NEURAL CORRELATES OF SYNTACTIC DEPENDENCIES
IN NATIVE ENGLISH AND CANTONESE SPEAKERS

KRISTJAN KALM

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Department of Human Communication Science

University College London

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Abstract

The focus of this research concerns the ERP response to violations of non-local syntactic dependencies. This was studied by recording neural event-related potentials (ERPs) during the processing of English sentences containing a syntactic unexpectancy of wh-movement by native English (n=19) and Cantonese speakers (n=15). Cantonese speakers were chosen as a control group for non-native language processing as their native language lacks the movement of constituents in wh-object questions.

Non-local syntactic unexpectancies elicited an early left-anterior negativity (ELAN) in native English speakers but not in Cantonese speakers. The result suggests a wider functional interpretation of ELAN and supports the claim that ELAN represents a domain-specific and automatic syntactic processor not available for second language speakers.

Both groups elicited a frontal P600-component in response to the violation. Frontal P600 has been associated in literature with differences in syntactic complexity or expectancy (Hagoort 2002) and domain-general declarative memory processes (Ullmann 2001).

The results are also consistent with previous studies of speech and language impaired children (van der Lely & Battell, 2003; Fonteneau and van der Lely, 2006), which suggest that speakers with no access to early automated syntactic processing would do not show ELAN in response to syntactic violations.

The frontal nature of P600 support the Fundamental Difference Hypothesis (Clahsen and Fesler 2006), which suggests that while first language processing may rely on more automatic, procedural processing, second language processing may be restricted to learned, explicit, declarative knowledge.

1 Introduction

1.1 Overview

A body of evidence has demonstrated that neural event-related potentials (ERPs) are sensitive to particular aspects of sentence processing (for a review see Hahne and Friederici 1999 and Friederici 2004 and 2005). ERPs are negative and positive voltage changes in the ongoing electroencephalogram that are time-locked to the onset of a sensory, motor or cognitive event (Hillyard & Picton, 1987). Attempts to identify ERP effects that are sensitive to syntactic aspects of sentence processing have produced a variety of effects (Friederici, 2005). Studies show that syntactic anomalies, including violations of verb subcategorisation, phrase structure and agreement constraints, elicit distinguishable ERP signatures of which a detailed overview is given in Section 1.3.

The primary question of this research concerns the ERP response to violations of non-local syntactic dependencies. According to Friederici (2005), violations in the initial sentence structure-building process would elicit an early left anterior negativity (ELAN) in the voltage waveforms. Previous research has recorded ELAN mainly in association with phrase structure violations (Friederici, 2005). The anomalous sentences of the WH-question type involve the violation of the dependency relations determined by the operation of movement. Previous research by McKinnon & Osterhout (1996) found only positive waveform differences (P600) in the violation of movement phenomena. On the other hand, van der Lely and Fonteneau (2006) report an ELAN component in adult native English speakers in response to structural syntactic dependency unexpectancies in wh-questions.

This study aims to further the functional interpretation of the ELAN. To do this, I conducted ERP recordings during the processing of English sentences containing a syntactic dependency violation[1] of wh-movement by native English (n=19) and Cantonese speakers (n=15). Cantonese speakers were chosen as a control group as their native language lacks the movement of constituents in wh-object questions, which allows to test the specificity of ELAN with respect to native vs. non-native speech processing. Cross-linguistic variability enables testing hypotheses not restricted to one language and thus allows gathering evidence regarding the nature of automated speech processing.

The focus of the present study is on the brain's response to one aspect of syntactic processing in the form of an ungrammatical object questions with wh-movement. A specific syntactic property of the wh-word, its animacy, is reactivated at the gap

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[1] Technically this work studies syntactic unexpectancies but the term "violation" is used in equal meaning from hereon as it is more consistent with the existing literature.

position, which is in turn analyzed by the syntactic "parser" during the sentence structure-building process. If the gap gets filled with a specific noun phrase (e.g. "What did Jack race the boat with the woman?") then the parser expects its animacy property not to match with the wh-word, because the initial filler-gap relationship is expected to be removed and the wh-word to be structurally related to another (missing) NP in the question. The unexpected animacy property therefore creates a syntactic violation (example above). Section 1.2 gives an explanation of theoretical framework behind this study.

