that had a larger mean amplitude in the central-mid region of the scalp compared to the elicited in utterance-medial position. According to Rugg and Coles (1995), amplitude differences in the ERP effects suggest different levels of engagement of the neural structures in the processing of stimuli. This suggestion is in line with the accumulating evidence from adult ERP studies: The nature of incoming stimuli influences the general cognitive processes (e.g., predictive and decision making processes) (e.g., Dröge et al., 2016). Given that our study used stimuli manipulated for perceptual salience, it is possible that the lengthening of the 3rd person singular –s enhanced children's detection of the violation, and thus the error of omission in the utterance-final position evoked an N400 instead of a LAN. According to the general cognitive processing view (e.g., Bornkessel-Schlesewsky et al., 2015), the processing of these perceptual salience cues may engage different cognitive processes associated with prediction and decision certainty, which are independent of the underlying linguistic process (e.g., morphosyntactic processing) is the same.

Therefore, in the present study, the N400 effect provides evidence for children's sensitivity to the S-V agreement violation. That is, they were able to detect the mismatch between the expected input and the actual input. However, this seems to have only applied to an expected grammatical morpheme that was missing was missing (errors of omission), but not to a superfluous unexpected morpheme. We interpret this lack of sensitivity to errors of commission to suggest that the 8-11-year-olds consider the error of commission as redundant information, which however, was shown to impact on adults' processing of S-V agreement.

Another important aspect to note is that the N400 effect varied in amplitude depending on utterance position. This was in line with our prediction that 8-11-year-olds were more sensitive to S-V agreement errors occurring in utterance-final positions that were more perceptually salient. These results demonstrate that perceptual salience enhances listeners' sensitivity to speech input and thus affect how the brain responds to grammatical violations. These findings corroborate results from infant-perceptual studies (e.g., Sundara et al. 2011) and processing studies in adults (e.g., Dube et al. submitted) which have shown that increased syllable (and morpheme) duration provides extra acoustic cues which listeners use during the comprehension of subtle morphosyntactic information such as 3SG –s.

Lastly, we suggest that the absence of the P600 effect may be due to maturational effects. In particular, the neural structures involved in the P600 effects—i.e. the frontal lobe—is still maturing (Paus et al., 1999; Friederici, 2002, 2006). Overall, the presence of an N400 effect, its variability due to utterance position, and the absence of P600 effects in children, support the view that sentence comprehension is subserved by general cognitive processes such as predictive and decision certainty. However, since this is the first study to report auditory perceptual salience effects on S-V agreement processing in children, further research is required with more participants to corroborate these findings.

Conclusion

This study used ERPs to explore the possibility that perceptual salience related to type of agreement violation (errors of omission vs. commission) and utterance position (medial vs. final) influences the computation of S-V agreement violation during auditory sentence comprehension. Previous studies have focused on investigating how maturational effects impact on the on-line processing of S-V agreement violation, with very few studies focusing on how other experimental- or stimuli-related factors influence this process. As a result, the perceptual salience associated with S-V agreement violations has not been considered as an important factor when interpreting and generalizing the processes that modulate agreement processing. In this study, we observed that the ERP effects elicited by S-V agreement violations in 8-11-year-olds English-speaking children differed qualitatively from those reported in previous adult studies—an N400 instead of LAN or P600 effects. Although this observation was contrary to previous findings from 8-11-year-olds and our predictions, we suggest that the differences could be due to different linguistic structures investigated in previous studies or the languages investigated. More research in English-speaking children may clarify these issues. These findings have important methodological and theoretical implications for understanding on-line sentence comprehension and language acquisition in children with and without language delay.

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CHAPTER 5

General Discussion

Introduction

As highlighted throughout this thesis, a key aspect of successful sentence comprehension is figuring out the relationship between various elements in a sentence, and one of these relationships is the S-V agreement (Eberhard, Cooper, & Bock, 2005; Nicol, Forster, & Veres, 1997). In the ERP literature, the on-line computation S-V agreement has been extensively studied using the LAN and/or P600 components. Traditionally, the on-line computation of S-V agreement is argued to be largely determined by morphosyntactic processes that involve thematic-role assignment (Friederici et al., 1993; Friederici, 2002). However, more recent has shown that the neural processes underlying S-V agreement computation are susceptible to factors other than morphosyntactic factors. Some of these include morphological-features salience (e.g., Nevins et al., 2007; Barber & Carreiras, 2005), experimental tasks (e.g., Kolk et al., 2003), orthographic saliency and language proficiency (e.g., Osterhout et al. 2006), modality of presentation (e.g., Hastings & Kotz, 2008), syntactic complexity of stimuli (e.g., Gouvea, Phillips, Kazanina, & Poeppel, 2009; Osterhout, McLaughlin, Kim, Greenwald, & Inoue, 2004), individual differences (e.g., Tanner, Inoue, & Osterhout, 2014) as well as the nature of experimental designs and data processing (e.g., Steinhauer & Drury, 2012) (for a review, see Molinaro et al., 2011).

