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Syntactic Co-activation in Bilinguals

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Summary

Each human language possesses a distinctive set of syntactic rules, and early, balanced bilinguals must learn two syntactic systems. The organisation of these systems in the bilingual brain is not yet clear; do they remain autonomous, or do they interact? This thesis examines the extent to which bilinguals' knowledge of syntactic rules are co-active during monolingual sentence processing. Thus, the primary objective is to assess (a) **whether** bilinguals co-activate idiosyncratic syntactic rules, (b) **how** syntactic co-activation occurs, and (c) **when** syntactic co-activation occurs, focusing on contextual constraints. To this end, I manipulated English sentences according to the Welsh rules of soft mutation (a morphosyntactic process that alters the initial consonant of words), such that English sentences included 'mutated' (e.g. prince → **b**rince) or 'aberrant' (e.g. prince → **g**rince) nonwords, presented either explicitly or implicitly. In Chapters 3 and 4, syntactic co-activation led to the modulation of the phonological mismatch negativity (PMN), but *only* in sentences that would elicit a mutation in Welsh. Crucially, processing of explicitly processed nonwords was not influenced by lexical overlap between languages, indicating that bilinguals co-activate abstract syntactic rules during sentence processing. In Chapter 5, eye-movements were measured to determine the extent to which syntactic co-activation occurs in natural sentence reading (in which manipulated target words were implicitly processed). Syntactic co-activation manifested on later processing measures, reflected in longer reading times. Interestingly, this effect was restricted to trials in which there was lexical overlap between languages, suggesting that co-activation is sensitive to a lexical boost effect. Based on these findings, I propose a model of syntactic co-activation that is constrained by contextual demands: syntactic co-activation can occur via abstraction of syntactic rules, but may also be reliant on cross language lexico-syntactic associations during certain contexts.

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Chapter 1

Literature Review and Thesis Aims

1.0. Chapter Overview

The primary purpose of this chapter is to review the evidence for language co-activation in bilinguals. It begins by outlining the substantial body of literature concerned with co-activation of lexical representations in bilinguals, leading to models of bilingual lexical activation. The focus then moves to the co-activation of syntax in bilinguals – the central problem investigated in this thesis - and for which the current literature is comparatively sparse. Whilst some investigations have focused on the representation of word-level syntactic information in bilinguals, the current thesis is concerned with the integration of word-level information within a sentence context. Given that bilingual models of comprehension and production generally use monolingual models as a foundation, brief summaries of monolingual lexical and syntactic processing are provided, where relevant. The chapter ends by outlining the thesis aims, addressing outstanding theoretical questions concerning syntactic co-activation.

1.1. An Overview of Language Access

Bilingual individuals must acquire two distinct language systems. Learning each language entails the acquisition of two orthographic, phonological, syntactic and semantic systems. Stored representations in either language must be selected rapidly and accurately in order to understand and communicate effectively in the language of operation. A topic of intense discussion in bilingualism research is whether the representations of both languages are stored in a single lexicon, or in two separate lexica. A related question is whether bilinguals activate only the representations of the language of operation during comprehension and production, or whether the representations of the non-operational language are to some extent co-active. The issue of language selective versus language nonselective access has received a substantial amount of attention over recent decades, with investigations primarily focusing on lexical retrieval. In the next sections, I will review data pertaining to lexical access in bilinguals, before discussing the relatively sparse literature on bilingual syntactic representations. Note that the primary focus of this thesis is *syntactic* representations in bilinguals, and as such the following review on bilingual lexical access is by no means exhaustive. Rather, its purpose is to inform the reader about the assumptions made when investigating the representation and activation of syntactic information.

1.2. Bilingual Lexical Access: Language Selective or Nonselective?

In the field of monolingual lexical access, computational models of word recognition focus primarily on the influence of orthographic information on the activation of lexical candidates. For example, the Interactive Activation Model (e.g. McClelland & Rumelhart, 1981) describes an interactive process, in which lexical representations are activated on the basis of orthographic similarity to the perceived word. Inhibitory and excitatory connections lead to the selection of congruent lexical representations. For example, the perceived word ‘TRAP’ might initially activate the lexical representations for ‘TRAP’, ‘TRIP’ and ‘CART’, among other orthographic neighbours (words that differ from the target word by a single letter). Inhibitory connections would lead to the inhibition of ‘TRIP’ and ‘CART’, whereas excitatory connections would strengthen the activation of ‘TRAP’, leading to its subsequent selection. A crucial point to make, however is that lexical selection concerns more than orthography: phonological, semantic, and syntactic properties can also influence the selection of a lexical candidate.

Bilingual models of lexical access are largely based on monolingual models, but debate centres on how the bilingual lexicon is organised and accessed. Under the language selective account of lexical access, lexical candidates from only the language of operation are activated. Early research in support of this view stressed the independence of language representations, and posited the possibility of a ‘language switch’: The representations of the operational language are enabled whilst the representations of the non-operational language are disabled (e.g. Macnamara & Kushnir, 1971). In a series of experiments, Macnamara and Kushnir (1971) reported slower reading times for bilingual paragraphs compared with monolingual paragraphs, indicating that bilinguals operated in a purely monolingual mode: presentation of words from the non-operational language resulted in processing difficulty due to the ‘deactivation’ of the non-operational language. In a more recent lexical decision study, Soares & Grosjean (1984) reported that bilinguals’ response times to words from the non-operational language were slower than response times to words in the operational language. Thus, these findings provide support for an initial language selective process, but suggest that the representations of the non-operational language may be co-activated under specific circumstances (see also Gerard & Scarborough, 1989; Meyer & Ruddy, 1974).

Subsequent studies refuted such a stringent view of lexical access. In a series of experiments, Kirsner, Smith, Lockhart, King and Jain (1984) tested five models of the bilingual lexicon, ranging from a model of separate, autonomous lexical representations, to a model of fully integrated and interconnected lexical representations. Their findings immediately dismissed the possibility of completely autonomous lexical representations in favour of more integrated models. However, on the basis of their findings, they could not distinguish between a model in which lexical representations are connected to semantically related lexical representations from both languages, and a model in which both languages share semantic representations, but have distinct lexical representations. Nevertheless, these findings provide support for an interconnected bilingual lexicon, and for a language nonselective view of lexical access. However, these models have been criticised by some for being *underspecified*: Whilst they outline the architecture of the bilingual lexicon, they provide no information regarding the processes involved during lexical access (see Kroll & Tokowicz, 2005 for a discussion).

As such, subsequent models of lexical access have focused on *how* lexical representations from both languages are activated. For example, the Bilingual Interactive Activation (BIA) model extends the Interactive Activation Model described above to incorporate an integrated bilingual lexicon: lexical candidates from *both* languages are initially activated on the basis of orthography (Dijkstra & van Heuven, 1998; van Heuven, Dijkstra & Grainger, 1998; see Dijkstra & van Heuven, 2002; Thomas & van Heuven, 2005, for adapted versions of the model that incorporate the influence of phonology and semantics on lexical activation). An in depth model of bilingual semantic representations is the Distributed Feature Model (e.g. de Groot, 1992). According to this model, semantic information can be shared between languages, but is modulated as a function of lexical category: concrete nouns are assumed to share semantic representations across languages, whereas abstract nouns are assumed to have more distinct semantic representations across languages. In addition, this model predicts the influence of semantic information on the selection of lexical candidates, and has derived support from studies reporting facilitated performance during trials in which target words and their translation equivalents were concrete nouns (e.g. van Hell & de Groot, 1998a). A more recent adaptation of the BIA model, the BIA+, details the processes by which semantic information can influence lexical activation: Spreading activation to the phonological and semantic properties of lexical candidate (activated on the basis of orthography) subsequently triggers the activation of phonologically and semantically related lexical candidates in both languages (Dijkstra & van Heuven, 2002; see Thomas & van Heuven, 2005, for a comprehensive review of bilingual models of lexical access).

Support for integrated models such as the ones described above come from a variety of behavioural and online tasks. For example, in a series of experiments, van Heuven et al. (1998) demonstrated the influence of orthographic neighbours on word recognition: Reaction times were slower for target words with a high number of orthographic neighbours compared with target words with a low number of orthographic neighbours. Furthermore, this effect extended to the orthographic neighbours of the non-operational language: Target words with a high number of orthographic neighbours in the non-operational language yielded longer reaction times than target words with a low number of orthographic neighbours in the non-operational language, supporting the suggestion that lexical candidates from both languages are activated on the basis of orthography. Furthermore, the influence of *phonology* on lexical access has been demonstrated using a range of online measures. In eye-tracking research, the visual world paradigm typically presents four images or objects corresponding to locations on a computer monitor or in real space, and participants' eye-movements are tracked as auditory presentation of a sentence unfolds. In a seminal study, Spivey and Marian (1999) presented Russian-English bilingual participants with four objects: a target, an interlingual decoy (an object that is phonologically related to the target in the non-operational language), and two unrelated objects. As the instruction unfolded (e.g. "*Poloji marku nije krestika*"; put the stamp below the cross), participants made significantly more eye-movements to an interlingual decoy (marker) – upon presentation of *marku* - before carrying out the instruction (see also Kaushanskaya & Marian, 2007). In addition, cognates (translation equivalents that overlap in orthography) typically elicit shorter lexical decision times compared with control (non-cognate) words (e.g. Dijkstra, Grainger & van Heuven, 1999; Lemhofer & Dijkstra, 2004; Van Assche, Duyck & Hartsuiker, 2012; Van Assche, Duyck, Hartsuiker & Diependaele, 2009; see Titone, Libben, Mercier, Whitford & Pivneva, 2011; van Hell & de Groot, 1998b, 2008, for contextual influences on bilingual word recognition). Interestingly however, interlingual homographs (words that share orthography between languages but are not translation equivalents) can elicit processing difficulty (e.g. Dijkstra et al., 1999; Libben and Titone, 2009), indicating that semantic information from both languages is automatically co-active during lexical selection.

More recent findings using online measurement of bilinguals' implicit word processing provide further support for the influence of semantic information during bilingual lexical selection. For example, Thierry & Wu (2007) presented Chinese-English participants with English word pairs that, unbeknown to participants, were manipulated such that they did or did not contain a character repetition in Chinese. They demonstrated that Chinese-English bilinguals are able to implicitly detect a character repetition in their first language (L1; Chinese) whilst completing a word-pair association task in their second language (L2; English). Given that the two languages are orthographically distinct, these results cannot be attributed to the automatic activation of lexical candidates based on orthography. Rather, they suggest that lexical candidates from both languages can be co-activated on the basis of semantic information (see also Gullifer, Kroll & Dussias, 2013; Knupsky & Amrhein, 2007; Wu, Cristino, Leek & Thierry, 2013; Wu and Thierry, 2010a). Taken together, research on bilingual lexical access is strongly indicative of nonselective lexical access that can be influenced by orthographic, phonological and semantic information: lexical items that are similar in any of these domains will be automatically co-active (irrespective of language). It thus appears that the bilingual lexicon is not only nonselective (in the sense that lexical representations from both languages are stored together in an integrated lexicon); it is also fully interactive, such that orthographic, phonological and semantic information from both languages can influence lexical activation.

Whilst current models of bilingual lexical access typically assume a language nonselective bilingual lexicon, researchers have highlighted the need for a mechanism of language selection: ultimately, a lexical candidate needs to be selected from the language of operation. In order to account for such a mechanism, Green (1998) proposed the Inhibitory Control (IC) model, in which lexical items stored in a language nonselective lexicon are associated with language tags. Task schemas strengthen the activation of lexical items in the language of operation, and inhibit the activation of lexical items in the non-operational language, via language tags. Furthermore, task schemas are sensitive to processing goals, indicating that lexical selection may be influenced by task demands (cf. Dijkstra & van Heuven, 2002).