1.2 Wh-movement

Wh-movement in English

The structure often assumed for English wh-object questions is as follows:

```
        CP
Spec          C'
        C            IP
              Spec          I'
                     I             VP
                            Spec          V'
                                   V             NP


Who_i   is    the    girl          pushing       [t_i]?
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(Spec = specifier; CP = complementizer phrase; C = copula;
IP = inflectional phrase; NP = noun phrase; t = trace).

In some linguistic frameworks, it is assumed that the wh-word moves from its interpreted position (e.g., the object NP) to the initial position of the sentence (Chomsky, 1995). In other frameworks, it is assumed that features are passed between the sentence-initial position and the interpreted position (Pollard & Sag, 1994). However, each type of account assumes that a relationship between the two positions must exist. The wh-word moves to the specifier position of the complementizer phrase, leaving a trace behind (Chomsky, 1995).

In principle, it is possible to produce a well-formed wh-subject question without having knowledge of the rules involving wh-words. Specifically, the wh-word could occupy the specifier position in IP, and the auxiliary verb is could remain in I. In contrast to the case for wh-subject questions, wh-object questions are clearly ill formed if movement (of constituents or features) does not occur. Thus, wh-object questions provide a more straightforward framework to test non-local dependency violations in English.

Wh-movement in Cantonese

The forming of English and Cantonese wh-questions is fundamentally different from the structural viewpoint. This can be seen through a comparison of simple declarative sentence in Cantonese and the corresponding wh-object question (example from Wong et al., 2004[2]).

zyu1zyu1	*sek3*	*bin1go3*?
Piglet	kiss	who?

An inspection of the question reveals preservation of the same subject, verb, object order seen for the declaratives and the wh-word reflecting the object occupies the post-verb position. Given that wh-object questions in Cantonese do not involve movement of constituents or features in the computational syntactic system, they form a perfect control group as second language (L2) speakers for measuring ERP responses to syntactic violations in English sentences.

Wh-questions and Children With Specific Language Impairment

Children with SLI have well-documented difficulties with grammar. However, these children do not show a uniform pattern of weakness in this area. One of the problematic areas can be seen in these children's use of wh-questions. van der Lely's (1998; van der Lely & Battell, 2003) work on SLI assumes that at least some children with SLI have an underlying deficit in the computational syntactic system. Focusing on a subgroup of children with SLI who show grammatical deficits (G-SLI), van der Lely and Battell (2003) have described the core deficit as involving movement and more specifically, "whereas the basic grammatical operation/rule Move in normal

[2] Morphemes are presented in Romanized form, and tones are indicated by numerals, following the system adopted by the Linguistic Society of Hong Kong (Wong 2004).

grammar is (by definition) obligatory, in G-SLI grammar it is optional" (van der Lely & Battell, 2003, p. 155).

In a recent study Fonteneau and van der Lely (2006) tested children with SLI, age-matched controls, and younger child and adult controls, with questions containing syntactic violations and sentences containing semantic violations. ERPs revealed a selective dissociation to ELAN only. Furthermore, children with SLI appeared to be partially compensating for their syntactic deficit by using neural circuitry associated with semantic processing and all non-grammar-specific and low level auditory neural responses were normal. These differences led authors to suggest that only the grammar-specific component (ELAN) reflects the pure syntactic structure and is atypical or absent within the SLI group.

1.3 Language related ERPs

ERPs (event-related potentials) are small voltage fluctuations time-locked to a stimuli resulting from evoked neural activity. These electrical changes are extracted from scalp recordings by computer averaging epochs (recording periods) of electro-encephalographic data of sensory, cognitive, or motor events. (Luck, 2005) In short, the ERP technique allows scientists to observe human brain activity that reflects specific cognitive processes. (See Section 2 (Methods) for more.) It is well known that while experiments in ERP have limitations in obtaining spatial information, they offer an excellent temporal resolution compared to the other non-invasive brain imaging techniques. EEG records changes in electrical activity of simultaneously active neuron populations on the level of a single millisecond. The temporal resolution of positron emission tomography (PET) is tens of seconds, and although functional magnetic resonance imaging (fMRI) can be collected at 50- to 100-ms intervals the intrinsic inertia of changes in blood flow limits the temporal resolution of fMRI to 2-4 seconds.

Within the language domain, four main different ERP components have been identified, each thought to reflect a particular neural process related to language processing. They could be roughly divided into syntactic and lexical-semantic processes.

Syntactic processes

Syntactic processes are multilayered because syntax becomes relevant at the following stages (Friederici, 2004):

1) Initial processing phase during which the incoming information is structured into phrases on the basis of word category information.
2) Thematic role assignments, i.e. relations between phrases need to be established in order to identify who is doing what to whom. Whenever the words in the sentence are not in their canonical order different markers are used for the assignment of grammatical (i.e. thematic) roles.
3) Final phase during which structural, lexical–semantic, and thematic information have to be integrated to achieve comprehension.

Each of these syntactic sub-processes can be traced electro-physiologically.

The ELAN component