These various factors have been shown to modulate the latency, amplitude, scalp distribution and presence or absence of the LAN and/or P600 components. This indicates that sentence comprehension is constrained by a number of factors, not just syntactic factors—the debate surrounding the models of sentence comprehension (e.g., Bornkessel-Schlesewsky et al. 2015; Frazier & Fodor 1978; Friederici 2002; Trueswell, Tanenhaus, and Garnsey 1994; Pickering and Garrod 2013). It is therefore important to understand the factors and processes that may modulate the on-line computation of agreement information as this may enhance our understanding of how speakers comprehend sentences. By understanding these processes, we may also get closer to resolving the ongoing debate on the functional interpretation of the neural correlates for morphosyntactic processing—the LAN/N400 and the P600 ERP components. Furthermore, findings from such investigations can potentially shed light on the factors that constrain the acquisition of morphosyntactic elements in children and L2 learners of English.

To this end, the goal of the current thesis was to contribute to sentence comprehension research by investigating one factor, perceptual salience, that has received little attention in sentence-processing research, yet it has been observed to influence listeners' sensitivity in off-line sentence comprehension (Sundara, Demuth, & Kuhl, 2011) and on-line prosodic processing studies (e.g., Dimitrova, Stowe, Redeker, & Hoeks, 2012). We assume that the lack of reports on perceptual-salience effects in ERP studies of sentence comprehension is in part due to the fact that most ERP studies of sentence comprehension have used the visual modality which is not sensitive to auditory perceptual salience. As such, little is known about the role of auditory perceptual salience in sentence comprehension.

We used ERPs to investigate how relative perceptual salience of S-V agreement, due to type of agreement violation (errors of omission vs. errors of commission and utterance position (medial vs. final) might influence sentence processing during on-line sentence comprehension. We investigated this in three different populations, i.e. adult English-speakers (L1), adult Mandarin-English learners (MLEs) and 8-11 year-old L1 children. While a number of factors have been attributed to L1 adults' variable ERP responses, the ERP responses from MLEs and children have been often explained in terms of L2 proficiency and maturational effects, respectively. Since it is not known how perceptual salience may affect the processing of S-V agreement violation in all these groups, we first tested adult L1 Australian-English speakers to establish a baseline against which to investigate if MLEs and children's sensitivity to S-V agreement violations differed as function of perceptual salience. In the following paragraphs, we briefly recap the results from the three studies and then give an overall discussion of these findings in light of the role of perceptual salience in sentence processing and discuss our results in light of the current sentence comprehension theories. We also discuss the implications of these findings have for experimental designs and language acquisition research.

Summary of findings

For the L1 adults, the predictions were as follows: agreement violations would elicit LAN and/or P600 effects as previously reported for morphosyntactic processing. However, the ERP effects would be modulated by perceptual salience effects. In particular, errors of commission would elicit more robust ERP effects than errors of omission due to the greater perceptual salience of the overt violation, and that the effect would be more robust in utterance-final position due to phrase-final lengthening. As predicted, our overall grammaticality results from the cluster-based permutation tests revealed AN/P600 effects with an earlier latency than that usually reported in reading studies (e.g., Molinaro et al., 2011). The early latency is however in line with other studies that used the auditory modality, e.g., Hasting & Kotz (2008). The AN/P600 effects indicated that adults were sensitive to the agreement violations. Furthermore, when we performed MANOVAs to investigate how the different perceptual salience manipulations might have contributed to the overall results, we observed that, in contexts where the S-V agreement violation had higher perceptual salience (errors of commission and utterance-final positions), a P600 effect manifested with broader scalp distribution and larger amplitude, whereas a negativity was observed for the least perceptually salient context. These results supported our prediction that listeners would be more sensitive to errors in more perceptually salient contexts (errors of commission and errors in utterance-final position.

Given findings from the L1 adults, the study on **Mandarin learners of English (MLEs)** sought to investigate if L2 learners who had been immersed in an English-speaking environment for 2-3 years would show native-like sensitivity to perceptual salience during on-line sentence comprehension. We therefore predicted that the MLEs would show similar ERP results as the L1 participants if they are processing the agreement information in a native-like manner. However, we also anticipated that MLEs may yield different ERP results from the L1 speakers due to their L2 proficiency. Contrary to our expectations, the overall grammaticality results from the cluster-based permutation tests did not yield any significant clusters. We assumed this could have been due to individual differences that cancelled out the effects. We conducted further cluster-based permutation tests separately for the four experimental conditions. We then observed that participants were sensitive to the more perceptually salient errors of commission, but only in utterance-final position, as indicated by an anterior P600. When we further explored the data by splitting participants according to their length of immersion in Australia, we only observed effects in those participants with longer immersion. The effects were however restricted to the utterance-final position, where errors of omission elicited a late negativity with a posterior distribution compared to errors of commission which elicited a P600 with a frontal distribution. No differences were observed in participants with shorter immersion.

We interpreted these results to suggest that, despite L1-L2 language structure differences, MLEs who have more experience listening to English are sensitive to grammatical morphemes, especially when these occur in perceptually salient contexts. These findings differed significantly from previous MLE studies which have reported N400 effects for learners with advanced proficiency (e.g., Xue et al., 2013). While the difference between this study and the previous MLE studies could be due to the nature of participants we studied (immersed in Australia for at least 3 years) as well as the experimental task used, we assume that the auditory modality and the relative perceptual salience manipulations of the violations, used in this study may have also played a role.