1.3. From Lexical Access to Lemma-level Syntactic Representation

The evidence reviewed to this point has centred on the nature of lexical activation in bilinguals in the absence of information concerning their grammatical function. The focus now shifts to the retrieval of word-level syntactic information in bilinguals. Experimental research and models derived from the monolingual literature specify that lexical representations are directly connected to lemma nodes (containing word-level syntactic properties such as word category and grammatical gender assignments) and conceptual nodes (containing information about the semantic properties of the word). The activation of a lexical representation automatically activates its corresponding lemma and conceptual nodes via spreading activation (e.g. Anderson, 1983; Collins & Loftus, 1975; Roelofs, 1992; Cottrel, 1984). As such, the syntactic properties of a word become available upon the activation of a lexical candidate (see Levelt, Roelofs & Meyer, 1999, for a detailed description of this process during language production). A fundamental question relating to language organisation in bilinguals, therefore, is whether explicit lexical activation in one language automatically triggers the activation of corresponding lexical *and* lemma-level information in the other, non-operational language. A further, related question concerns the language specificity of lemma nodes. It is an empirical question whether a single lemma node (e.g., classification of a given word as a 'noun') is associated with words in both languages, thus linking all lexical items in the category 'noun', irrespective of language, or, whether two separate lemma nodes are stored; one for each language.

Over the last decade, several studies have investigated this issue with respect to bilinguals' representation of grammatical gender: a morphosyntactic property represented in the lemma stratum. Two competing theories have been proposed: The 'language autonomy' view assumes that grammatical gender representations are language specific, such that a grammatical gender lemma node is connected to the relevant lexical representations of one language only. Conversely, the 'gender integrated' view assumes that grammatical gender representations are shared between languages, such that a grammatical gender node is connected to the relevant lexical representations of both languages. These stances are therefore philosophically similar to the language selective and language nonselective accounts of bilingual lexical access, respectively.

Typically, studies investigating the representation of grammatical gender in bilinguals have involved picture naming and lexical decision tasks. These tasks are often manipulated so that half of the experimental stimuli have congruent grammatical assignments across languages (for example, 'apple' is feminine in both Italian: *'mela'* and Croatian: *'jabuka'*) and half have incongruent grammatical assignments across languages (for example, 'tomato' is masculine in Italian: *'pomodoro'*, but feminine in Croatian: *'rajčica'*; Costa, Kovacic, Frank and Caramazza, 2003). According to a gender integrated view, responses should be faster for congruent trials compared with incongruent trials, due to the activation of a single lemma node from two lexical representations. In contrast, the language autonomy view would not predict any difference to occur between congruent and incongruent trials.

Costa et al. (2003) found no difference between the naming latencies of congruent and incongruent trials during a picture-naming task, which they interpreted as support for a language autonomous view. However, subsequent studies have yielded somewhat conflicting results, with the balance of evidence supporting a gender integrated view (e.g. Ganushchak, Verdonschot & Schiller, 2011; Kaushanskaya & Smith, in press; Lipski, 2014; Morales, Paolieri, Cubelli & Bajo, 2014; Salamoura & Williams, 2007). For example, in a picture-naming task, Paolieri et al. (2010) reported faster naming latencies during gender-congruent trials compared with gender-incongruent trials, suggesting co-activation of the non-operational language, and providing support for the gender integrated view. Similar effects have been observed in studies assessing grammatical gender access in comprehension (e.g. Lemhofer, Spalek and Schriefers, 2008). In this study, the effect was larger for cognates, indicating that lexical and semantic overlap between languages facilitated the activation of lemma nodes in the non-operational language.

From the studies reviewed, it appears that lemma nodes can be shared between languages, indicating that access to word-level syntactic information in bilinguals is largely nonselective. However, the research reviewed thus far has focused on the representation of syntactic features that are shared between languages, and has not investigated the influence of language-specific syntactic representations on word recognition. Recently, Kaushanskaya and Smith (in press) investigated syntactic co-activation in an associative learning task. Participants were presented with word pairs consisting of an inanimate object and a proper name (e.g. corn-Patrick), and were instructed to learn the associated names. Half of the word pairs were congruent (such that the gender of the proper noun matched the grammatical gender of the Spanish translation of the inanimate objects) and half were incongruent (such that the gender of the proper noun did not match the grammatical gender of the Spanish translation of the inanimate objects). They reported poorer performance during incongruent trials compared with congruent trials, indicating that the syntax of the non-operational language had influenced performance. It thus appears as though idiosyncratic syntactic rules are co-activated during monolingual tasks, and that these co-active rules are able to influence task performance. Interestingly, this effect was only found for participants who reported a high degree of exposure to Spanish on a daily basis, indicating that syntactic co-activation may only occur in specific bilingual populations.

1.4. The Role of Syntax during Sentence Processing

Thus far, the reviewed research has focused on the representation and retrieval of word-level syntactic information in bilinguals. In this section, I turn to the relatively understudied topic of a bilingual's representation of syntax during sentence processing. Before detailing the processes governing bilingual sentence processing, it is first necessary to outline this process in monolinguals.

Understanding information at the sentence level is an integral part of human communication, and whilst language comprehension is a mostly effortless process, it involves rapid integration of lexical, syntactic, and semantic information. Simply put, the reader or listener must be able to accurately deconstruct a sentence in order to understand its meaning (who did what to whom).

In a seminal paper, Chomsky (1965) suggested that lexical items are associated with, and constrained by *strict subcategorization rules* that specify the context in which they can occur, as well as *selectional rules* that denote their syntactic categories. For example, selectional rules would denote the lexical item 'table' as an inanimate noun, whereas subcategorization rules would specify its possible placement in a noun phrase (NP). Subsequent theoretical models have also emphasised the role of lexical representations in the semantic and syntactic deconstruction of sentences (e.g. Kaplan & Bresnan, 1982), but an outstanding empirical question is the way in which these representations are accessed and integrated during sentence processing.

Empirical studies of sentence comprehension have repeatedly shown evidence of immediate lexical, semantic and syntactic processing (e.g. Marslen-Wilson, 1975; Seidenberg, Tanenhaus, Leiman & Bienkowski, 1982; Tanenhaus, Spivey-Knowlton, Eberhard & Sedivy, 1995), suggesting that sentence processing occurs incrementally (that is, activation of a lexical representation automatically activates its corresponding syntactic and semantic properties). As such, the syntactic properties of a word become available upon the activation of a lexical candidate (see Levelt et al., 1999 for a detailed description of this process during production), via spreading activation (e.g. Anderson, 1983; Collins & Loftus, 1975; Roelofs, 1992).

Under this 'lexicalist' account, lexical- and associated lemma- level information is then integrated into the larger grammatical structure (e.g. Bresnan, 2001; Harbusch & Kempen, 2002; Marslen-Wilson, 1987). In the comprehension literature, the integration process is referred to as 'unification', in which activated lexical frames derived from lexical representations undergo a form of 'binding' to create plausible grammatical structures. According to models of sentence parsing, the activation of a lexical item leads to the activation and selection of a connected 'lexical frame'. For the sake of term consistency, these lexical frames are analogous to the subcategorization rules described earlier in this section (Chomsky, 1965). For example, the common noun 'table' would activate, among others, the lexical frame for a noun phrase. In line with an incremental view of sentence processing, activated lexical frames are sequentially entered into a 'unification space' in which they undergo a binding process to create grammatical constructions (e.g. Vosse & Kempen, 2009; see also Jackendoff, 2007).

A similar lexicalist model has been proposed in the production literature, based on the findings of syntactic priming studies. Syntactic priming refers to the linguistic phenomenon in which speakers are more likely to use a particular grammatical construction if they have recently used or heard the same construction (Bock, 1986; see also Bock & Loebell, 1990; Branigan, Pickering, Liversedge & Urbach, 1995; see Pickering & Ferreira, 2008, for a review). Pickering and Branigan (1998) proposed a model of syntactic representation, which assumes a direct link (implying automatic activation) between lexical representations and their corresponding lemma nodes (c.f. Levelt, 1989; Levelt et al., 1999; Roelofs, 1992). Unlike previous production models however, an additional level of processing is presented, in which lemma nodes are linked to 'combinatorial' nodes (containing information regarding specific syntactic constructions), such that the activation of a lemma node automatically activates its corresponding combinatorial nodes. To clarify, combinatorial nodes are analogous to the 'lexical frames' and 'subcategorization rules' described earlier in this section, whereas lemma nodes are analogous to the aforementioned 'selectional rules'. Thus, according to this model, syntactic priming is driven by the residual activation of combinatorial nodes (but see Chang, Dell & Bock, 2006, for an alternative view).

1.5. Bilingual Representation of Syntax during Sentence Processing

It is reasonable to assume that the fundamental mechanisms governing sentence processing in monolinguals would also apply to bilinguals. However, it is currently unclear whether bilinguals only activate the syntactic representations of the language of operation, or whether the syntactic representations of both languages are co-active during sentence processing. Studies examining this question to date have primarily used cross-linguistic syntactic priming paradigms to determine whether syntactic representations are shared between languages. Recall that in the monolingual literature, syntactic priming was explained by the residual activation of a combinatorial node shared between languages. If bilinguals represent syntactic information separately in either language (such that a single combinatorial node connects to the relevant lexical representations of one language only), cross-linguistic syntactic priming should not occur. However, if syntactic information is shared between languages (such that a single combinatorial node connects to the relevant lexical representations of both languages), cross-linguistic syntactic priming should occur.

Current research provides evidence for shared syntactic representations. Using a bilingual scene-description task (Branigan, Pickering & Cleland, 2000), Hartsuiker, Pickering and Veltkamp (2004) reported that English passive sentences were produced more often following a Spanish passive sentence than following a Spanish active sentence (see also Loebell & Bock, 2003; Meijer & Fox Tree, 2003). Based on their findings, the monolingual model of syntactic representations (Pickering & Branigan, 1998) was adapted to accommodate shared conceptual and combinatorial nodes between languages. The model moreover accommodates the specification of language tags (see Dijkstra and van Heuven, 2002; Green, 1998; van Heuven et al. 1998; see Figure 1 for a depiction of this model). Thus, the model attributes cross-linguistic syntactic priming to the residual activation of a shared combinatorial node via the activation of a lexical candidate.

Subsequent cross-linguistic syntactic priming studies provide support for the proposed model (see Hartsuiker & Pickering, 2008 for an early review), but several factors have also been found to influence the extent to which syntax is shared between languages. Bernolet, Hartsuiker and Pickering (2013) for example investigated the influence of language proficiency on syntactic priming. They found stronger priming effects in high- compared with low- proficiency Dutch-English bilinguals. Such findings indicate that combinatorial nodes may initially be language specific (cf. Ullman, 2001), and that shared, language non-specific combinatorial nodes develop as a function of increased proficiency (see also

Hartsuiker & Bernolet, in press; Schoonbaert, Hartsuiker & Pickering, 2007). A shared model of syntax may therefore be more representative of highly proficient bilinguals, rather than unbalanced bilinguals.

Additionally, Bernolet, Hartsuiker and Pickering (2007) reported syntactic priming between Dutch and German, but not between Dutch and English. They attributed the latter null effect to word order differences in Dutch and English, concluding that combinatorial nodes are only shared between languages that share the same word order (see also Loebell & Bock, 2003).

1.5.1. Shared syntactic representations or syntactic co-activation?

Thus far, I have reviewed studies that have primarily focused on whether combinatorial nodes can be shared between languages in bilinguals. A related – and much understudied topic – concerns syntactic co-activation in bilinguals. Importantly, co-activation of syntax also implies nonselective access, but it is not restricted to instances in which syntactic representations are shared between languages. For example, Kantola & van Gompel (2011) proposed a modified model of bilingual syntactic representations, whereby separate combinatorial nodes exist for each language, which are nevertheless connected. Thus, combinatorial nodes are not shared, but the activation of a combinatorial node in one language can lead to activation of the equivalent combinatorial node in the other language. The theoretical possibility of fundamentally separate yet co-active combinatorial nodes raises an important empirical research question concerning the activation of syntactic representations during language processing.