An early left anterior negativity (ELAN) has been found to correlate with the first of the mentioned syntactic stages, i.e. early structure-building processes. ELAN between 100 and 300 ms has been related mainly with phrase structure violations in the auditory domain. Friederici et al. (1993) and Hahne and Friederici (1999, 2002) presented syntactically correct and incorrect sentences as connected speech. Syntactic incorrectness was realized as a word category violation (e.g. *Der Freund wurde im besucht.* vs. *The friend was in the visited.*). In German, the case-marked preposition "im" necessarily requires a noun phrase to follow. The ungrammatical sentences elicited an ELAN around 180 ms and a following second negativity between 300 and 500 ms.

The effect was interpreted to reflect highly automatic processes of initial structure building. To examine this claim Hahne and Friederici (1999) studied different degrees of automaticity in an auditory sentence comprehension study by varying the proportion of phrase structure violations (incorrect sentences being either of a low (20% violation) or a high (80% violation) proportion). They found an ELAN equally pronounced under both proportion conditions, supporting the idea that the early structure-building processes are independent of the subjects' conscious expectancies and behaviour and can therefore be described as automatic in nature. In contrast, a P600 was observed for a low proportion of syntactically incorrect sentences only.

The observed independence of the ELAN from attentional variation indicates that the processes reflected by the ELAN are highly automatic. Importantly, this has lead to a suggestion that ELAN is only associated with grammar-specific language processing whereas other language related ERP-components (like N400 or P600) are linked to lexical and re-analysis tasks. Thus, the ELAN's sensitivity appears domain-specific to syntactic structure. As noted, it is insensitive to task demands or violation frequency that incurs other cognitive processes (Hahne and Friederici; 1999, 2002).

As most of the work carried out on ELAN has focused on local (phrase structure) syntactic violations, the component has been shown mainly to appear in response to processing of phrase structure violations involving grammatical category information of closed class words. That means if (on the basis of the syntactic context) a particular word class (e.g. noun, verb, adjective, etc.) is allowed whereas other word classes are not, the early negativity is elicited to a word of a category that is illegal in that position.

The LAN component

A number of studies have investigated morpho-syntactic aspects relevant for the identification of the grammatical relation between words and found a left anterior negativity (LAN). It usually appears about 300-500 ms after the onset of the critical word with a maximum at left fronto-temporal electrode-sites. Typically, the stimulus material has been presented visually in a word-by-word manner in these studies (Gunter et al., 1999; Friederici et al., 2000; Friederici et al., 2004; Kutas & Hillyard, 1983), and might account for the later activation of this neural correlate.

Two types of violations were mainly investigated:

1) agreement information such as
    a. noun-number agreement (e.g. *Some shells is even soft.* (example by Friederici 2004).)
    b. verb-tense agreement (e.g. *This allows them to stayed under water for a longer period.*) (Kutas & Hillyard, 1983),

c. article-noun agreement (e.g. *Der* (masculine) *Haus* (neutral), "The house" (example provided by Friederici 2004).)

2) verb-argument structure information (e. g. incorrectly case-marked elements causing a mismatch between the verb's argument structure and its argument).

Agreement violations have been investigated in English, Dutch, and German (for a review see Hahne and Friederici 1999 and Friederici 2004 and 2005). Most of these negativities displayed a centro-frontal or frontal maximum, often with a left dominance.

It has also been proposed that the functional role of the LAN is an index of general auditory working memory. Kluender & Münte (1998), found that questions with wh-movement were associated with a larger left anterior negativity at the filler and gap positions, an effect that has been interpreted to reflect the greater working memory load associated with object questions in which the filler has to be kept active for a longer time. Some researchers have tried to disentangle the two interpretations by demonstrating that working memory related negativities can be measured globally over the whole sentence, while morpho-syntactic LAN effects are measurable only locally after the violated element of the sentence (Coulson et al., 1998).

The P600 component

A late syntax-related ERP component, a positive wave after 600 ms (P600), has been observed with several language processing related phenomena. Further Hagoort and colleagues (1993) and Hahne & Friederici (1999) consider the P600 to reflect two different components with different neural origins. At least three different syntactic phenomena have been proposed to generate the late positive wave between 600 and 900 ms after the stimulus.

1) Violations of structural preferences

Osterhout et al. (1994) reported a late centro-parietal positivity peaking around 600 ms for so-called "garden-path" sentences (e.g. *The broker persuaded to sell the stock*) at the disambiguating element (in this example, the word "to"), which indicates that the underlying structure of the sentences is not a simple subject-verb-object structure. From this a view was developed that the P600 is a marker of the garden-path effect and present whenever the parser has to revise a structure. Thus, the P600 may be considered to reflect processes of structural reanalysis. Osterhout proposed that the amplitude of the P600 reflects 'cost of syntactic processing', with higher processing costs being correlated with a higher amplitude.

2) Outright syntactic violations

Most of ERP studies investigating the processing of syntactic violations and thus, processes of syntactic repair (for a review see Friederici 2004) report a pattern with a LAN followed by a P600. This pattern has been found to co-occur with a variety of syntactic anomalies, but also with outright phrase structure violations, subjacency violations and agreement violations. Thus Friederici and her collaborators (Friederici et al., 1996) have specifically linked this type of two-phased pattern to the second or reanalysis stage of two stage parsing models (Gorrell, 1995).

3) Syntactic integration