Having established the effects of perceptual salience in the L1 and L2 adults, the study of **L1 children** sought to examine whether children process agreement information in the same way as adults. If so, we expected to observe the same ERP results reported in the L1 adult study. If not, children's processing of agreement violation could be potentially constrained by neural maturation (Brauer, Anwander, & Friederici, 2011; Meier, 2008). In this case we would observe different ERP effects in the L1 children compared to the adults. The overall grammaticality results from the cluster-based permutation tests revealed a negativity that was sustained and broadly distributed over the scalp—indicating that the children were sensitive to the agreement violation. This negativity was contrary to our prediction that 8-11-year-olds would elicit responses similar to adults but in line with our counter prediction that children may not show adult like sensitivity due to constraints of neural maturity (Friederici, 2011; Meier, 2008).

However, when we performed MANOVAs to investigate how the different perceptual salience manipulations might have contributed to the overall results, we observed that, 8-11-year-olds were differentially sensitive to errors of omission as a function of utterance position. Errors in the utterance-final position elicited a negativity with a greater mean amplitude that was strongest in the central-mid region compared to the errors in the utterance-medial position. Due to its scalp distribution, we interpreted this negativity to an N400 effect. A similar effect has been previously reported in English-speaking adolescents (Meier, 2008) where it was interpreted to reflect inadequate cognitive capacities due to maturational development. Taken together with the absence of P600 effects, these results are in line with previous studies that have suggested that the underlying brain structures associated with syntactic processes are still developing in 11year-olds (Friederici, 2002; Hahne, Eckstein, & Friederici, 2004; Paus et al., 1999). However, the differential effects for errors of omission in utterance medial and utterance-final position indicates that children were sensitive to perceptual salience (utterance position) despite the fact that their neural systems for syntactic processing are still developing. The absence of effects for errors of commission may suggest that unlike adults, children are not sensitive to perceptual salience that is due to superfluous information.

Taken together, results from these three studies have demonstrated that the processing of S-V agreement during on-line comprehension is influenced by the perceptual salience of the grammatical error. However, the effects observed in MLE and L1 children manifest differently from those of L1 adults as a function of language proficiency and maturational development, respectively. While these findings on proficiency and maturational effects are in line with previous studies, the observation that brain responses to S-V agreement violations varied as a function of perceptual salience has not been reported before. Now we turn to the discussion on the importance of perceptual salience in sentence processing and the implications this has for the functional interpretation of ERP components as well as methodological design of ERP experiments.

The role of perceptual salience in sentence processing

Recall, that in the introduction to this thesis, we discussed two psycholinguistics views that have influenced sentence-processing research: The serial/syntactic-first view

(Frazier & Fodor, 1978), and the parallel/interactive view (e.g., Trueswell, Tanenhaus, & Garnsey 1994; Trueswell, Tanenhaus, & Kello 1993), on which the internal models are based (e.g., Pickering & Garrod, 2007, 2013; Bornkessel-Schlesewsky & Schlesewsky, 2015). The former view does not account for how non-syntactic factors, such as the perceptual salience of the input, influence morphosyntactic processing, (e.g., S-V agreement processing). However, the latter does. According to the internal models of sentence comprehension, the nature of incoming stimuli may engage different general cognitive processes depending on the available syntactic and non-syntactic cues (e.g., Pickering & Garrod, 2013).

For example, in processing S-V agreement, the grammatical features and contextual information associated with S-V agreement may influence how listeners predict and match incoming stimuli to the underlying linguistic representations (the predictive processes) or make decisions about the meaning of the sentence (decision certainty processes). The predictive processes are often associated with the elicitation of a negativity effect, whereas the decision certainty processes are associated with the P600 effect cues (for discussion, see Dröge, Fleischer, Schlesewsky, & Bornkessel-Schlesewsky, 2016). Furthermore, these models propose that the engagement of the cognitive processes may also vary depending on the listeners' previous experiences with the incoming stimuli, implying that language proficiency may further impact on how listeners process sentences during online comprehension.

The proposals made in these models fit the findings from the three studies summarised above. In all the three groups of participants, we observed different participants' brain responses to the S-V agreement violations, which vary in the degree of perceptual salience. This difference was due to the auditory perceptual salience associated with the type of agreement and/or utterance position. Notably, while L1 adults showed differential sensitivity to errors of omission and commission in utterance-medial and utterance-final position, MLEs with longer immersion in an English speaking environment showed differential sensitivity to errors of omission and errors of commission, only in utterance-final position,. On the other hand, 8-11-year-olds only showed differential sensitivity to errors of omission in utterance-medial and utterance-final position. While results from L1 adults and MLEs with longer immersion show utterance-position effects for both types of errors, the different patterns of sensitivity observed in children (sensitivity to errors of omission only) deserve further investigation. Our premature assumption is that children are only sensitive to grammaticality mismatches that violate the expected grammatical structure; superfluous information in the errors of commission is irrelevant for how they process agreement. However, despite the differences observed between the groups, our results show that perceptual salience due to utterance position (phrase-final lengthening) impacted on how participants responded to the violations. This supports the view that perceptual salience due to utterance-position plays an important role in sentence comprehension (Sundara et al., 2011).