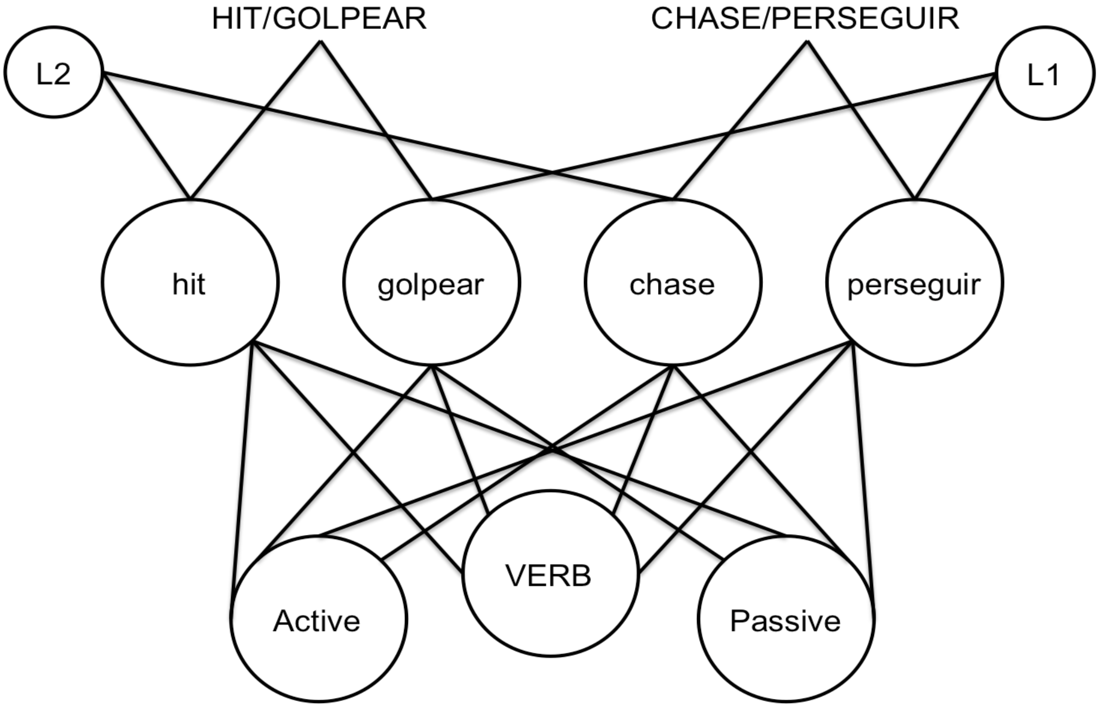

Figure 1. Hartsuiker, Pickering & Veltkamp's (2004) model of bilingual syntactic representation (restricted to conceptual, lexical, lemma and combinatorial nodes). Shared conceptual nodes are represented at the top of the model, and are connected to the lexical representations of both languages. Lexical representations are also connected to language nodes (denoted by L1 and L2). Furthermore, lexical representations are connected to shared lemma nodes (denoted by 'VERB') and shared combinatorial nodes (denoted by 'Active' and 'Passive').

To assess the co-activation of syntax in bilinguals, Hatzidaki, Branigan and Pickering (2011) asked participants to produce sentence completions following target words that did (convergent) or did not (divergent) share the same syntactic number as their translation equivalents. For example, participants were presented with the sentence 'The money…', and were required to produce a sentence completion. More agreement errors (indexed by the production of a verb and/or adjective with a different syntactic number to the subject) were reported during divergent trials compared with convergent trials. For example, ‘money’ is considered singular in English, but plural in Greek, and as such, sentences containing ‘money’ were more likely to yield an agreement error such as ‘The money *help*’, indicating that bilinguals had co-activated the syntactic rules of both languages. Based on their results, they proposed an integrated model of bilingual syntactic representations, in which shared representations are assumed for syntactic rules that are common in both languages, and in which idiosyncratic syntactic features are only connected to lexical representations from one language. As such, activation of the idiosyncratic rule occurs via the co-activation of the target word’s translation equivalent (see Figure 2). Interestingly, stronger effects of syntactic co-activation were found during bilingual tasks compared with monolingual tasks, indicating that syntactic co-activation may be sensitive to task demands (see section 2.2. for a discussion on the influence of task demands and language context on language co-activation).

Thus, Hatzidaki et al. (2011) suggest that syntactic co-activation occurs even in the absence of shared syntactic representations. Moreover, the mechanism by which syntactic co-activation is enabled is identified as spreading activation between lexical- and lemma-level representations. This interpretation is consistent with investigations of syntactic activation in monolinguals: syntactic priming effects are often stronger as a function of lexical repetition (e.g. Pickering & Branigan, 1998), and non-existent in its absence (e.g. Arai, van Gompel & Scheepers, 2007; Ledoux, Traxler & Swaab, 2007; Tooley, Traxler & Swaab, 2009; see Traxler & Tooley, 2008 for a review; but see also Thothathiri & Snedeker, 2008). Such ‘lexical boost’ effects also occur in cross-linguistic priming studies (Bernolet, Hartsuiker & Pickering, 2012; Cai, Pickering, Yan & Branigan, 2011).

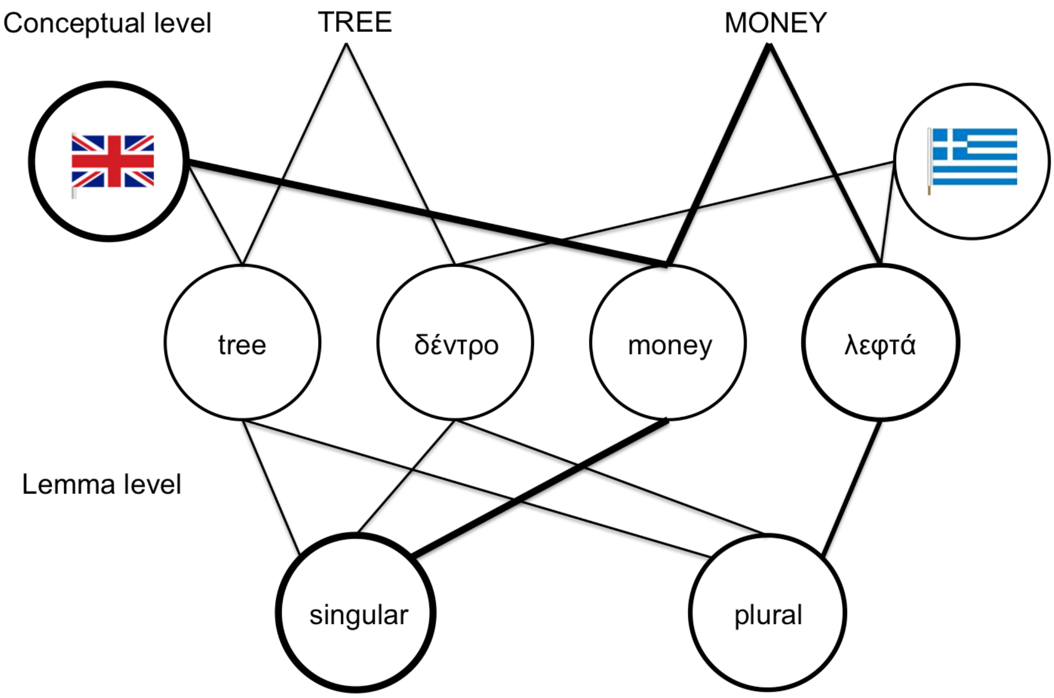

Figure 2. Hatzidaki, Branigan and Pickering's (2011) model of syntactic co-activation during production (restricted to conceptual, lexical, and lemma nodes). Language tags are denoted by the British and Greek flags, and thicker lines illustrate the strength of connections between representations.

However, at least one study from the comprehension literature suggests that syntactic co-activation may occur via the application of abstract syntactic rules, rather than via lexical links. In a recent ERP study, Sanoudaki and Thierry (2014) investigated the possible co-activation of abstract syntactic rules that differ between languages. Specifically, they tested whether knowledge of a syntactic rule in the non-operational language influenced implicit brain responses to a syntactic violation in the language of operation. Bilingual Welsh-English and monolingual English groups were shown a picture (to the left or the right of centre-screen), followed by an English sentence that contained an adjective-noun pair either in the correct order for English (e.g., *The <u>blue car</u> is on the right* -adjective first), or the reverse order, only correct in Welsh (e.g., *The <u>car blue</u> is on the right* –noun first). Participants indicated whether the sentence accurately described the picture location *only* when either the colour or the object described in the sentence matched the picture. Results showed that monolinguals dropped their expectation of further task-relevant information when encountering the noun (e.g., after reading ‘car’), irrespective of its position relative to the adjective. Bilinguals, however, kept expecting further information even when the noun was presented before the adjective (which is aberrant in English, but legal in Welsh), providing support for cross-language syntactic activation. Given that word order is abstract, in the sense that it is independent of lexical information, these findings suggest the co-activation of abstract syntactic rules, and support the suggestion that syntactic rules can be co-active, even when they differ between languages.

Whilst the two studies described above have contributed greatly to the understanding of syntactic representations in bilinguals, they do not address the fundamental question of whether *idiosyncratic* syntactic rules are also co-active: Whilst syntactic number, and word order may differ between languages, they are syntactic properties that exist in both the investigated languages. As such, the degree to which abstract syntactic information interacts in bilinguals is still unknown: Do bilinguals only activate abstract syntactic rules that exist in both of their languages, or do they also co-activate abstract syntactic rules that exist in only one language?

1.6. Thesis Aims

The purpose of this thesis is to address the highly understudied topic of syntactic co-activation. Specifically, my aim is to identify the parameters of syntactic co-activation. To date, investigations on syntactic representation in bilinguals have focused predominantly on the empirical question of whether representations can be shared between languages. Recently, studies have attempted to investigate the representation and activation of syntactic rules that differ between languages, however these studies focused on syntactic properties that exist in both languages. In this thesis, I aim to extend the current literature on syntactic co-activation to investigate whether *idiosyncratic* syntactic rules are also co-active. Furthermore, I aim to investigate the underlying mechanisms of syntactic co-activation in order to discover whether it occurs via lexico-syntactic associations, or via the application of abstract syntactic rules. Finally, I aim to determine the influence of context on syntactic co-activation, via the inclusion of stringent monolingual contexts (see Chapter 2 for a detailed discussion about the theoretical and practical considerations of these aims). To summarise, the thesis aims are to examine:

1. **Whether** bilinguals co-activate idiosyncratic syntactic rules
2. **How** syntactic co-activation occurs
3. **When** syntactic co-activation occurs, focusing on contextual constraints

Moreover, the research presented in this thesis will specifically focus on syntactic co-activation in the context of *language comprehension*. Given the currently sparse research on the representation of syntax in bilinguals, and, specifically, on syntactic co-activation, I have drawn upon research from both the comprehension and production literature in this review. I note here that common representations are allegedly activated during comprehension and production (e.g. Pickering & Garrod, 2004; Pickering & Garrod, 2013), but any inconsistencies in the findings outlined here and in other studies (e.g., Hatzidaki et al., 2011) can perhaps be attributed to differences involved in comprehension and production processes. This issue is revisited in the General Discussion chapter (Chapter 6).

1.7. Chapter Summary

In this chapter, I reviewed the evidence for language co-activation in bilingual individuals. A substantial amount of research has been conducted on lexical and semantic co-activation, but relatively few studies have investigated the co-activation of syntax during sentence processing, with studies focusing largely on whether syntactic representations are shared between languages. This thesis goes beyond an investigation of *shared* syntactic representations to examine *co-active* representations, with a view to assessing the extent of interactivity in a bilingual's syntactic system(s). Throughout the thesis, I refer back to the **whether**, **how** and **when** aims, answering each point in turn. In the following chapter, I will outline the experimental manipulations, methodology and the bilingual populations used in the experimental studies that follow.