Kaan and colleagues (2006) constructed sentences that varied in the difficulty of integration while keeping all other aspects constant and found a P600 for the difficult-to-integrate element. On the basis of this finding they argued that the P600 is a marker for syntactic integration difficulty.

There has been some debate regarding the syntactic nature of the component of P600, coming from the fact that P600 shows some similarities to the P3b component, which is assumed to be elicited by unexpected, task-relevant events, reflecting a general reanalysis process not restricted to the language domain. Münte et al. (2001) presented a finding suggesting that P600 is not specific to syntactic processing, but rather reflects a reanalysis process after any kind of linguistic error, such as semantic and orthographic ones.

Moreover, several other studies (a review see Friederici 2004) suggest that sentence complexity and violation probability affect the P600 amplitude, much as they do P3b, indicating that both components share a common feature. Contrary to this view, Osterhout et al. (1997) study mentioned above, maintains that P600 is distinct from P3b, based upon the findings in their study that P600 and P3b show differences in scalp distributions, responses to the 22 stimulus manipulations, and additive effects in morphological and syntactic anomalies. They concluded that P600 is, at least partially, related to syntactic processes.

Hagoort and colleagues (Hagoort & Brown, 2000; Hagoort 2002) have proposed that the late positive shift might in fact reflect two aspects of the parsing process. An experiment with different types of grammatical violations (Hagoort & Brown, 2000) elicited a positive shift at 500 ms after the onset of the word that rendered the sentence ungrammatical. The P600 consisted of two phases, an early phase with a relatively equal anterior–posterior distribution and a later phase with a strong posterior distribution. The authors interpreted the first phase as an indication of structural integration complexity, and the second phase as an indication of failing parsing operations and/or an attempt at reanalysis.

Hagoort has hypothesized (Hagoort & Brown, 2000; Hagoort 2002) that one of the reasons behind two possible stages of positive shift is related to the complexity of syntactic processing. This account is supported by Hagoort's own findings that whenever the syntactic manipulation is not in the form of a straightforward violation but implicates differences in syntactic complexity or expectancy the distribution of the P600 is more frontal than in the case of a straightforward grammatical violation. In the latter case a more posteriorly oriented distribution of the P600 is observed which might indicate the failure of a parse, and / or the attempt at a revision of the syntactic structure.

It is crucial to note that despite the discussion over the nature of P600, it has been shown to reliably co-vary with syntactic factors.

Lexical-semantic processes

The N400 component

The N400 is a negative frontally distributed waveform peaking at around 400 ms after the onset of the critical stimulus. This component has been identified to be correlated with lexical–semantic processes. Kutas and Hillyard (1983) observed such a negative wave for sentence-final words that mismatched the preceding context semantically (e.g. *He spread the warm bread with socks.*). The N400 component has been found in different languages including English, French, Dutch, German, Hebrew, and even American Sign Language (for a review see Friederici 2004 and 2005). When words appear in sentential context, the amplitude of the N400 component varies inversely with the semantic expectancy of a word in a given context. An N400, however, has not only observed in sentential context, but also when a word is presented in the context of another word (i.e., two words are presented one after the other as a prime-target pair). The amplitude of the N400 is larger when primes and targets are semantically unrelated than when semantically related (Kutas and Hillyard, 1983).

1.4 ERPs and second language speakers

A basic question in second language research is how two or more languages are processed with respect to each other. It could be the case that the speaker's second language (L2) forms a completely separate system, relying on completely different processing mechanisms. However, it is equally conceivable that both first (L1) and second language (L2) have access to either partially overlapping or identical processes.

Studies using the ERP methodology on L2 learning have recently begun to emerge in the literature, with findings showing both similarities and differences in ERP results for L1 and L2 processing (Hahne 2001, Hahne and Friederici 2001, Fesler 2003, Müller 2005). In general, even late learners seem to develop highly proficient lexical-semantic processing mechanisms in their L2, as reflected by the N400 component. In contrast syntactic processing seems to be more sensitive to maturational constraints on language development. P600 effects are often present in L2 processing studies, although they are often highly delayed for late learners and their presence may depend on similarities between the L1 and L2 (Hahne and Friederici 2001).

Weber-Fox and Neville (1996) conducted the first ERP study with L2 (English and Mandarin speakers) speakers focusing on syntactic processing. Phrases containing word category violations (*The scientist criticized Max's of proof the theorem* vs. *The scientist criticized Max's proof of the theorem*) led to both an early (N125) and a later left lateralized negativity (N300–500) in native English speakers (L1). Additionally, a P600 in the time window between 500–700 ms was found for L1 speakers. For the L2 speakers, the pattern differed from that of native speakers irrespective of age of acquisition. The early left negativity (N125) was not observed in the L2 learners, except for the group with age of acquisition between 11-13, who showed a reversed left–right topographical distribution. In this group the N125 effect was larger over right scalp sites. The later negativity (N300–500) was present in all L2 groups, but bilaterally distributed if the age of acquisition was greater than 11 years. The P600 effect was similar to native speakers in the groups up to the age of 10 years.