In light of the internal models, we assume that phrase-final lengthening cues make the incoming input clearer and easier to match to the underlying representations, thus the sentence reanalysis (decision certainty processes) occurs (e.g., the centro-posterior P600 effect in L1 adults, the frontal P600 effect in MLEs). However, when these cues were missing the errors only elicited negativity effects, (e.g., anterior negativity in L1 adults, N600 in MLEs, and N400 in children). However, we must be quick to mention that the 8-11-year-olds elicited an N400 effect, albeit with a broader scalp distribution, in the more perceptual salient utterance-final position where we expected a P600 effects. We interpreted the absence of the P600 effects in children in light of neural maturation

(Friederici, 2006). Thus, although 8-11-year-olds showed sensitivity to S-V agreement violations involving errors of omission, we assume that the decision certainty processes did not occur due to immature areas of the brain associated with sentence processing.

Implications for the interpretation of the LAN, N400 and P600 effects

The processing of agreement violations is traditionally assumed to elicit LAN/P600 effects in adult native speakers (e.g., Coulson, King, & Kutas, 1998; Osterhout & Mobley, 1995; Shen, Staub, & Sanders, 2013), LAN-like/N400 or P600-like effects in children (e.g., Clahsen et al., Hanhe, et al., Meier, 2008) and N400 effects in L2 learners (e.g., Osterhout et al., 2006; Xue et al., 2013). The LAN is often taken to reflect detection of morphosyntactic violations (e.g., Friederici, 2002), while the N400 reflects lexical-semantic integration difficulties (e.g., Kutas & Hillyard, 1980), and the P600 to reflect syntactic reanalysis (Friederici, et al., 1993; Osterhout & Mobley, 1985).

However, this modular-specific approach to the functional interpretation of language related components has been challenged. For example, some studies have reported N400 effects for the processing of morphosyntactic violations (e.g., Coudhary et al., 2009; Nevins et al., 2007), while others have failed to observe any LANs (Kaan, Harris, Gibson, & Holcomb, 2000; Osterhout, McKinnon, Bersick, & Corey, 1996) or P600 effects (Kutas & Hillyard, 1983; O'Rourke & Van Petten, 2011) for these type of violations. Furthermore, some studies have reported amplitude and scalp distribution differences of the P600 effects, due to other non-syntactic factors, such as modality of presentation (Hasting & Kotz, 2008) or orthographic salience (e.g., Osterhout et al. 2006). These findings have been interpreted to suggest that there must be other non-syntactic processes independent of the specific language modules.

As a result, various explanations have been proposed to account for variable realisations of the LAN/P600 ERP components (e.g., Molinaro et al., 2011; Steinhauer &

Drury, 2012; Tanner & Van Hell, 2014). However, some of the accounts do not apply to our current data. For example, Hagoort & Brown (2000) only observed a negativity when they used the auditory modality but not the visual modality. As a result, they suggested that the presence of the LAN varied as a function of the modality of presentation. However in this thesis, we used the auditory modality but only observed negative ERP effects (an AN in L1 adults, an N400 in children, a late negativity in MLEs) in one of the four conditions that was the least perceptual salient. Although these negativities differed in scalp distribution, we interpreted them to be generated by the same underlying predictive processes. This finding suggests that the occurrence of the negativity is not modulated by the modality of presentation as previously argued by Friederici et al. (1993).

Other factors that have been argued to modulate the presence of the negativity include the morphological richness of a language (Friederici & Weissenborn, 2007), working memory load of the stimuli (Vos et al., 2001), and individual differences (Tanner & van Hell, 2014; Tanner, 2015). However, in this thesis, these explanations would not suffice given that the negativity was only observed in one of the four experimental conditions, (errors of omission) despite using the same mode of presentation, the same language, controlled utterance-length (until the point of violation) and the same participants within each group, respectively. Instead, results from our study seem to suggest that the presence of negativity depends on the perceptual salience of the violation. This is because we only observed a P600 effect when the S-V agreement violation occurred in contexts that were more perceptually salient (e.g., errors of commission in utterance-final position) while we observed the negativity in the least perceptually salient context (errors of omission in utterance-medial position).

A possible explanation that fits our findings is that the absence of negativity effects is due to overlap between components. For example, Kuperberg (2007) argued that when sentence reanalysis overlapped with semantic integration, the early P600 obscured the N400. In the case of the present findings, it is likely that the presence of an early P600 in the absence of a negativity in the more perceptually salient contexts is due to an overlap between morphosyntactic violation detection and syntactic reanalysis influenced by perceptual salience. In contrast, in the case of the less perceptually salient violations, since there is no sentence reanalysis, we observe the negativity, which signals morphosyntactic violation detection.

This explanation is in line with the internal models of sentence comprehension which assume that the nature of incoming stimuli may engage different general cognitive processes (e.g., predictive and decision certainty processes) depending on the available cues (e.g., Dröge, Fleischer, Schlesewsky, & Bornkessel-Schlesewsky, 2016). The predictive processes involve anticipation of upcoming information whereby speakers may use contextual or previous experience to match incoming input the underlying abstract representations. On the other hand, decision certainty processes involve making decisions about whether the input matches the predicted outcome (for further discussion, see Bornkessel-Schlesewsky et al., 2015). The more perceptually salient violations influenced the violation detection (decision certainty, i.e. P600 effects) whereas the in the less perceptually salient violations the decision certainty processes were less engaged (only negativity effect). It is thus suggested that the engagement of these cognitive processes may thus result in quantitatively or qualitatively different ERP responses, despite similar underlying neural functions.