Chapter 2

Methodological Considerations

2.0. Chapter Overview

In this chapter, I will describe the methodological considerations of the thesis. I will begin by describing the experimental manipulation used in all three experiments, which derives from Welsh soft mutation. I will then justify the population of bilinguals who participated in these experiments. Finally, I outline the two methodologies used in this thesis – event related potentials and eye-tracking – specifying how these methods are appropriate for the research questions under investigation.

2.1. Welsh Soft Mutation as a means to examine Syntactic Co-activation

Recent studies indicate support for syntactic co-activation in bilinguals (e.g. Hatzidaki, Branigan & Pickering, 2011; Sanoudaki & Thierry, 2014). In both studies, experimental manipulations centred on inter-language differences (syntactic numbering and word order), but crucially, both syntactic numbering and word order *existed* in the languages of comparison. In this thesis, I manipulate a rule that exists only in one language (Welsh), to examine whether it is co-activated during sentence processing in the other language (English). To accomplish this, I investigated whether the Welsh rules of soft mutation (a morphosyntactic process that is completely alien to English) are co-active during English sentence reading.

2.1.1. A brief overview of soft mutation

Soft mutation is a morphosyntactic process that alters the initial consonant of Welsh words in specific syntactic contexts. During soft mutation, stops, liquids and the nasal /m/ undergo a process of lenition (p→b, t→d, k→g, b→v, d→ð, g→Ø, ɬ→l, r̥→r, m→v; Thomas & Gathercole, 2007) following specific contextual cues. For example, feminine nouns such as *'cadair'* (chair) would undergo a process of soft mutation when preceded by the determiner *'y'* (the), whereas masculine nouns such as '*bwrdd'* (table) would not:

a) *Eisteddodd Huw ar y* ***g****adair* (c→g mutation)

Huw sat on the chair

b) *Eisteddodd Huw ar y* ***b****wrdd* (no mutation)

Huw sat on the table

Furthermore, the gender neutral pronoun *ei* (his/her/its) always elicits a mutation, but the type of mutation that should occur is determined by the antecedent of the sentence; a soft mutation only occurs when referring back to a masculine antecedent:

c) *Eisteddodd Huw are ei* ***g****adair*

Huw sat on his chair

As a final example, soft mutation can be elicited by a syntactic trigger that is not directly adjacent to the mutated word, indicating that it is a morphosyntactically driven process (Harlow, 1989). In example sentence (d), the mutation is triggered by the nonadjacent verb *cymerodd* (took), and is not influenced by the adjacent proper noun *Huw*.

d) *Cymerodd Huw gadair*

Huw took (a) chair

These examples are by no means exhaustive, and are merely used to reflect the complexity of soft mutation (see Ball & Müller, 1992, for a thorough account of Welsh mutations). In addition to the rules described above, soft mutation is used as an index of grammatical gender: Adjectives that follow feminine nouns undergo the process of soft mutation, whereas adjectives that follow masculine nouns do not. Soft mutation is therefore an integral part of Welsh sentence processing, and whilst it is frequently used during production and comprehension, the complex processes involved may result in increased cognitive load.

2.1.2. Application of soft mutation to English: special considerations

In order to investigate syntactic co-activation, I applied the morphosyntactic rules of soft mutation to English sentences, such that the initial consonants of English target words were manipulated to create nonwords. Such nonwords were either consistent with the consonant changes of soft mutation (e.g. **p**rince → **b**rince; p→b manipulation) or inconsistent with the consonant changes of soft mutation (e.g. **p**rince → **g**rince; aberrant p→g manipulation that would never occur in Welsh). Whilst Welsh and English are orthographically similar, there are some inconsistencies between the phonology of Welsh consonants as compared to English. For example, the consonant 'f' differs in terms of phonology between the two languages (English = *f*ence; Welsh = *v*an). English target words were therefore restricted to words starting with the initial consonants 'p', 't' or 'c', as their 'mutated' counterparts (b, d, g) shared similar orthography and phonology in English and Welsh. For example, English words beginning with 'd' were excluded, as the mutated form of 'd' is '*dd*' – a consonant that does not exist in English and as such would cause greater processing difficulty (e.g. '*ddoor'* would cause more processing difficulty than '*dable'*). Whenever possible, English target words were additionally controlled such that their Welsh translation equivalents began with the initial consonants 'p', 't', or 'c' (e.g. 'prince' was selected as a target word as its Welsh translation equivalent starts with the consonant 't'; *tywysog*, whereas parent was not selected as its Welsh translation equivalent starts with the consonant ‘rh’; *rhiant*). Finally, English target words were selected on the basis that their mutated and aberrant counterparts would create *nonwords* (e.g., the word ‘park’ was excluded, since its mutated equivalent produces the real English word ‘bark’).

2.1.3. Phonological familiarity vs syntactic co-activation

Manipulating the initial consonants of English words allowed for the comparison of responses to mutated nonwords (e.g. **b**rince) and aberrant nonwords (e.g. **g**rince). A crucial further manipulation was to place these words in the context of English sentences, the structure of which would or would not elicit a sentence-final mutation (had they been presented in Welsh). For example, the sentence *The King and Queen had a son, who was a prince* would elicit a sentence-final mutation in Welsh, whereas *The King and Queen had a son: the prince* would not. The central hypothesis in this thesis, in support of syntactic co-activation, is stated here, and repeated in each experimental chapter:

If Welsh syntax is co-active during English sentence reading, bilinguals will demonstrate greater acceptance of mutated English nonwords, but only when presented in a syntactic context that would lead to a mutation in Welsh.

The hypothesised interaction effect is important, since greater acceptability of the mutated word without the syntactic context could be attributed to a frequency effect: Welsh-English bilinguals are more accustomed to particular phoneme changes. The inclusion of this contextual manipulation thus enables the distinction between *phonological* and *syntactic* influences.

2.1.4. Lexico-syntactic associations vs abstract syntactic rules

To date, syntactic co-activation is predominantly thought to be implemented via lexical links between languages. However, it is also possible that under some circumstances, syntactic co-activation can occur via abstraction of the rule. That is, the syntactic rules of the non-operational language can be co-active, even in the absence of lexical links.

In this thesis, I expand on the current literature by explicitly testing the underlying mechanisms of syntactic co-activation: English target words used throughout the thesis were manipulated such that they did or did not share an initial consonant with their Welsh translation equivalents (e.g. overlap: **t**elevision - ***t****eledu*; no overlap: **p**rince - ***t****ywysog*). If syntactic co-activation occurs via lexico-syntactic associations, a lexical boost should be observed: Syntactic co-activation should be more prominent for overlap trials as compared with no overlap trials. If syntactic co-activation occurs via the application of abstract syntactic rules however, the extent to which syntactic co-activation occurs should be comparable in overlap and no overlap trials. Such a manipulation additionally allows for an investigation of the underlying mechanisms of syntactic analysis: does syntactic analysis occur via learned lexico-syntactic associations, or are abstract rules extracted and applied through generalisation (Elman, 1998; Plunkett and Marchman, 1993).

2.2. The Influence of Task Demands and Language Context on Syntactic Co-activation

Studies investigating language co-activation in bilinguals have repeatedly demonstrated the influence of language context and task demands on participant performance, both during isolated word recognition tasks (e.g. Soares & Grosjean, 1984) and sentence processing tasks (e.g. van Hell & de Groot, 2008). As such, it is possible that the degree to which a bilingual 'co-activates' the different properties of both languages is dependent on the linguistic context they are placed in. That is, bilinguals may operate in specific language modes (Grosjean, 1998, 2008). Language modes can be best visualised along a continuum, ranging from a completely monolingual mode (in which the bilingual activates the representations of only one language) to a completely bilingual mode (in which the bilingual activates the representations of both languages). For example, a bilingual would operate in a completely monolingual mode whilst reading a book, whereas they would operate in a completely bilingual mode during a conversation in which they are likely to engage in code-switching. Furthermore, exposure to any input from the non-operational language would result in an automatic shift along the continuum, from a completely monolingual mode to a more bilingual mode, in which some aspects of the non-operational language are activated.

In some ways, the 'language mode' is analogous to the task schemas proposed in the IC model (Green, 1998) and the BIA+ model (Dijkstra & van Heuven, 2002), however the 'language mode' model does not assume that the representations of the non-operational language are 'inhibited' by task schemas; rather it assumes the complete deactivation of the representations of the non-operational language. Whilst this theory can be used to explain the frequently observed cognate facilitation effect (e.g. Dijkstra, Grainger & van Heuven, 1999), it does not explain the co-activation of lexical items during completely monolingual tasks (in which the participant is not exposed to their other language at any point; e.g. Thierry & Wu, 2007). It thus appears that bilinguals co-activate the lexical representations of both languages even during monolingual tasks. Given the lack of empirical research on syntactic co-activation, it is not currently clear whether bilinguals co-activate the syntactic properties of both languages during monolingual tasks. In this thesis, monolingual task settings are used to examine co-activation under the most conservative conditions. This is made possible by the use of methods commonly used in cognitive neuroscience to study automatic, online responses.

2.3. Experimental Methods: Event-related Potentials (ERPs)

Research investigating language co-activation has relied predominantly on behavioural methods such as lexical decision times during word recognition tasks, and cross-linguistic priming. Whilst these studies have provided a wealth of information regarding language processing in bilinguals, it is possible that they are insufficiently sensitive to examine the parameters of language co-activation. For example, behavioural experiments on language co-activation may fail to report significant differences between conditions, but the absence of behavioural differences does not necessarily demonstrate that the non-operational language was not accessed: Rather, it demonstrates that the non-operational language did not influence *behaviour*. The online method of event related potentials (ERPs) provides a measure of implicit language processing, potentially capturing effects that are too subtle to be observed in behaviour.

In relation to research on bilingualism, ERPs have enabled significant strides in our understanding of first vs second language processing, often demonstrating subtle electrophysiological differences in the absence of behavioural effects (see Mueller, 2005, for an early review). Due to the sensitivity of the measure, and its ability to detect differences in the absence of behavioural effects, ERPs may provide a more sensitive and accurate account of language co-activation in the bilingual brain. Furthermore, ERPs are typically time locked to the onset of a specific stimulus, allowing for a detailed, millisecond-by-millisecond account of the influence of a manipulated target word on brain activity.

2.3.1. Using ERPs to investigate language co-activation

ERPs therefore enable a measure of implicit activation of the non-operational language in a monolingual context (of the operational language). In a measure of lexical co-activation in bilinguals, Wu and Thierry (2010a) presented Chinese-English participants with

English word pairs, which did or did not contain a phonological repetition in Chinese. Although the experimental manipulation went unnoticed by the participants, phonologically related word pairs yielded reduced mean amplitudes compared with phonologically unrelated word pairs, indicating that participants had automatically activated the phonology of the non-operational language (Chinese) during second language (English) processing. Additionally, no behavioural evidence of language co-activation was reported. Similarly, Tokowicz and MacWhinney (2005) used ERPs to show that second language learners' implicit responses to grammatical violations in their second language were modulated by the grammatical rules of their first language. Their explicit responses (accuracy scores) were *not* influenced by their first language, however. These example studies show that implicit detection of language co-activation is possible, even in the absence of an overt behavioural response.