Hahne and Friederici (2001) investigated phrase structure processing in late L2 learners of German. Similar to Weber-Fox and Neville (1996) they used word category violations and compared correct sentences (*Der König wurde ermordet.* 'The king was killed') to syntactically incorrect sentences (*Der König wurde im ermordet.* 'The king was in the killed'). During auditory sentence processing native speakers of German show an early ELAN followed by a P600 for syntactically incorrect sentences. Native Japanese late L2 learners of German, on the other hand, showed neither of the two ERP effects in response to word category violations, but instead showed a greater (in terms of voltage amplitude) P600 for the correct sentences as compared to native speakers. To explain the absence of the P600 effect in response to the violations the authors suggest that the L2 speakers might already have to recruit an upper level of processing capacities for the processing of correct sentences, possibly leading to a kind of 'ceiling effect'.

In contrast to Japanese speakers, native Russian L2 learners of German showed a P600 for syntactically incorrect sentences with slightly delayed peak latency (Hahne, 2001). As was the case in the Japanese group, no ELAN effect was observed for the Russian group. These studies indicate that, at least for the emergence of the P600, proficiency might play a crucial role. One additional factor (directly or indirectly influencing the ERP differences between the two groups) might be related to the presence of similar syntactic structures in the L2 learners' L1. While syntactic structures like those used in the German test sentences are familiar to native Russian speakers, they are unknown to native speakers of Japanese. Nonetheless, there was no indication for the availability of relatively automatic syntactic processes as reflected in the ELAN for either group.

In sum, there is no clear consensus regarding the role of syntactic ERPs in L2 speakers. On the one hand striking similarities to native speakers have been found, notably the P600 (Weber-Fox and Neville, 1996; Hahne 2001), which suggests that more controlled syntactic parsing processes can at least in principle be acquired in a number of grammatical domains. On the other hand, the processes underlying the ELAN or LAN effect seem to be comparatively difficult to acquire if the L2 is learned at later stage (Hahne 2001; Hahne and Friederici, 2001; Weber-Fox and Neville, 1996).

Several recent studies have explored the possibility that L2 learners may never be able to acquire native-like parsing and processing mechanisms in their second language (Clahsen and Fesler 2006). This is an idea that others have applied previously to L2 grammatical knowledge (i.e., the 'Fundamental Difference Hypothesis," as described by Clahsen and Fesler 2006). These studies suggest that while L1 processing may rely on more automatic, procedural processing, L2 processing may be restricted to learned, explicit, declarative knowledge. Thus L2 learners may fail to project syntactic structure at all in parsing.

Moreover, psycholinguistic studies involving the interface between generative grammar, particularly with regard to grammatical gender and processing in L2 acquisition have also recently begun to emerge (see Müller 2005 for a review of non-generative ERP studies of L2 morpho-syntactic processing). The results from these studies show quantitatively and qualitatively different neural responses for L1 vs. L2 processing when grammatical features differ between the two languages.

More specifically Ullmann (2001) and Sabourin et al. (2006) (as described by Müller 2005) argue that learning individual lexical items and their associated features in the second language might be possible. However access to the syntactic processes that differ from those in the L1 may be unachievable. Thus it is possible that highly automatic syntactic processes (as indexed by the ELAN or LAN) are not available until more controlled syntactic and semantic processes (as indicated by the P600 and the N400) are established, if they are acquired at all by L2 learners.

1.5 Hypotheses

Previous studies investigating children with SLI (van der Lely & Battell 2003, Fonteneau & van der Lely, 2006) indicate that syntactic dependencies involved in wh-movement are a core part of the highly automatic syntactic processes (ASP). Assuming ASP are not available for Cantonese speakers processing English sentences, this interpretation could be supported or rejected by comparing the ERP-responses from native English and Cantonese speakers. A number of specific hypotheses can therefore be derived.

ELAN

Taking into account that previous studies (Fonteneau & van der Lely, 2006) have recorded an ELAN in English-speaking adults in response to the processing of a wh-gap expectancy violation I hypothesise that

H1 The processing of a wh-gap expectancy violation will elicit an ELAN in native English speakers

Considering

a) the different structure of Cantonese grammar, which does not include wh-movement in wh-object questions
b) that previous studies have shown that early automatic syntactic processes are not supposed to be available for L2 speakers

I hypothesise that

H2 The processing of a wh-gap expectancy violation will not elicit an ELAN in native Cantonese speakers.

LAN

Because of the short wh-object questions no significant working memory load would be expected. Therefore I hypothesise that

H3 The processing of a wh-gap expectancy violation will not elicit a LAN in native English speakers.

Previous studies have also shown that the LAN component is not available for L2 speakers. Thus I hypothesise that

H4 The processing of a wh-gap expectancy violation will not elicit a LAN in native Cantonese speakers.

P600

Taking into account that P600 has been shown to reliably co-vary with the load in syntactic parsing I hypothesise that

H5 The processing of a wh-gap unexpectancy will elicit a P600 in native English speakers.

Considering that P600 is a component thought to be available for L2 speakers I hypothesise that

If the gap (marked in the following examples by ____) such as:

(a) Who is Jane pushing ______?

gets filled, a structural syntactic violation is created:

(b) Who is Jane pushing the boat?

If the gap gets filled with a specific noun phrase (e.g. "Who is Jane pushing the boat with the woman?") then at the point of processing the noun the parser expects it's animacy property not to match with the wh-word, because the initial filler-gap relationship is expected to be removed and the wh-word to be structurally related to another (missing) NP in the question.