Since the cognitive processes are said to occur independently of the linguistic processes (e.g., morphosyntactic processing), internal models of sentence comprehension suggest that the variable realizations of responses to linguistic violations should not be interpreted as reflecting modular-specific processes. We therefore interpreted the ERP responses observed in this thesis (monophasic negativity (AN/N400) and positivity) to be a function of the degree of perceptual salience of the S-V agreement violations. Thus, we propose that the presence of a negativity without a following P600 and the presence of a P600 without a preceding negativity, as observed in the three studies reported here, was modulated by the perceptual salience of the S-V agreement violation. This suggests that the absence of LAN or AN does not necessarily mean a lack of morphosyntactic violation detection, but overlap with the P600 due to the relative perceptual salience of S-V agreement violations, coupled with the speaker's cognitive abilities due to proficiency or neural maturity.

Methodological implications

As presented above, findings from all the three groups of participants suggest that sensitivity to S-V agreement violations differed as a function of perceptual salience associated with the type of agreement violation and/or utterance position. This sensitivity influenced the processing of S-V agreement during on-line speech comprehension. However, the perceptual salience effects manifest differently within each group. In adults, for example, listeners were more sensitive to errors of commission in utterance-final position (robust P600 effects) —the most perceptually salient condition—than errors of omission in utterance-medial position—the least perceptually salient condition. Previous studies have not been able to investigate such effects because they used the visual modality in which perceptual salience is irrelevant for S-V agreement. By using auditory stimuli, this study successfully explored how perceptual salience associated with the type of agreement violation and utterance position influence the computation of agreement during sentence comprehension in L1 adults, MLEs and 8-11-year-old English speaking children. The auditory modality is more ecologically valid than the visual modality for investigating the processing of S-V agreement, especially in younger populations or second-language learners who may not be efficient reader, but are exposed to spoken sentences every day.

Another important implication based on the current study is that collapsing errors of omission and commission is not ideal as it confounds some of the processes that underlie the computation of agreement information. Our results show that errors of omission and commission are processed differently due to the degree of perceptual salience associated with the type of violation and utterance position. In general, error of omission and errors of commission elicited different effects in utterance-medial compared to utterance-final position. It is, therefore, important for future studies investigating the processing of S-V agreement violations to avoid confounding type of agreement violation and utterance position given the different ERP effects. This has important theoretical implications for the functional interpretation of the LAN-like and P600 effects (see also Steinhauer and Drury, 2009 on the discussion of experimental design effects on ERPs).

Besides the experimental design, our findings also show that the nature of participants selected for the study, especially in the case of L2 learners, matters. Our results indicated that MLEs with longer immersion exposure (greater proficiency) were more sensitive to the acoustic cues of the S-V agreement errors, whereas those with less immersion exposure (lower proficiency) were not. Previous studies of MLEs who were advanced learners of English, but not in an immersion environment, (e.g., Xue et al., 2013) did not report any positivity. Our findings are therefore in line with research showing that immersion enhances proficiency and plays a role in L2 sentence processing (e.g., Bowden, Steinhauer, Sanz, & Ullman, 2013; Kotz, 2009; Steinhauer, White, & Drury, 2009; Van Hell & Tokowicz, 2010). It is therefore important for these factors to be considered when interpreting and generalising ERP components for L2 sentence processing.

Overall, findings from the three studies in this thesis suggest that auditory perceptual salience plays an important role in morphosyntactic processing and sentence comprehension as a whole. We also observed that S-V agreements violation effects manifest differently in MLEs and 8-11-year-olds compared to L1 adults, as a function of language proficiency and neural maturational development, respectively. While the findings on proficiency and maturational development are in line with previous findings, the observation that brain responses to S-V agreement violations varied as a function of perceptual salience has not been reported before. This is the first study to investigate how stimuli manipulation involving type of agreement violation (errors of omission vs. errors of commission and utterance position (medial vs. final) impact on S-V agreement violation processing during on-line sentence comprehension in L1 adults, L1 children and L2 adults. Findings from the study will add to our understanding of the factors that modulate sentence processing. In turn, this will inform the ongoing debate on the functional interpretation of the ERP components for language processing, the LAN, N400 and the P600 and enhance our understanding of the role of perceptual salience in language acquisition, both in children and L2 learners.

Limitations

Although we compare the ERP responses to S-V agreement across all three groups, there were some minor differences in these groups. One of those concerns the number of participants which was not evenly balanced. There were fewer children and MLEs compared to L1 adults. This was due to the fact that several participants from these two groups were excluded due to excessive EEG artifacts. Some children could not sit still, thus introducing a lot of muscle movement signals to the data. Also, some of the

MLEs were not familiar with doing language experiments, so they tended to be impatient and could not sit still; this also introduced muscle movement artifacts to the data. As a result of the few MLEs, we had to do the median split analysis for proficiency as we would not get enough power if we did MANOVA with proficiency as a between group factor. We will recruit more participants to follow-up on this. The other difference, related to the nature of the participants, concerns the filtering procedures applied across the groups. Given that the data from L2 and children was very noisy we used different filters compared to those used for L1 adults. It should also be noted that we did not use filler sentences as usually done in some ERP studies, but instead used catch trials to reduce the possible effects of repetitive lexical presentation of lexical items. Since we were investigating several manipulations of S-V agreement, adding filler sentences would have made the experiment too long. However, the robust effects within all groups suggest that the effects are big, and were adequate to allow for the discussions we raised on the role of perceptual salience in sentence processing.