2.3.2. The phonological mismatch negativity

Due to the extensive amount of language research involving ERPs, several key components have been defined as reflecting specific processes, and it is generally assumed that early ERP components (e.g. P1, N1) reflect lower-level perceptual processes, whilst later components (e.g. N4, P6) reflect higher-level linguistic processes such as semantic (e.g. Kutas & Hillyard, 1980) and syntactic integration (Osterhout & Holcomb, 1992). In the ERP experiments presented in this thesis, I have focused on the phonological mismatch negativity (PMN; Connolly & Phillips, 1994): An ERP index sensitive to lexical processing modulated by phonological expectation formed on the basis of a word's initial letter**.** For example, whilst the sentences below are equally plausible in terms of semantics, sentence (e) is arguably more predictable than sentence (f) in the sense that participants would expect the sentence final word 'dog' more than 'fish'. As such, a more negative PMN mean amplitude (indicative of an unexpected phoneme) may be observed for sentence (f) than sentence (e).

e) The man had two pets; one cat and one dog

f) The man had two pets; one cat and one fish

Whilst the PMN has typically been investigated during auditory tasks, it is noteworthy that such phonological expectancy effects are also found in reading tasks (Savill and Thierry, 2011; Savill, Lindell, Booth, West and Thierry, 2011). For example Savill et al. (2011) demonstrated that participants automatically activated the phonological forms of words during reading: In a sentence judgement task, target words that were phonologically similar (homophones and pseudo-homophones) to the expected sentence completions yielded reduced mean amplitudes compared with unrelated sentence completions. Furthermore, recent investigations into language co-activation reveal that bilinguals co-activate the phonology of the non-operational language during reading (Wu & Thierry, 2010a). Modulation of the PMN also relies on phonological expectancy, and thus is only elicited when a prediction is made about the target word. In the context of the studies presented in this thesis, the PMN thus allows an analysis of phonological expectancy (of the mutation word) driven by predictions made on the basis of the sentence structure. In Chapters 3 and 4, I describe two ERP experiments in which modulation of the PMN was used as an index of syntactic co-activation.

2.4. Experimental Methods: Eye-tracking

Whilst ERPs provide a sensitive measure of the implicit processes involved during language comprehension, responses are typically time locked to the presentation of individual words, and are therefore not well suited for the investigation of the processes involved during natural reading. However, to determine whether co-activation occurs under conservative task conditions, it is necessary to investigate whether it is a feature of natural reading contexts.

Eye-tracking is ideally suited to measure online cognitive processing during natural sentence reading, and a number of fine-grained measures enable the investigation of how multiple linguistic factors (e.g. phonology, orthography, semantics and syntax) influence sentence processing. As such, this method is well suited to examine whether syntactic co-activation occurs in monolingual sentence processing.

2.4.1. Eye-tracking measures

Researchers concerned with the cognitive aspects of reading typically focus on measures derived from fixation durations (the length of time the eye is relatively still before a saccade is triggered). A crucial assumption of eye-tracking research is that fixation durations reflect processing difficulty, with longer fixations indicative of greater processing load (Just & Carpenter, 1980; see Rayner, 1998 for a review). Fixation measures in reading research typically concern local indicators of processing difficulty on specific stimuli (such as individual words in a reading experiment), and can be used to determine the part of the sentence that causes the most processing difficulty.

The most commonly reported local measures are first fixation duration (the duration of the fixation that occurs when the reader first reads the word in the fovea), single fixation duration (the duration of the fixation when a reader only makes a single fixation on a word), and gaze duration (the summation of all fixations on a word before a saccade is made to another word). These three measures are sometimes referred to as 'first pass measures', since they measure fixation durations that occur when the word is first processed in the fovea (that is, before the reader moves to another section of text). In addition to these first pass measures, reading researchers also often report regression path durations (the total amount of time spent fixating on a word and its preceding context before a forward saccade is made) and re-reading times (the time spent re-fixating on a target word before making a forward saccade to a post-target region; Liversedge, Paterson & Pickering, 1998). Whilst the exact processing stages reflected in these measurements remains debatable, it is generally accepted that first pass measures typically reflect early lower-level processing stages, whilst regression path durations and re-reading times reflect later, higher-level processing stages.

2.4.2. The Boundary Paradigm

An informative eye-tracking method used to investigate implicit processing in sentence contexts is the boundary paradigm (Rayner, 1975). In this paradigm, target words are typically manipulated in the parafovea (an area 2-6 degrees of visual angle from the focal point of a given fixation) such that they appear in an incongruent or a congruent form during sentence reading (see Example 1). Once a participant makes a saccade over an invisible boundary (typically placed between the target word and the word immediately preceding it), the target word changes back to its original form (and as such, the experimental manipulation remains undetected, due to the assumption that vision is suppressed during a saccade; Matin, 1974).

Example 1.

1. Congruent parafoveal preview

   The tired waitress cleared **t**ables during the banquet

   The tired waitress cleared **t**ables during the banquet

2. Incongruent parafoveal preview

   The tired waitress cleared **d**ables during the banquet

   The tired waitress cleared **t**ables during the banquet

Traditionally, the boundary paradigm is used to investigate how much information is processed parafoveally, and a consistent finding is that of a preview benefit (typically reflected in reduced fixation durations on target words) for trials including a congruent parafoveal preview as compared with trials including an incongruent parafoveal preview (see Schotter, Angele & Rayner, 2012 for a review). Whilst these effects are typically taken to reflect parafoveal processing at the lower (orthographic and phonological) levels, studies have also used the boundary paradigm to investigate whether higher-lever semantic and syntactic information can be processed parafoveally. Research in English suggests that parafoveal processing of semantic information does not occur during sentence reading (e.g. Schotter, 2013; Rayner, Balota & Pollatsek, 1986), however research investigating languages with more transparent phonologies (e.g. German; Hohenstein, Laubrock & Kliegl, 2010; Hohenstein & Kliegl, 2014), and languages in which semantic information is closely linked with orthography (e.g. Chinese; Tsai, Kliegl & Yan, 2012; Yan, Richter, Shu & Kliegl, 2009; Yan & Sommer, 2015; Yan, Wang, Tong & Rayner, 2012) have demonstrated that semantic information *is* processed in the parafovea. Furthermore, studies have demonstrated that *syntactic* information can also be processed in the parafovea (e.g. Kim, Radach & Vorstius, 2012, but see Angele & Rayner, 2013).

With regards to the thesis aims, the boundary paradigm enables presentation of manipulated nonwords in the parafovea only, creating a completely monolingual sentence reading context. To date, three studies have manipulated parafoveal previews according to the properties of the non-task language (Altarriba, Kambe, Pollatsek & Rayner, 2001; Wang, Yeon, Zhou, Shu & Yan, 2015; Wang, Zhou, Shu & Yan, 2014), but in these studies, the bilingual nature of the task manipulation was used as a tool to investigate semantic preview benefits, rather than as an attempt to understand the co-activation of linguistic representations in bilinguals. Chapter 5 describes two experiments in which the boundary paradigm was used to measure syntactic co-activation during natural, monolingual sentence reading.

2.5. Bilingual Populations

A final but important point to make in this chapter is to specify and justify the bilingual populations used in the experiments included in the thesis. Studies have reported the influence of language proficiency on cross-linguistic syntactic priming and syntactic co-activation, with stronger effects observed in highly proficient bilinguals (e.g. Bernolet, Hartsuiker & Pickering, 2013; Hartsuiker & Bernolet, 2015; Sanoudaki & Thierry, 2015; Schoonbaert, Hartsuiker & Pickering, 2007). I therefore recruited three separate populations of early, highly proficient bilinguals for each of the experiments described in this thesis. Given that the experimental work described here represents an initial systematic investigation of syntactic co-activation in bilinguals, I will discuss how this work can be adapted for other types of bilinguals in the General Discussion (Chapter 6).

2.6. Chapter Summary

In this chapter, the methodological considerations of the thesis were discussed. I explained the rationale behind the experimental manipulation used in all three experimental chapters, and described the two online methods used in this thesis. In the next three chapters, I will describe and discuss the findings of four experiments investigating syntactic co-activation: Chapters 3 and 4 will describe two ERP studies, whilst Chapter 5 will describe the results of two eye-tracking studies. Note that these chapters are intended for publication. Chapter 3 is already published in *The Journal of Neuroscience*, and Chapters 4 and 5 have been written for submission to *Neuropsychologia* and *Journal of Experimental Psychology: Human Perception and Performance*, respectively.

Chapter 3

Syntactic Co-activation in Welsh-English Bilinguals: an ERP Study

This chapter is published as:

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Abstract

Each human language possesses a set of distinctive syntactic rules. Here, we show that balanced Welsh-English bilinguals reading in English unconsciously activate and apply a morphosyntactic rule that only exists in Welsh. The Welsh soft mutation rule determines whether the initial consonant of a noun changes based on the grammatical context (e.g., the feminine noun *cath*–'cat' mutates into *gath* in the phrase *y gath*–'the cat'). Using event-related brain potentials, we establish that English nouns artificially mutated according to the Welsh mutation rule (e.g., 'goncert' instead of 'concert') require significantly less processing effort than the same nouns implicitly violating Welsh syntax. Crucially, this effect is found regardless of whether the mutation affects the same initial consonant in English and Welsh, showing that Welsh syntax is co-activated and applied to English regardless of phonological overlap between the two languages. Overall, these results demonstrate for the first time that abstract syntactic rules from both languages are co-active during sentence processing, even when such rules only exist in one language.

Language syntax is an abstract, rule-based mechanism in which combinatorial operations govern the classification and use of words (Chomsky, 1995). It remains unknown however, which mechanisms underlie the creation of such linguistic rules and whether syntactic analysis is performed on the basis of lexico-syntactic associations or whether abstract rules are extracted that can be applied through generalisation (Elman, 1998; Plunkett & Marchman, 1993). In the current study, we tested the possibility of implicit syntactic co-activation in early adult bilinguals to determine whether the implementation of abstract linguistic rules relies on lexico-syntactic associations (Thierry & Wu, 2007; Wu, Cristino, Leek & Thierry, 2013; Wu & Thierry, 2010) or syntactic contingencies (Hartsuiker, Pickering & Veltkamp, 2004; Loebell & Bock, 2003; Sanoudaki & Thierry, 2014: Scheutz & Eberhard, 2004). This allowed us to characterize the mechanisms by which syntax can generalise across languages.

We recorded electrophysiological brain responses in Welsh-English bilinguals reading English sentences. All test sentences ended in nonwords created by substituting the initial consonant of the final word with a consonant that either produced a mutated or an aberrant form, according to the Welsh mutation rule (e.g., ‘p’ substituted by ‘b’-mutated, or ‘g’-aberrant). Syntactic structure was manipulated such that the Welsh translation of the English sentences required a word-final mutation or not. For example, the soft mutation rule in Welsh imposes a change to the noun’s initial consonant following specific syntactic triggers (Ball & Müller, 1992), which can be non-adjacent to the mutated word and is defined as a morphosyntactically driven process (Harlow, 1989). This allowed us to distinguish between brain processing of expected and unexpected initial consonants of the final noun depending on the syntactic context. The phonological mismatch negativity (PMN) is an ERP index sensitive to lexical processing modulated by phonological expectation formed on the basis of a word’s initial letter**,** and peaks between 250-300 ms post-stimulus (Connolly & Phillips, 1994; Diaz & Swaab, 2007; Hagoort & Brown, 2000). Assuming that Welsh syntactic rules are active during reading in English, we hypothesised that PMN amplitude would be reduced for mutated word forms, but only in sentences that would elicit a soft mutation if they had been encountered in Welsh.

We also manipulated phonological overlap between English and Welsh, such that in half of the experimental trials, the final word and its mutated form shared their initial consonant with their Welsh translations (see Table 1). If syntactic co-activation occurs as a result of cross-language lexico-syntactic associations (Thierry & Wu, 2007; Wu et al., 2013; Wu & Thierry, 2010b), we expected a PMN reduction only when the English word and its translation in Welsh shared their initial consonant. However, if syntactic co-activation occurs as a result of implementing abstract morphosyntactic rules, the PMN reduction should also be observed when there is no overlap between Welsh and English.