Animacy properties of words enter into overt grammatical processes in languages, such as Romance and American-Indian languages. For example, two words (noun, verb) in a sentence might have to agree in animacy properties, in the same way as in English words overtly agree in person (*He jumps* vs. *I jump*) and number (*A cat* vs. *Some cats*). Thus, the grammaticalisation of properties of words such as, person and number, as well as animacy, is generally found in languages.

The study employed wh-object questions used by Fonteneau and van der Lely (2006). Questions where the wh-word-noun pair either matched (syntactic violation) or mismatched (control) were used. For questions that contained the animacy match (syntactic violation), a preposition and NP followed the critical noun, making the overall question ungrammatical. For the mismatch pair (control) following the critical noun only a preposition was added, making the overall question grammatical. (e.g., *Who did Barbie push the clown into the wall?* (animacy match- syntactic violation), *Who did Barbie push the ball into?* (animacy mismatch—control questions)).

All the critical nouns were controlled for frequency, length, imageability and age of acquisition (Fonteneau and van der Lely, 2006). Acoustic analysis showed no differences in pitch (Hz), intensity (dB) or duration (ms) between our two experimental conditions before the preposition position. Maximally short wh-object questions were composed in order to control for the working memory effect. The greater the distance between the wh-word and its interpreted position, the longer the listener must delay interpretation of the wh-word, and thus the greater the processing burden placed on the listener. (For the sample of sentences used see Annexe 1.)

Only ERPs were analysed (omitting behavioural responses by participants) because the focus of the study was to identify which neural responses are elicited when a subject encounters the syntactic violation nouns; also native Cantonese speakers were expected to make more mistakes than native English speakers.

2.3 Procedure

Participants listened to 160 wh-questions presented with 80 animated familiar characters / personalities (e.g. Homer, Marge, and other cartoon characters and personalities) in subject position. Each of these subject NPs was heard twice, once in each condition, but with a different verb and target object noun. 80 transitive verbs were used which were repeated once for each participant, but presented with a different subject and object NP in the two conditions (syntactic violation, control). The repetition order (violation, control) was controlled. The object NPs consisted of a determiner (the, his, her) and 160 nouns – 80 animate, and 80 inanimate.

The nouns and verbs were controlled for age-of-acquisition (under 6 years), frequency, number of syllables and imageability between the two conditions (Masterson & Druks, 1998; Fenson et al., 1993; Bird, Franklin, & Howard, 2001; Druks & Masterton 2000; Baker, 1996). None of the object NPs were repeated. Participants were asked to judge the appropriateness of each sentence by pressing the ☺ or the ☹ button on the remote-pad.

2.4 ERP analysis

ERPs were recorded using the EGI system (128 channels, 250Hz sampling rate, 0.1 - 100 Hz). Prior to off-line averaging, all single trial waveforms with artefacts were rejected. ERPs from the critical noun in the object position (*clown*, *ball*) were analysed.

The *Ref* electrode was used as the recording reference. Segments containing vertical EOG (eye blink) or horizontal EOG (eye movement) activity greater than 150 µV were excluded from averaging. This resulted in two sets (control and violation) of averaged evoked potentials for each participant. ERPs were re-referenced according to the average reference.

ERPs (1000 ms epochs) were quantified by mean amplitude measures after the onset of the critical word (direct object noun) for different time windows (TW):

1. ELAN 100 to 300 ms
2. LAN / N400 300 to 500 ms
3. P600 600 to 900 ms

Millisecond values are relative to the 100 ms pre-stimulus baseline. Mean amplitudes (mean average amplitude within a time window of interest in µV) were measured as a dependant variable. The length of the time windows were chosen to match the previous research conducted in the area of ERP analysis of syntactic processing (see Friederici 2004 and Friederici 2005).

Data were analysed in two steps. First, 2 groups (native English speakers, native Cantonese speakers) x 2 conditions (violation; control) x 9 Regions Of Interest (the head was divided into nine Regions Of Interest, and for each a single mean amplitude from 6 to 11 electrodes, see Annexe 2) ANOVA was computed for each time window.

Secondly, I computed separate 2 conditions (violation; control) x 3 caudality (anterior; median; posterior) x 2 laterality (left; right) ANOVA for both groups (native English speakers, native Cantonese speakers). Caudality and laterality variables were defined as ROI groups of electrodes (see Annexe 2).

The Greenhouse-Geisser correction was applied to all analyses when evaluating effects with more than one degree of freedom in the numerator.

3 Results

3.1 ELAN

Overall ANOVA

A significant group x condition x region of interest (ROI) (df=2.733; ms=3.819; F=3.036; p=.032) interaction was revealed. A significant condition x caudality x language group interaction (df=2.335; ms=49.847; F=9.967; p=<.005) was also recorded, but the condition x laterality x language group interaction (df=1.998; ms=2.465; F=0.715; p=.612) was not significant.

Follow-up analysis revealed a significant effect of condition only in anterior sites. A significant group x condition interaction was revealed for Anterior Left (df=1,32;

ms=6.282; F=6.709; p=.017) and Anterior Central (df=1,32; ms=5.147; F=5.524; p=.027) regions.

These interactions were further analysed group-wise.

English speakers

t-tests showed that the ELAN was significant in the Left Anterior region (df=20.043; t=1.354; F=0.327; p=.032) and in the Left Median region (df=21.848; t=1.964; F=0.031; p=.011). No other regions showed significant effects for the group.

Cantonese speakers

Analysed ERPs from the native Cantonese speakers revealed a main effect of caudality (df=1,16; ms=32.119; F=7.026; p=.002); but no other effects were significant for the group.

Figures

Figure 1 - Native English speakers' EEG response to stimulus word on F5 (left anterior region) electrode

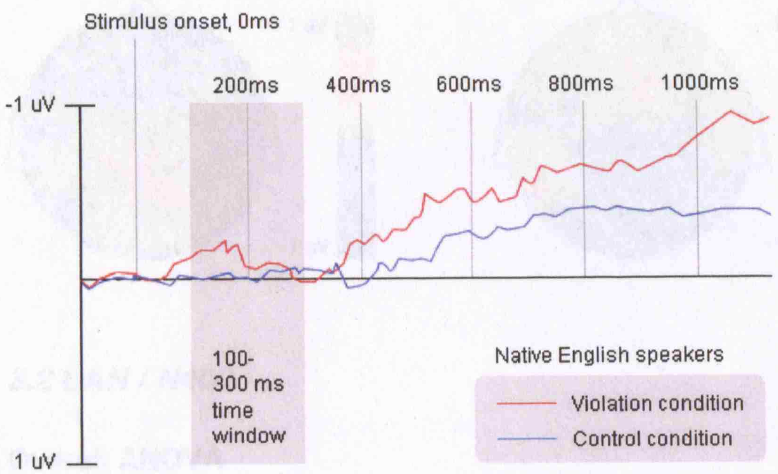


Figure 2 - Native Cantonese speakers' EEG response to stimulus word on F5 (left anterior region) electrode