Future Directions

Given that our study is the first to investigate the effects of perceptual salience on S-V agreement processing in English, there is a need for future studies to replicate this study to explore the extent to which perceptual salience influences on-line sentence processing. One of the ways to do so is to conduct a cross-linguistic study investigating effects of perceptual salience on S-V agreement processing or other types of agreement violation. Also, since the present study investigated S-V agreement in L1 adults and children, it will be interesting to also investigate whether younger L2 children process S-V agreement like L2 adults or L1 children. Such research may have implications for distinguishing bilingual children with typical syntactic development from those with SLI/ language delay.

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Appendix A: List of experimental stimuli

	Medial-Singular	Final-Singular
1	The boy often *bakes/*bake* in the night	The boy often *bakes/*bake*
2	The dog often *barks/*bark* at the gate	The dog often *barks/*bark*
3	The boy often *bats/ *bat* in the field	The boy often *bats/ *bat*
4	The phone often *beeps/*beep* in the bag	The phone often *beeps/*beep*
5	The girl often *burps/*burp* in the car	The girl often *burps/*burp*
6	The boy often *cheats/*cheat* in the test	The boy often *cheats/*cheat*
7	The bird often *chirps/*chirp* in the cage	The bird often *chirps/*chirp*
8	The boy often *chops/*chop* on the board	The boy often *chops/*chop*
9	The girl often *claps/*clap* at the show	The girl often *claps/*clap*
10	The boy often *cooks/*cook* on the stove	The boy often *cooks/*cook*
11	The jar often *cracks/*crack* at the top	The jar often *cracks/*crack*
12	The snail often *creeps/*creep* on the lawn	The snail often *creeps/*creep*
13	The boat often *docks/*dock* in the bay	The boat often *docks/*dock*
14	The bat often *shrieks/*shriek* in the cave	The bat often *shrieks/*shriek*
15	The pin often *drops/*drop* on the mat	The pin often *drops/*drop*
16	The flag often *flaps/*flap* in the wind	The flag often *flaps/*flap*
17	The duck often *floats/*float* in the pond	The duck often *floats/*float*
18	The boy often *hikes/*hike* in the bush	The boy often *hikes/*hike*
19	The owl often *hoots/*hoot* in the night	The owl often *hoots/*hoot*
20	The boy often *hops/*hop* in the park	The boy often *hops/*hop*
21	The girl often *knits/*knit* in the train	The girl often *knits/*knit*
22	The pipe often *leaks/*leak* on the road	The pipe often *leaks/*leak*
23	The girl often *leaps/*leap* on the stairs	The girl often *leaps/*leap*
24	The cat often *licks/*lick* at the bowl	The cat often *licks/*lick*
25	The boy often *mops/*mop* at the store	The boy often *mops/*mop*
26	The girl often *naps/*nap* on the chair	The girl often *naps/*nap*
27	The bird often *pecks/*peck* at the tree	The bird often *pecks/*peck*
28	The boat often *rocks/*rock* in the storm	The boat often *rocks/*rock*
29	The boy often *shakes/*shake* on the stage	The boy often *shakes/*shake*
30	The boy often *shoots/*shoot* at the goal	The boy often *shoots/*shoot*
31	The girl often *shops/*shop* at the mall	The girl often *shops/*shop*
32	The girl often *shouts/*shout* at the dog	The girl often *shouts/*shout*
33	The girl often *slips/*slip* in the rain	The girl often *slips/*slip*
34	The dog often *sits/*sit* on the couch	The dog often *sits/*sit*
35	The girl often *skates/*skate* in the rink	The girl often *skates/*skate*
36	The girl often *skips/*skip* on the rope	The girl often *skips/*skip*
37	The boy often *sleeps/*sleep* in the train	The boy often *sleeps/*sleep*
38	The boy often *smokes/*smoke* in the bar	The boy often *smokes/*smoke*
39	The girl often *speaks/*speak* at the show	The girl often *speaks/*speak*
40	The boy often *spits/*spit* on the floor	The boy often *spits/*spit*
41	The girl often *squats/*squat* in the gym	The girl often *squats/*squat*
42	The car often *stops/*stop* on the road	The car often *stops/*stop*
43	The boy often *sweeps/*sweep* in the yard	The boy often *sweeps/*sweep*
44	The boy often *trips/*trip* on the rope	The boy often *trips/*trip*
45	The boy often *trots/*trot* in the field	The boy often *trots/*trot*
46	The girl often *types/*type* on the desk	The girl often *types/*type*
47	The girl often *waits/*wait* in the queue	The girl often *waits/*wait*
48	The boy often *weeps/*weep* on the pillow	The boy often *weeps/*weep*