Methods

Participants

Nineteen Welsh-English bilinguals (5 males; 14 females) were included in the analysis on the basis of good knowledge of the Welsh soft mutation rule, assessed via a written sentence-completion test (cutoff score > 65%), and self-reported that they were L1 Welsh speakers, having learned English from an early age (*M* = 4.9 years; *SD* = 2.7). Five participants were excluded owing to poor mutation performance or self-report of stronger written and oral abilities in English than Welsh. A further three participants obtained too few epochs per condition. All participants possessed normal or corrected to normal vision. Ethical approval was granted by the School of Psychology, Bangor University ethics committee and participants gave written consent.

Table 1

Experimental design and stimulus examples

	Correct form	Mutated form	Aberrant form
Phoneme Overlap			
Mutation Context			
Each book starts with a page listing its	**c**ontents	**g**ontents	**d**ontents
(Dechreuir pob llyfr â thudalen yn rhestru ei	***g**ynnwys)*		
No Mutation Context			
The lid was lifted to examine the	**c**ontents	**g**ontents	**d**ontents
(Codwyd y caead er mwyn archwilio'r	***c**ynnwys)*		
No Phoneme Overlap			
Mutation Context			
As a doctor she saw a lot of	patients	**b**atients	**d**atients
(Fel meddyg, roedd hi'n gweld nifer o	*gleifion)*		
No Mutation Context			
At the hospital he would read to the	patients	**b**atients	**d**atients
(Yn yr ysbyty, byddai'n darllen i'r	*cleifion)*		

Note. The Welsh translation is shown here for information only.

Stimuli

Eighty target words, half of which shared an initial consonant with their Welsh translation equivalents and half of which did not (phoneme overlap manipulation), were selected. Two sentences, which varied according to their syntactic structures, were constructed for each target word (sentence context manipulation). Finally, each target word was manipulated such that it appeared in both its mutated form (e.g. **b**atients) and its aberrant form (e.g. **d**atients; word form manipulation). In 11% of trials the sentence ended in the correct, most expected word (fillers), with nonwords completing the remaining 89% of trials.

Thus, our experiment comprised of a 2 (phoneme overlap: overlap, no overlap) x 2 (sentence context: mutation, no mutation) x 2 (word form: mutated, aberrant) repeated measures design, with each participant viewing all sentence versions.

In a separate pre-test, the cloze probability of all test sentences was measured. Twenty-six monolingual English participants were presented with incomplete versions of the test sentences, and were asked to provide a semantically and syntactically appropriate word to complete the sentences. If the completions matched our experimental sentences, they were given a score of 1, and all other answers were scored 0. Cloze probability was calculated by averaging scores across sentences. In the event that the experimental test word was not the most predictable completion, it was removed from the stimulus list. Overall probability was .66, with no significant differences between any of the experimental conditions (no phoneme overlap / no mutation context = .69; no phoneme overlap / mutation context = .67; phoneme overlap / no mutation context = .63; phoneme overlap / mutation context = .64; p = .816). Additionally, translation accuracy was independently assed in a group of 15 balanced Welsh-English bilinguals who did not take part in the study. Participants were presented with whole sentences and were asked to translate the second clause of each sentence (including the mutation trigger). Translations were deemed accurate (score = 1) if they satisfied two conditions: 1) that the sentence context appropriately elicited a mutation or not, and 2) that the target word was the same as the item included in the experimental items. Translation agreement was very high (89% on average) and, critically, did not differ significantly between mutation and no mutation context sentences (p = .131). Target words and their Welsh translation equivalents were controlled for written frequency, word length and number of syllables.

Procedure

Participants viewed all 360 sentences, resulting in 40 trials per condition and 40 filler trials in a single session. Sentences were presented in white 18 point font on a black background. The first clause was presented as continuous text and was self-paced, followed by individual word presentation (200 ms with 500 ms inter-stimulus interval (ISI)). Presentation order was pseudorandomized, such that two target words never appeared in immediate succession. In order to ensure participant engagement, a third of all sentences were followed by a comprehension question. Participants responded correctly to comprehension questions with an average accuracy of 94% (*SD* = 4%, *range* = 83-98%) and their reading time of the first half of each sentence (*M* = 2639 ms, *SD* = 575 ms) did not differ significantly between conditions (mutation context / mutated nonword = 2676 ms; mutation context / aberrant nonword = 2635 ms; no mutation context / mutated nonword = 2617 ms; no mutation context / aberrant nonword = 2626 ms; $p = .374$).

ERP Recording

Electrophysiological data was recorded from 64 Ag/AgCl electrodes according to the extended 10-20 convention and were referenced to Cz at a rate of 1 kHz. The electroencephalogram (EEG) activity was filtered online with a band-pass filter between 0.1 and 200 Hz and offline with a low-pass zero-phase shift digital filter which was set at 20 Hz. Observed eye blinks in the EEG were corrected for mathematically and remaining artefacts were removed by manually inspecting the data. Epochs ranging from -100 to 1000 ms after the onset of the target word were extracted from the EEG recordings. Epochs with activity exceeding ±75μV at any electrode site were automatically discarded. There was a minimum of 30 epochs per condition for every participant. Baseline correction was performed in reference to pre-stimulus activity, and individual averages were digitally re-referenced to the global average reference.

Results

We analysed ERP amplitudes over six electrodes where the PMN is known to be maximal (linear derivation of FCZ, FC2, FC4, CZ, C2, C4; Connolly & Phillips, 1994; Figure 3) by means of a repeated measures analysis of variance (ANOVA) with phoneme overlap (overlap vs. no overlap), sentence context (mutation vs. no mutation), and word form (mutated vs. aberrant) as independent variables.

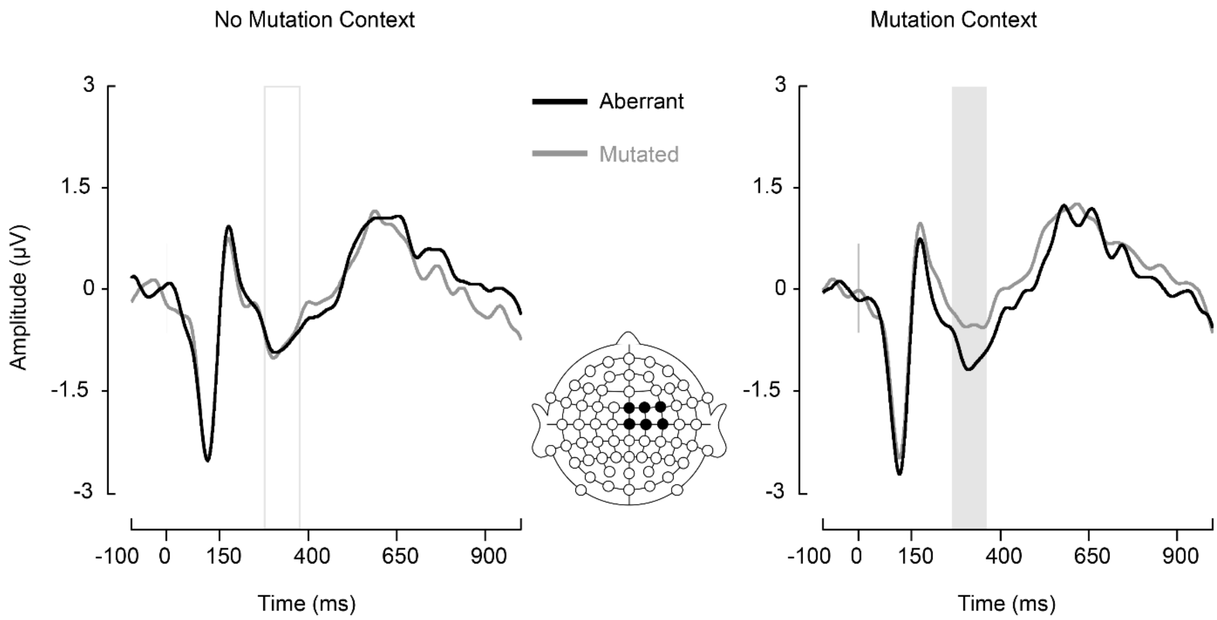

*Figure 3***.** ERPs elicited by mutated and aberrant nonwords collapsed across phoneme overlap and no phoneme overlap conditions. The plain grey box indicates the window of analysis in which mean ERP amplitude significantly differed between conditions (260-360 ms post-stimulus).

We found no main effect of either phoneme overlap, mutation context or word form. However, there was a significant mutation context x word form interaction; $F(1,18) = 6.08$, $p = .024$, $\eta_p^2 = .25$. Post hoc paired samples t-tests revealed that correctly mutated words elicited less negative PMN amplitudes than aberrant words when presented in a mutation context; $t(18) = 3.066$, $p = .007$, and this was not the case in no mutation context sentences; $t(18) = -0.09$, $p = .926$. No other significant interactions were found. In particular, phoneme overlap between English and Welsh did not interact with the mutation context effect; $F(1,18) = 0.349$, $p = .562$. Finally, analyses in earlier time windows (N1 and P2) did not show significant differences in amplitude between experimental conditions.

Discussion

Here, we questioned whether the syntactic rules of one language may be co-activated during sentence processing in another language by testing for a covert influence of Welsh mutations applied to English material. English words were manipulated into nonwords that either adhered to the Welsh mutation rules in terms of consonant change (e.g. p→ b; mutated nonword) or did not (e.g. p → g; aberrant nonword), and were placed in sentence contexts that did or did not elicit a mutation in Welsh (mutation context vs. no mutation context). We found that mutated nonwords are more easily integrated than aberrant nonwords, but only when presented in a context that would elicit a mutation in Welsh.

The implicit co-activation of Welsh mutation rules during English sentence processing was indexed by a reduction of mean amplitude in the range of the Phonological Mismatch Negativity (PMN): an ERP modulation known to be sensitive to phonological expectation and phonetic stimulus properties (Conolly & Phillips, 1994; Diaz & Swaab, 2007; Hagoort & Brown, 2000). Whilst the PMN has typically been investigated during auditory tasks, it is noteworthy that such phonological expectancy effects are also found in reading tasks (Savill, Lindell, Booth, West & Thierry, 2011; Savill & Thierry, 2011). If predictions normally applying to the Welsh language were also made in relation to English words, we expected reduced PMN amplitude for mutated relative to aberrant nonwords, according to the sentence context. Our results support this prediction, suggesting that the morphosyntactic rules of Welsh soft mutation, along with their accompanying constraints on phonological expectancy, were co-activated during English sentence processing.

Importantly, the effect reported here is not merely an artificial process triggered by the use of nonwords in the experiment, because a PMN modulation can only be elicited when participants make *predictions* regarding the upcoming final word and in particular, its first phoneme. If the effect was merely triggered by the encounter of a nonword, there is no reason why participants should expect a particular phoneme rather than another, unless they engaged in syntactic processing governed by the rules of the Welsh language. Additionally, in 11% of cases, participants were presented with filler sentences ending in a correct English completion word and therefore did not systemically approach the final word as a nonword.

Crucially, this effect was found irrespective of phonological overlap between English words and their Welsh translation equivalents, and thus cannot be attributed to lexico-syntactic associations. Indeed, language nonselective lexical access (Thierry & Wu, 2007; Wu et al. 2013; Wu & Thierry 2010b) fails to account for the results obtained here. If the effect reported here could be accounted for by nonselective lexical access alone, it should only have occurred when the word-initial phonemes were identical in English and Welsh. The finding that participants appeared to apply the Welsh mutation rule even in the absence of phonological overlap between languages demonstrates that the observed effect is the result of the implementation of a morphosyntactic rule. Beyond the issue of phonological overlap, the timing of the effect is also incompatible with a lexical mediation account since priming was observed here between 260 and 360 ms, which is considerably earlier than in previous studies of spontaneous access to translation equivalents (e.g., Wu & Thierry, 2007). Furthermore, this finding is compatible with results from behavioural studies demonstrating cross-linguistic syntactic effects in bilingual contexts (e.g. Bernolet, Hartsuiker & Pickering, 2007; Hartsuiker et al., 2004; Hatzidaki, Branigan & Pickering, 2011; Loebell & Bock, 2003; Vandeberg, Guadalupe & Zwaan, 2011), and an electrophysiological study, demonstrating the co-activation of word-order in bilinguals during a monolingual task (Sanoudaki & Thierry, 2014).