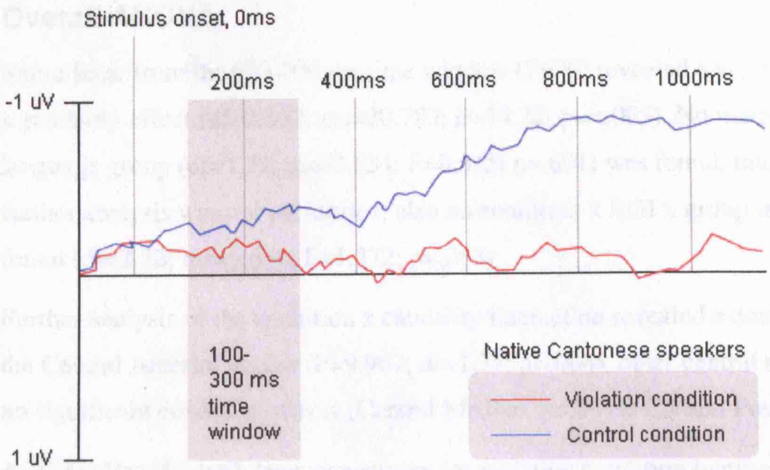


Figure 3 - Native English speakers' scalp distribution of differences between the violation minus control in the 100-300 ms time window

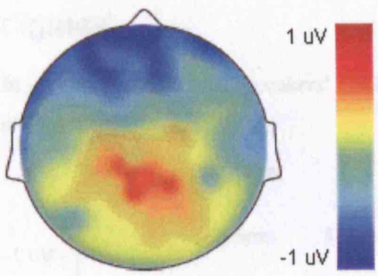
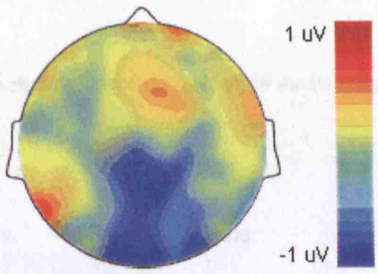


Figure 4 - Native Cantonese speakers' scalp distribution of differences between the violation minus control in the 100-300 ms time window



3.2 LAN / N400

Overall ANOVA

Recordings from the 300-500 ms time window (LAN, N400) did not reveal a significant group x condition x region of interest (ROI) (df=2.025; ms=9.581; F=2.275; p=.112). No significant condition x caudality effect was revealed (df=1,32; ms=1.88; F=1.158, p=.291). Thus no further analysis was performed.

3.3 P600

Overall ANOVA

Recordings from the 600-900 ms time window (P600) revealed a significant condition x caudality effect (df=2.637; ms=20.783; F=14.32; p=<.005). No main effect of language group (df=1,32; ms=2.534; F=0.515; p=.601) was found, thus group-wise further analysis was not performed; also no condition x ROI x group interaction was found (df=2.23; ms=5.636; F=1.372; p=.263)

Further analysis of the condition x caudality interaction revealed a condition effect in the Central Anterior region (F=9.967; df=1,32; p=.004), other central regions revealed no significant condition effects (Central Median: p=.0872; Central Posterior: p=.19).

A P600 effect for both language groups for violation condition (native English speakers: df=21.714; t=1.923; F=.03; p=.009; native Cantonese speakers: df=20.043; t=3.652; F=.327; p=.002) was revealed in the Central Anterior region.

No significant hemispheric interactions were found for both of the groups.

Figures

Figure 5 - Native English speakers' EEG response to stimulus word on Fz (central median region) electrode

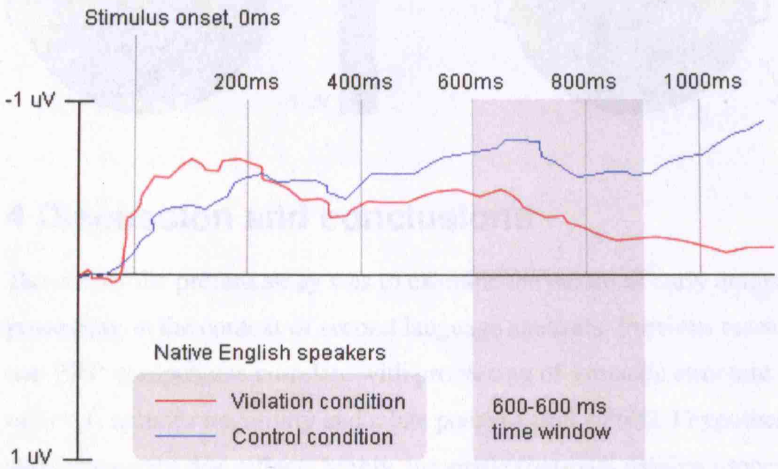


Figure 6 - Native Cantonese speakers' EEG response to stimulus word on Fz (central median region) electrode

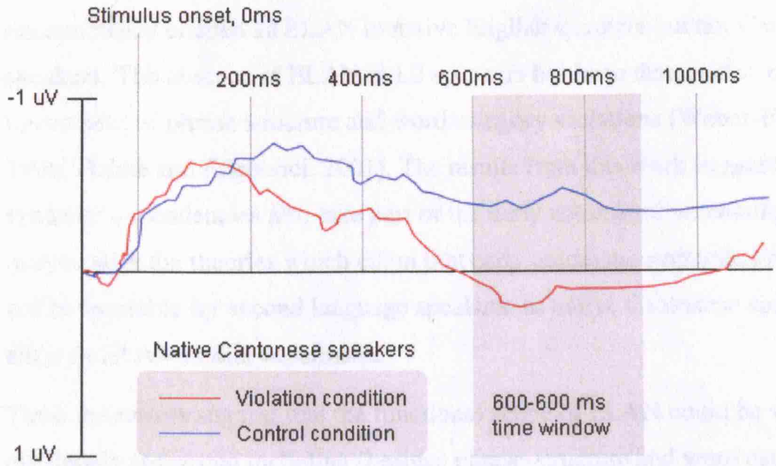


Figure 7 - Native English speakers' scalp distributions of differences between the violation minus control in the 600-900 ms time window

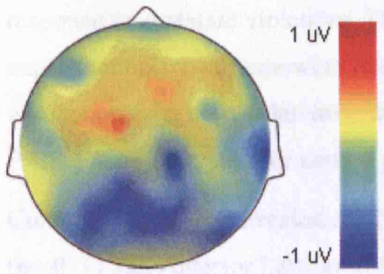
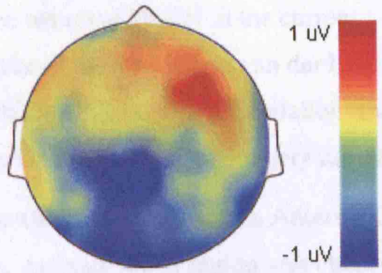


Figure 8 - Native Cantonese speakers' scalp distributions of differences between the violation minus control in the 600-900 ms time window



4 Discussion and conclusions

The aim of the present study was to examine the nature of early automated syntactic processing in the context of second language speakers. Previous research showed that two ERP-components correlate with processing of syntactic structure information: an early left anterior negativity and a late positive shift / P600. I hypothesized that the early negativity that reflects highly automatic first-pass parsing processes would be unavailable to L2 speakers, whereas the late positivity that reflects the following second-pass parsing processes that are of a more controlled nature would be available to L2 speakers. The results supported the hypotheses.

ELAN

One of the main findings of this work is that the non-local syntactic dependency unexpectancy elicited an ELAN in native English speakers but not Cantonese speakers. The absence of ELAN in L2 speakers has been demonstrated before only in the context of phrase structure and word category violations (Weber-Fox and Neville, 1996; Hahne and Friederici, 2001). The results from this work suggest that non-local syntactic dependencies also take part of the early automated processing stage. This is in sync with the theories which claim that early automatic syntactic processes might not be available for second language speakers, as native Cantonese speakers did not elicit an ELAN in this experiment.

Thus, the results suggest that the functional scope of ELAN could be wider than previously suggested including (besides phrase-structure and word category violations) also a subset of syntactic dependency involving unexpectancies. The results are consistent with ERP-studies of children with SLI (van der Lely & Battell, 2003; Fonteneau and van der Lely, 2006), which suggest that speakers with no access to early automated syntactic processing (children with SLI) show no ELAN in response to syntactic violations. However the nature of ELAN in the current experiment differed somewhat from the results of Fonteneau and van der Lely (2006), who recorded a more bilaterally distributed ELAN (Condition x Caudality: df=2,38; F=10.17, $p<.001$; anterior central $p<.001$) in the adult (but not younger) subjects.

Current experiment revealed an ELAN response most significant in Anterior Central (p=.011) and Anterior Left (p=.032) regions. Anterior Right region was clearly non-significant (df=20.315; F=.029; p=.492) in contrast with significant right distribution in Fonteneau and van der Lely and with experiments which elicited ELAN on word category violations (see Hahne & Friederici, 2001; Weber-Fox and Neville, 1996). The contrast with previous experiments could be explained by the difference in the syntactic anomalies (phrase structure and world category violations vs. syntactic dependency unexpectancies) which might elicit a somewhat different neurophysiological response. Differences in the nature of ELAN between current work and Fonteneau & van der Lely (2006) could be a topic of further research.

The results on ELAN also support the idea that the processes underlying the ELAN or LAN effect seem to be comparatively difficult to acquire if the L2 is learned at later ages. In this regard my results are consistent with previous ERP-studies of L2 speakers which have not recorded ELAN in L2 speakers in response to any syntactic anomalies so far (Hahne 2001, Hahne and Friederici 2001, Fesler 2003, Müller 2005).

LAN / N400

Morpho-syntactic LAN has been associated with violations in agreement and verb-argument structure (Friederici 1999 and Friederici 2004 and 2005). Weber-Fox and Neville's study (1996) showed a LAN component for phrase structure violations in L2 learners with a peak of 300 to 500ms post-stimulus, though it did not have the same left hemisphere bias as with native English speakers. I hypothesised that native English speakers in my experiment would not elicit LAN because the unexpectancy processing would happen in an earlier stage (ELAN). This hypothesis was confirmed by the results. Also L2 speakers did not reveal a LAN response, which contradicts with the results recorded by Weber-Fox and Neville (1996), but is consistent with the majority of L2 processing research which has not reported a LAN in response to syntactic anomalies (for a review see Müller 2005).