49	The boy often *works/*work* on the farm	The boy often *works/*work*
50	The boy often *writes/*write* on the board	The boy often *writes/*write*
	Medial-Plural	**Final-Plural**
1	The boys often *bake/*bakes* in the night	The boys often *bake/*bakes*
2	The dogs often *bark/*barks* at the gate	The dogs often *bark/*barks*
3	The boys often *bat/ *bats* in the field	The boys often *bat/ *bats*
4	The phones often *beep/*beeps* in the bag	The phones often *beep/*beeps*
5	The girls often *burp/*burp s* in the car	The girls often *burp/*burp s*
6	The boys often *cheat/*cheats* in the test	The boys often *cheat/*cheats*
7	The birds often *chirp/*chirps* in the cage	The birds often *chirp/*chirps*
8	The boys often *chop/*chops* on the board	The boys often *chop/*chops*
9	The girls often *clap/*claps* at the show	The girls often *clap/*claps*
10	The boys often *cook/*cooks* on the stove	The boys often *cook/*cooks*
11	The jars often *crack/*cracks* at the top	The jars often *crack/*cracks*
12	The snails often *creep/*creeps* on the lawn	The snails often *creep/*creeps*
13	The boats often *dock/*docks* in the bay	The boats often *dock/*docks*
14	The bats often *shriek/*shrieks* in the cave	The bats often *shriek/*shrieks*
15	The pins often *drop/*drops* on the mat	The pins often *drop/*drops*
16	The flags often *flap/*flaps* in the air	The flags often *flap/*flaps*
17	The ducks often *float/*floats* in the pond	The ducks often *float/*floats*
18	The boys often *hike/*hikes* in the bush	The boys often *hike/*hikes*
19	The owls often *hoot/*hoots* in the night	The owls often *hoot/*hoots*
20	The boys often *hop/*hops* in the park	The boys often *hop/*hops*
21	The girls often *knit/*knits* on the train	The girls often *knit/*knits*
22	The pipes often *leak/*leaks* on the road	The pipes often *leak/*leaks*
23	The girls often *leap/*leaps* on the stairs	The girls often *leap/*leaps*
24	The cats often *lick/*licks* at the bowl	The cats often *lick/*licks*
25	The boys often *mop/*mops* at the store	The boys often *mop/*mops*
26	The girls often *nap/*naps* on the couch	The girls often *nap/*naps*
27	The birds often *peck/*pecks* at the tree	The birds often *peck/*pecks*
28	The boats often *rock/*rocks* in the storm	The boats often *rock/*rocks*
29	The boys often *shake/*shakes* on the stage	The boys often *shake/*shakes*
30	The boys often *shoot/*shoots* at the goal	The boys often *shoot/*shoots*
31	The girls often *shop/*shops* at the store	The girls often *shop/*shops*
32	The girls often *shout/*shouts* at the dog	The girls often *shout/*shouts*
33	The girls often *slip/*slips* in the rain	The girls often *slip/*slips*
34	The dogs often *sit/*sits* on the couch	The dogs often *sit/*sits*
35	The girls often *skate/*skates* in the rink	The girls often *skate/*skates*
36	The girls often *skip/*skips* on the rope	The girls often *skip/*skips*
37	The boys often *sleep/*sleeps* in the train	The boys often *sleep/*sleeps*
38	The boys often *smoke/*smokes* in the bar	The boys often *smoke/*smokes*
39	The girls often *speak/*speaks* at the show	The girls often *speak/*speaks*
40	The boys often *spit/*spits* on the floor	The boys often *spit/*spits*
41	The girls often *squat/*squats* at the gym	The girls often *squat/*squats*
42	The cars often *stop/*stops* in the road	The cars often *stop/*stops*
43	The boys often *sweep/*sweeps* in the yard	The boys often *sweep/*sweeps*
44	The boys often *trip/*trips* on the rope	The boys often *trip/*trips*
45	The boys often *trot/*trots* in the field	The boys often *trot/*trots*
46	The girls often *type/*types* on the desk	The girls often *type/*types*
47	The girls often *wait/*waits* in the queue	The girls often *wait/*waits*
48	The boys often *weep/*weeps* on the pillow	The boys often *weep/*weeps*
49	The boys often *work/*works* at the farm	The boys often *work/*works*
50	The boys often *write/*writes* on the board	The boys often *write/*writes*

Appendix B: Ethics Approval

Office of the Deputy Vice-Chancellor (Research)

Research Office
Research Hub, Building C5C East
Macquarie University
NSW 2109 Australia
T: +61 (2) 9850 4459
http://www.research.mq.edu.au/
ABN 90 952 801 237
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MACQUARIE University
SYDNEY·AUSTRALIA

25 February 2015

Professor Katherine Demuth
Department of Linguistics
Faculty of Human Sciences
Macquarie University
NSW 2109

Dear Professor Demuth

Reference No: 5201200795

Title: *Neuro-Physiological processing of Morphosyntax in younger L2 learners of English*

Thank you for your correspondence dated 9 February 2015 submitting an amendment request to the above study. Your proposed amendment was reviewed and approved by the Ethics Secretariat, effective 16/02/2015

I am pleased to advise that ethical approval of the following amendments to the above study has been granted:

- Changes to the recruitment brochures and screening task for children as follows:

    1. Rewording of the brochure using simpler language and the addition of an EEG picture to make the information easier to understand and to reduce the drop out rate.
    2. Separate and translate the original brochure into Mandarin Chinese to enable parents of the target Mandarin-English speaking children access to the study. This will increase the chances of getting bilingual children.
    3. Using the latest version of the Test of Non Verbal Intelligence (TONI (4th edition) that is divided into specific age ranges and takes lesser time to administer.
    4. The addition of a short production screening task to get an idea of L2 learners morpheme production abilities.