The use of ERPs in the current study presents an important methodological breakthrough in the investigation of syntactic processing in adult bilinguals, providing unique insights into covert co-activation of syntactic rules from both languages within the same individual (e.g., Wu & Thierry, 2013). We provide the first tangible evidence for spontaneous and anomalous co-activation of syntax in bilinguals, even at the level of subtle morphosyntactic changes elicited by a rule alien to English. These data suggest that syntactic co-activation involves the abstraction of syntactic rules rather than lexico-syntactic associations, and lend strong support to theories positing rule-based representation of syntax (Doeller, Opitz, Krick, Mecklinger & Reith, 2006; Opitz & Friederici, 2004). Future studies will investigate the underlying mechanisms of the observed co-activation effect, as well as the occurrence of syntactic co-activation in a more natural reading context.

Chapter 4

Elucidating the Underlying Mechanism of Syntactic Co-activation

Abstract

Recent evidence shows that bilinguals' syntactic systems are co-active, to the extent that the subtle morphosyntactic rules of the non-operational language are co-active during sentence processing in the operational language, even if they only exist in one of the two languages. Here, we further examine the triggers responsible for syntactic co-activation: Specifically, whether a bilingual's syntactic systems(s) are simply co-active, or whether the rules of one language are integrated into the syntax of the other language. To this end, we measured event-related brain potentials (ERPs) whilst Welsh-English bilinguals read English test sentences ending in mutated nonwords, which were created by implementing an initial consonant change consistent with the Welsh soft mutation rules (e.g. carrot → ***g***arrot). We also manipulated the preceding sentence context such that the soft mutation rule could be activated via triggers that could be operationalized in both the non-operational language (Welsh; the language to which the rule belongs) and the operational language (English; the language to which the rule does *not* belong), or via triggers specific to the operational language. ERP modulations were consistent with the latter hypothesis: Mutated nonwords were detected as appropriate completions when preceded by triggers specific to the operational language, even though the soft mutation rule does not exist in English. These results suggest that the syntactic rules of the non-operational language are co-active, and can be integrated into the syntactic system of the operational language. Overall, our results show that syntactic co-activation is a fully interactive process.

Bilinguals possess two distinct sets of syntactic rules, but the organisation of these syntactic systems in the bilingual brain is not yet clear; do they remain autonomous, or do they interact? Research to date has provided conflicting evidence, with some research providing support for an autonomous view (e.g. Costa, Kovacic, Franck & Caramazza, 2003), in which each syntactic system is independent and activated separately of the other. Other studies present evidence in favour of an interactive view, in which syntactic information can be shared between languages, and activated simultaneously (e.g. Hartsuiker & Pickering, 2008; Hartsuiker, Pickering & Veltkamp, 2004; Hatzidaki, Branigan & Pickering, 2011; Paolieri et al., 2010). Currently, the weight of evidence arguably falls in favour of the interactive account (Desmet & Declercq, 2006; Ganushchak, Verdonschot & Schiller, 2011; Lemhöfer, Spalek & Schriefers, 2008; Sanoudaki & Thierry, 2014; Scheutz & Eberhard, 2004; Weber & Indefrey, 2009; see Hartsuiker & Pickering, 2008 for a review), though several factors have been found to affect the extent to which syntactic representations interact, including language proficiency (Bernolet, Hartsuiker & Pickering, 2013; Hartsuiker & Bernolet, in press), immersion (Morales, Paolieri, Cubelli & Bajo, 2014), exposure (Kaushanskaya & Smith, in press), and similarity in syntactic structure (Kidd, Tennant & Nitschke, 2015; Loebell & Bock, 2003; Bernolet, Hartsuiker & Pickering, 2007; Kantola & van Gompel, 2011). As such, the currently preferred model of bilingual syntactic representation stipulates that syntax is shared between languages, but only when the syntactic structure is present in both languages, and only when the individual is equally proficient in each of their languages (Hartsuiker & Pickering, 2008; Hartsuiker & Bernolet, in press). Thus, syntactic co-activation for fluent bilinguals may be constrained by the extent of overlap in the syntactic features of either language.

However, Vaughan-Evans and colleagues recently showed that bilinguals co-activate the morphosyntactic rules of the non-operational language (Welsh) whilst processing sentences in the operational language (English), even when such rules do not exist in English (Vaughan-Evans, Kuipers, Thierry & Jones, 2014). In this ERP experiment, Welsh-English bilinguals read English sentences ending in nonwords that were either 'mutated' according to a morphosyntactic rule of Welsh (e.g., **p**rince → **b**rince) or in an 'aberrant' form, which would never occur in Welsh (e.g., **p**rince → **g**rince). The results showed that English nonwords mutated according to Welsh rules were more acceptable than aberrant nonwords, but crucially, only when presented in sentence contexts that would elicit a mutation in Welsh (Ball & Müller, 1992; Harlow, 1989). Contrary to most current models of bilingual syntax, these findings indicate that morphosyntactic rules can be co-activated between languages even if they exist in one language but not the other. Furthermore, co-activation occurred irrespective of phonological overlap between the English target words and their Welsh translation equivalents, indicating that syntactic co-activation involves abstraction of the rule itself, and is not dependent on lexico-syntactic associations.

Thus, data from Vaughan-Evans et al. (2014) suggests that interactivity in bilinguals' syntactic systems may be less dependent on overlap in syntactic features between languages than previously supposed. That being said, the English sentences constructed for this experiment were very similar in word order to their Welsh translation equivalents, and the syntactic triggers used to manipulate expectancy of a soft mutation contained identical message-level information across languages. It is therefore possible that this level of overlap automatically activated the equivalent lexical representations in Welsh along with their corresponding syntactic representations, which automatically activated the mutation rule during sentence reading in English. For example, the Welsh word '*dau*' (two) always triggers a mutation, and contains equivalent message-level information to its English translation. Therefore, reading the English word 'two' could have automatically activated the lexical representation of its Welsh equivalent, *dau*, along with its corresponding syntactic representations, thus providing a trigger for mutation. Under this account, morphosyntactic rules of the non-operational language (Welsh) are co-activated automatically, but may remain functionally independent of the syntax of the operational language (English). However, an alternative explanation is possible, in which a morphosyntactic rule of the non-operational language (Welsh) can become embedded within the syntax of the operational language (English). Under this account, it should be possible to trigger a mutation via relevant syntactic information available only in English (i.e., when there is no translation equivalent in Welsh).

In this study, we again recorded electrophysiological brain responses in Welsh-English bilinguals as they read English sentences containing a sentence-final nonword manipulated according to a soft mutation rule. However, the paradigm was crucially modified such that the soft mutation rule could be triggered via information from the non-operational language (Welsh; the language to which the rule belongs), or via information from the operational language (English; the language to which the rule does *not* belong). The latter scenario would indicate that the morphosyntactic rules of either language are not only simultaneously active, they are also fully *inter*active. To distinguish between these alternatives, we used a specific rule of soft mutation that utilises both syntactic and semantic information. In Welsh, the gender-neutral singular pronoun *ei* (his/her/its) triggers a mutation, but the type of mutation that occurs is determined by the gender of the antecedent; only a masculine antecedent will trigger a soft mutation. In English, however, singular pronouns are gender specific. For example, the pronoun ‘his’ contains relevant lexical-semantic information that directly informs the reader that the antecedent is masculine. The plural pronoun *eu* (their) does not elicit a mutation in Welsh and contains equivalent message-level information in Welsh and English.

We therefore presented participants with English sentences, manipulated both in terms of personal pronoun and sentence antecedent(s) (see Table 2). Sentences signalled a soft mutation via a masculine antecedent (e.g., *Ben*) – which is the means by which a mutation is derived in Welsh. However, in English, relevant information was also available via the masculine personal pronoun *his*. Plural antecedents (e.g. *Ben and Sally)* and the plural pronoun *their* – equivalent in Welsh and English – would not signal a mutation, thus providing an effective control. We examined how these manipulations modulated responses to the sentence-final nonword, which presented an initial phoneme switch consistent with the rules of soft mutation (e.g., **g**arrots in Table 2).

Table 2

Experimental design and stimuli examples

	Masculine antecedent
Masculine pronoun	*Ben* was told he could see in the dark if he ate all *his* **g**arrots.
Plural pronoun	*Ben* was told he could see in the dark if he ate all *their* **g**arrots.
	Plural antecedent
Masculine pronoun	*Ben and Sally* were told they could see in the dark if they ate all *his* **g**arrots.
Plural pronoun	*Ben and Sally* were told they could see in the dark if they ate all *their* **g**arrots.

Note. Italics and bold font are purely illustrative and were not used in the experiment.

In accordance with the findings of Vaughan-Evans et al. (2014), we anticipated that syntactic co-activation would occur, resulting in expectation of phonemic changes consistent with the rules of Welsh soft mutation. Thus, we expected modulation of the phonological mismatch negativity (PMN; an ERP index that reflects phonological expectancy; Connolly & Phillips, 1994). If syntactic co-activation involves co-activation of morphosyntactic rules that remain somewhat functionally independent of one another, we predicted that participants would derive expectancy of mutations as they would do in Welsh. That is, only a masculine antecedent (*e.g.* Ben) would lead to reduced PMN amplitude on the mutated target word (main effect of antecedent). If syntactic co-activation involves integration of the morphosyntactic rule into the syntax of the operational language, we expected participants to derive phonological expectancy from lexical-semantic information available from the English singular pronoun. Thus only a masculine pronoun (his) would lead to reduced PMN amplitude on the mutated target word (main effect of pronoun). Finally, if syntactic co-activation involves a combination of cues derived from both Welsh and English features, we predicted that both a masculine antecedent and a masculine pronoun would maximally reduce the PMN amplitude on the mutated target word (antecedent * pronoun interaction effect).

Methods

Participants

Twenty-two Welsh-English bilinguals (8 male, 14 female) who reported that they were L1 Welsh speakers and had learnt English from a young age (*M* = 4.85**)** were included in the analysis. All participants included in the analysis demonstrated the ability to correctly produce soft mutations (*M* = 78%). Three participants were removed due to poor mutation ability (< 43% correct), and a further four participants were removed due to alpha contamination in the data. Ethical approval was obtained from Bangor University Psychology Ethics Committee, and all participants provided written consent.

Stimuli and Design

Forty target words were selected, none of which shared an initial consonant with their Welsh translation equivalents. Each target word was manipulated according to the soft mutation rules in terms of consonant change (e.g. **p**rince → **b**rince), and presented in the sentence-final position of four experimental sentences (see Table 2). Filler trials included sentence-final aberrant nonwords, in which the initial consonant of the target word was altered in a way that did not conform to any mutation rule (e.g. **p**rince → **g**rince; 16% of all trials), and sentence-final correct forms (**p**rince; a further 16% of all trials). Note that, contrary to Vaughan-Evans et al. (2014), aberrant words were not included as an experimental manipulation in the current experiment.

The experiment therefore comprised a 2 (antecedent; masculine, plural) x 2 (pronoun; masculine, plural) repeated measures design. In a separate pre-test, the cloze probability of all test sentences was measured. Participants were presented with open-ended sentences along with four possible sentence completions, and were asked to circle the most appropriate ending. Participants were given a score of 1 if they selected the sentence completion (target word) used in the experimental sentence, and a score of 0 if they did not. If a word was selected more frequently than the sentence completion used in the experimental sentence, the sentence was removed. Scores were averaged across participants and items, and cloze probability of all test sentences was .52.