The absence of an LAN component in my results suggests that working memory load is not a significant factor in the neural processing of syntactic dependency violations. Furthermore, the sentences I adopted were all relatively short wh-object questions, and thus, should not impose a heavy burden on working memory as proposed by earlier studies (King & Kutas, 1995; Kluender & Kutas, 1993). Gibson (1998) argued that the temporary storage of a displaced constituent during sentence processing, its retrieval from working memory, and its subsequent integration with its sub-categorizer are all assumed to use up a certain amount of processing resources. Results from this work suggest that working memory load alone cannot be held accountable for the result in the processing of non-local syntactic dependencies.

Even late L2 learners seem to develop highly proficient lexical-semantic processing mechanisms as evidenced by the N400 recorded in many L2 processing studies (see Hahne and Friederici 1999; Osterhout and Holcomb 1995, Osterhout, et al 2004). However Osterhout and colleagues (2004) showed that when investigating subject-verb agreement, after one month of instruction L2 learners showed an N400 for agreement violations, but after four months of instruction this negativity was replaced with a P600-like positivity. Authors argue that this is a result of lexical-like learning of subject + inflected verb pairs in early acquisition, with subsequent reanalysis into subject + verb stem + inflectional morpheme. Thus, this kind of lexical compensation of rule-learning may elicit N400 in response to syntactic anomalies in early L2 speakers. The absence of N400 in my experiments' L2 group indicates their advanced level of English knowledge.

P600

Both native English and Cantonese speakers showed a significant P600 response suggesting that syntactic re-analysis takes place in both L1 and L2 speakers independently of access to the early syntactic processing. However the nature of the late positive shift is different from the topography usually associated with P600. Friederici (2004) reports that most of the studies reporting late positive shift in response to the syntactic violations display centro-parietal patterns of activity.

Current experiment revealed anterior distribution for both native English (df=21.714; t=1.923; F=.03; p=.009) and Cantonese speakers (df=20.043; t=3.652; F=.327; p=.002). However, the results are consistent with Fonteneau's and van der Lely's (2006) results, who claim that the sentence structure at the point of measurement is unexpected, rather than a strict grammatical violation. The frontal late P600 could thus be modulated by general cognitive processes as suggested by Coulson and colleagues (2006).

Ullmann (2001) has argued that the late positive shift is indicative of declarative memory procedures because of its association with the tempero-parietal brain structures (used in declarative processes) and because the finding that it is subject to a great deal of control. The results from current work seem to support this hypothesis considering that in both language groups P600 is rather equally distributed over anterior sites. However a strong posterior distribution of P600 (600-900ms) has been generally associated (Friederici, 2004; Kaan et al., 2000) with an attempt at syntactic reanalysis.

Hagoort et al. (1999) observed that unexpectancies like non-preferred continuations (e.g. *The broker persuaded to sell the stock <u>was sent to jail</u>.*) generally elicit a frontally distributed positive voltage ERP. Thus Hagoort and colleagues (1999) proposed that the frontally distributed positivity reflects costs associated with overwriting the preferred, most active structural representation of the sentence, whereas the posteriorly distributed positivity reflects costs associated with a collapse of the structural representation, as is the case in ungrammatical continuations (see Coulson et al., 1998). This dissociation is consistent with the results from current work as I tested the participants with syntactic unexpectancies rather that grammatical violations.

A further study of P600 in future experiments would be needed to distinguish whether the relative lateness and uniformity of the positive shift is because of the delay in latency or because the anterior P600 recorded is functionally different from the posterior late P600 described by Hagoort and Brown (2000) and Friederici (2004). Müller (2005) reports that P600 effects are often highly delayed for late L2 learners and their presence may depend on similarities between the L1 and L2. All the L2 speakers in current experiment were highly proficient in English indicating an early age of acquisition. This could explain why there is no significant delay in P600 between two language groups.

The frontal nature of P600 and it's consistency with Ullmann's findings support the Fundamental Difference Hypothesis (Clahsen and Fesler 2006), which suggest that while L1 processing may rely on more automatic, procedural processing, L2 processing may be restricted to learned, explicit, declarative knowledge.

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Annexe 1 – Sample of sentences used in the experiment

Syntactic violation – animacy match

What	did	Bella	bump	her	face	into	the wizard?
What	did	Goofy	hold	the	screw	for	you?
What	did	Dumbo	bite	the	balloon	with	the hippo?
What	did	Mr Potato Head	cover	the	chair	for	mum?
What	did	Barbie	comb	her	hair	with	grandpa?

Who	did	Superman	drop	the	swan	behind	the pool?
Who	did	Yogie Bear	smack	the	dentist	with	amusement?
Who	did	Coco the Clown	swing	his	daughter	with	affection?
Who	did	Spiderman	paint	a	beetle	on	the aquarium?
Who	did	Baloo Bear	push	the	postman	into	the ocean?

Syntactic control – animacy mismatch

What	did	Alice in Wonderland	bump	her	doctor	into	?
What	did	Cruella de Vill	hold	the	ladybird	for	?
What	did	Clifford	bite	the	lamb	with	?
What	did	Barney Rubble	cover	the	kid	for	?
What	did	Maggie Simpson	comb	her	cat	with	?

Who	did	Michael Owen	scrub	the	fork	with	?
Who	did	Wayne Rooney	tickle	his	foot	with	?
Who	did	Cinderella	pull	the	ribbon	from	?
Who	did	Buzz Lightyear	drive	the	tractor	into	?
Who	did	Daffy Duck	remember	the	word	with	?

Annexe 2 – Regions of Interest and the corresponding electrode sites