The HREC (Human Sciences and Humanities) Terms of Reference and Standard Operating Procedures are available from the Research Office website at:

http://www.research.mq.edu.au/for/researchers/how_to_obtain_ethics_approval/human_research_ethics

Please do not hesitate to contact the Ethics Secretariat should you have any questions regarding your ethics application.

The HREC (Human Sciences and Humanities) wishes you every success in your research.

Yours sincerely

Dr Karolyn White
Director, Research Ethics & Integrity
Chair, Human Research Ethics Committee (Human Sciences and Humanities)

This HREC is constituted and operates in accordance with the National Health and Medical Research Council's (NHMRC) National Statement on Ethical Conduct in Human Research (2007) (the National Statement) and the CPMP/ICH Note for Guidance on Good Clinical Practice.

The following documentation submitted with your email correspondence has been reviewed and approved by the HREC (Human Sciences & Humanities):

Documents reviewed	Version no.	Date
Macquarie University HREC Request for Amendment Form	2.0	Received 9/2/2015
Child brochure L1 & L2 (Translated Chinese-Mandarin)	1	Feb 2015
Child brochure L1 & L2	2	Feb 2015
Participant Information & Consent Form (Parent-Child)	3	Feb 2015
Elicited Production Task		Feb 2015

MACQUARIE University

SITHEMBINKOSI DUBE <sithembinkosi.dube@students.mq.edu.au>

Approved- Ethics application- Demuth (Ref No: 5201200795)

Ethics Secretariat <ethics.secretariat@mq.edu.au> 14 November 2012 at 08:51
To: Prof Katherine Demuth <katherine.demuth@mq.edu.au>
Cc: Dr Jon Brock <jon.brock@mq.edu.au>, Ms Sithembinkosi Dube <sithembinkosi.dube@students.mq.edu.au>

Dear Prof Demuth

Re: "Neuro-Physiological processing of Morphosyntax in younger L2 learners of English" (Ethics Ref: 5201200795)

Thank you for your recent correspondence. Your response has addressed the issues raised by the Human Research Ethics Committee and you may now commence your research.

This research meets the requirements of the National Statement on Ethical Conduct in Human Research (2007). The National Statement is available at the following web site:

http://www.nhmrc.gov.au/_files_nhmrc/publications/attachments/e72.pdf.

The following personnel are authorised to conduct this research:

Dr Jon Brock
Ms Sithembinkosi Dube
Prof Katherine Demuth

NB. STUDENTS: IT IS YOUR RESPONSIBILITY TO KEEP A COPY OF THIS APPROVAL EMAIL TO SUBMIT WITH YOUR THESIS.

Please note the following standard requirements of approval:

1. The approval of this project is conditional upon your continuing compliance with the National Statement on Ethical Conduct in Human Research (2007).

2. Approval will be for a period of five (5) years subject to the provision of annual reports.

Progress Report 1 Due: 14 November 2013
Progress Report 2 Due: 14 November 2014
Progress Report 3 Due: 14 November 2015
Progress Report 4 Due: 14 November 2016
Final Report Due: 14 November 2017

NB. If you complete the work earlier than you had planned you must submit a Final Report as soon as the work is completed. If the project has been discontinued or not commenced for any reason, you are also required to submit a Final Report for the project.

Progress reports and Final Reports are available at the following website:

http://www.research.mq.edu.au/for/researchers/how_to_obtain_ethics_approval/human_research_ethics/forms

3. If the project has run for more than five (5) years you cannot renew approval for the project. You will need to complete and submit a Final Report and submit a new application for the project. (The five year limit

on renewal of approvals allows the Committee to fully re-review research in an environment where legislation, guidelines and requirements are continually changing, for example, new child protection and privacy laws).

4. All amendments to the project must be reviewed and approved by the Committee before implementation. Please complete and submit a Request for Amendment Form available at the following website:

http://www.research.mq.edu.au/for/researchers/how_to_obtain_ethics_approval/human_research_ethics/forms

5. Please notify the Committee immediately in the event of any adverse effects on participants or of any unforeseen events that affect the continued ethical acceptability of the project.

6. At all times you are responsible for the ethical conduct of your research in accordance with the guidelines established by the University. This information is available at the following websites:

http://www.mq.edu.au/policy/

http://www.research.mq.edu.au/for/researchers/how_to_obtain_ethics_approval/human_research_ethics/policy

If you will be applying for or have applied for internal or external funding for the above project it is your responsibility to provide the Macquarie University's Research Grants Management Assistant with a copy of this email as soon as possible. Internal and External funding agencies will not be informed that you have final approval for your project and funds will not be released until the Research Grants Management Assistant has received a copy of this email.

Please retain a copy of this email as this is your official notification of final ethics approval.

Yours sincerely
Dr Karolyn White
Director of Research Ethics
Chair, Human Research Ethics Committee