Procedure

Participants viewed all 240 sentences (160 test sentences; 80 filler sentences), presented in white 18 point font on a black background. The first clause was presented as continuous text and was self-paced. Participants pressed a button to signal that they had finished reading the first clause, and the remainder of the sentence was presented by individual word presentation (200 ms with 500 ms inter-stimulus interval (ISI)). The experiment was divided into eight blocks, and presentation order was pseudorandomized, such that two target words never appeared in the same block. Comprehension questions were presented after a third of all sentences to ensure that participants attended to the experimental stimuli (Mean accuracy = 85.68%, *SD* = 5.68%, Range = 75-95%).

Having completed the experimental task, participants were asked to complete two offline questionnaires: a language history questionnaire, and a mutation task. The language history questionnaire was used to obtain demographic information such as age of acquisition, frequency of use and native language. The mutation task was used to obtain an estimate of participants' ability to correctly apply soft mutation. Participants were presented with 40 Welsh words followed by 40 open ended Welsh sentences, and were instructed to write the target word at the end of the sentence in its correct form (in its root, non-mutated form or in its mutated form). Mutation tasks were scored manually; words written in their correct form (mutated or not mutated) were given a score of 1, whilst words written in their incorrect form were given a score of 0.

ERP Recording

Electrophysiological data was recorded from 64 Ag/AgCl electrodes according to the extended 10-20 convention and were referenced to Cz at a rate of 1 kHz. The electroencephalogram (EEG) activity was filtered online with a band-pass filter between 0.1 and 200 Hz and offline with a low-pass zero-phase shift digital filter which was set at 20 Hz. Observed eye blinks in the EEG were corrected for mathematically and remaining artefacts were removed by manually inspecting the data. Epochs ranging from -300 to 700 ms after the onset of the pre-target word (pronoun), and -300 to 1000 ms from the onset of the target word were initially extracted from the EEG recordings. Epochs with activity exceeding ±100μV at any electrode site were automatically discarded. There was a minimum of 30 epochs per condition for every participant. Baseline correction was performed in reference to 300 ms of pre-stimulus activity, and individual averages were digitally re-referenced to the global average reference. A baseline shift was initially observed, therefore the data was re-filtered using a more conservative high pass filter (0.5 Hz; Luck, 2005).

Results and Discussion

We first analysed ERP amplitudes over six electrodes where the PMN is known to be maximal (FCZ, FC2, FC4, CZ, C2, C4; Connolly & Phillips, 1994; Vaughan-Evans et al., 2014; Figure 4). A 2 (antecedent; masculine, plural) x 2 (pronoun; masculine, plural) repeated measures analysis of variance (ANOVA) revealed no significant main effects or interactions (main effect of antecedent: $F(1,21) = 0.27$, $p = .609$, $\eta_p^2 = .013$; main effect of pronoun: $F(1,21) = 0.05$, $p = .824$, $\eta_p^2 = .002$; antecedent*pronoun interaction: $F(1,21) = 2.95$, $p = .1$, $\eta_p^2 = .12$).

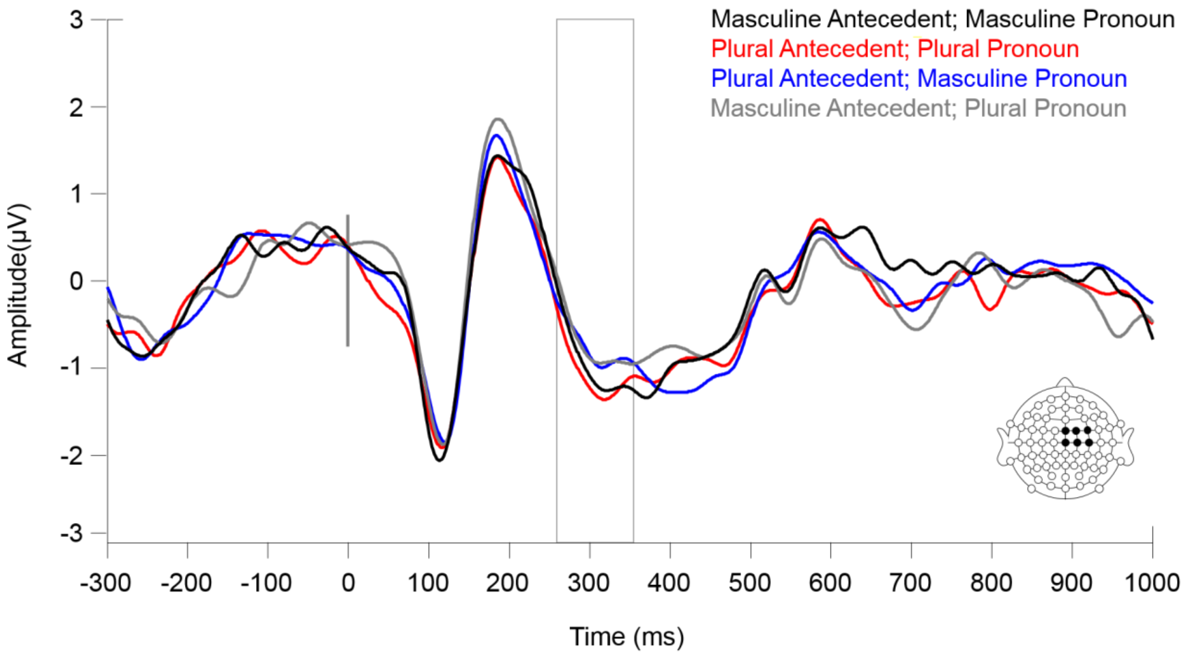

Figure 4. ERPs elicited by mutated nonwords across all sentence types. The plain box indicates the time window used during the analysis (260-360 ms post-stimulus).

Thus, in relation to the window associated with the PMN, we found no evidence of syntactic co-activation. In a bid to identify the source of this null effect, we considered the possibility that our experimental manipulation interfered with participants' ability to make predictions about the target word. Previous studies have demonstrated that sentences that contain pronoun violations are more difficult to process than sentences that do not contain pronoun violations (Hammer, Jansma, Lamers & Münte, 2008). In this study, half of all sentences contained a pronoun violation (in which the pronoun and sentence antecedent did not match: e.g. masculine antecedent & plural pronoun; plural antecedent & masculine pronoun). We therefore conducted an additional analysis, in which ERP modulations were measured in relation to the pre-target word (the personal pronoun). The four experimental conditions were collapsed into two, henceforth referred to as ‘match’ sentences (in which the sentence antecedent and the sentence pronoun were congruent and thus did not contain a pronoun violation: masculine antecedent & masculine pronoun; plural antecedent(s) & plural pronoun) and ‘mismatch’ sentences (in which the sentence antecedent and the sentence pronoun were incongruent and thus contained a pronoun violation: masculine antecedent & plural pronoun; plural antecedent(s) & masculine pronoun).

A paired-samples t-test was conducted to compare mean ERP amplitudes over nine electrodes (C1, C3, CZ, FC1, FC3, FCZ, F5, F3, FZ; Figure 5) that elicited a left anterior negativity (LAN; Friederici, Pfeifer, & Hahne, 1993). A significant effect was found $t(21) = 3.05$, $p = .006$, with mismatch sentences eliciting more negative mean amplitudes ($M = -1.75$, $SE = 0.25$) than match sentences ($M = -1.38$, $SE = 0.3$): Participants demonstrated greater processing difficulty for sentences in which a pronoun violation occurred than for sentences in which a pronoun violation did not occur, consistent with previous demonstrations that pronoun violations impair sentence processing (Hammer et al., 2008). We suggest that, due to the inconsistency of the preceding sentence context, participants failed to generate predictions concerning the phonology of the upcoming word. This would have eradicated modulations in the PMN, as it is entirely dependent upon the *predictability* of the initial phoneme in an upcoming word.

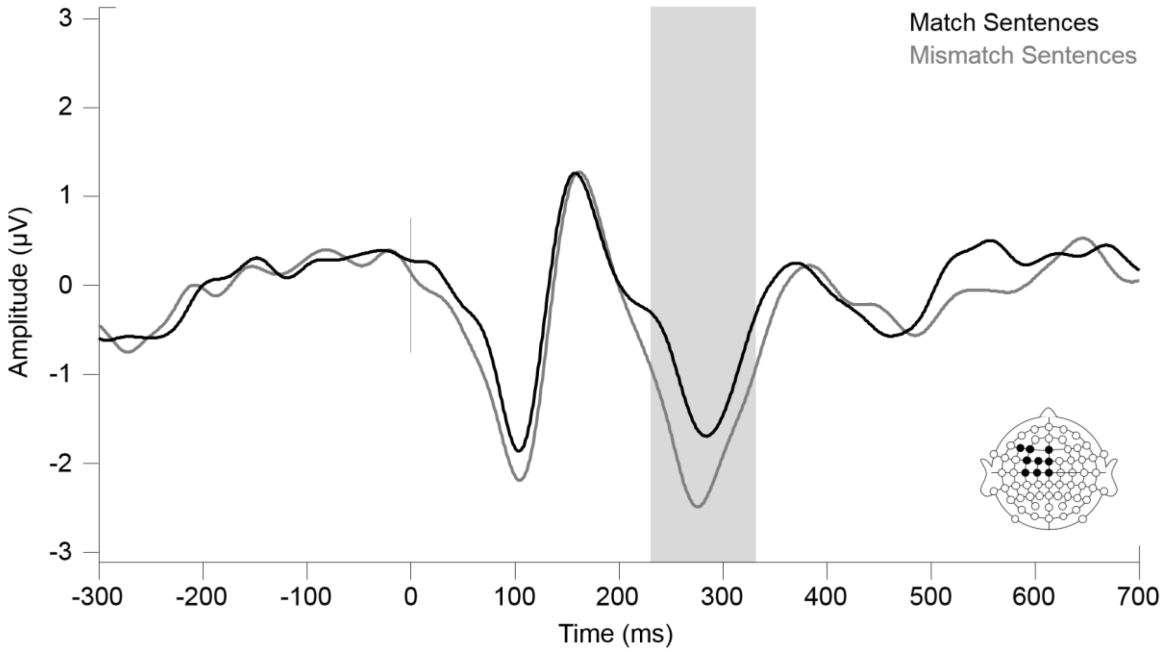

Figure 5. ERPs elicited by match and mismatch sentences. The plain grey box indicates the time window of the analysis in which mean ERP amplitudes significantly differed between conditions (220-320 ms post-stimulus).

We next analysed ERP amplitudes over six parietal electrodes, consistent with the topography of the P3 (P1, P2, PZ, PO3, POZ, PO4; Polich, 2007). Unlike the PMN, the P3 is considered an index of *stimulus evaluation* rather than *prediction*, and is therefore less likely to be affected by a pronoun violation in the preceding context. A 2 (antecedent; masculine, plural) x 2 (pronoun; masculine, plural) repeated measures ANOVA revealed a significant main effect of pronoun $F(1,21) = 9.71$, $p = .005$, $\eta_p^2 = .316$, with masculine pronoun sentences eliciting a more positive mean amplitude ($M = 1.43$, $SE = 0.32$) than plural pronoun sentences ($M = 0.91$, $SE = 0.29$; Figure 6). There was no main effect of antecedent ($F(1,21) = 2.311$, $p = .143$, $\eta_p^2 = .099$) nor an antecedent*pronoun interaction ($F(1,21) = 0.745$, $p = .398$, $\eta_p^2 = .034$). Thus, P3 mean amplitudes were greater for mutated nonwords that were preceded by a masculine pronoun (his), than for mutated nonwords preceded by a plural pronoun (their).

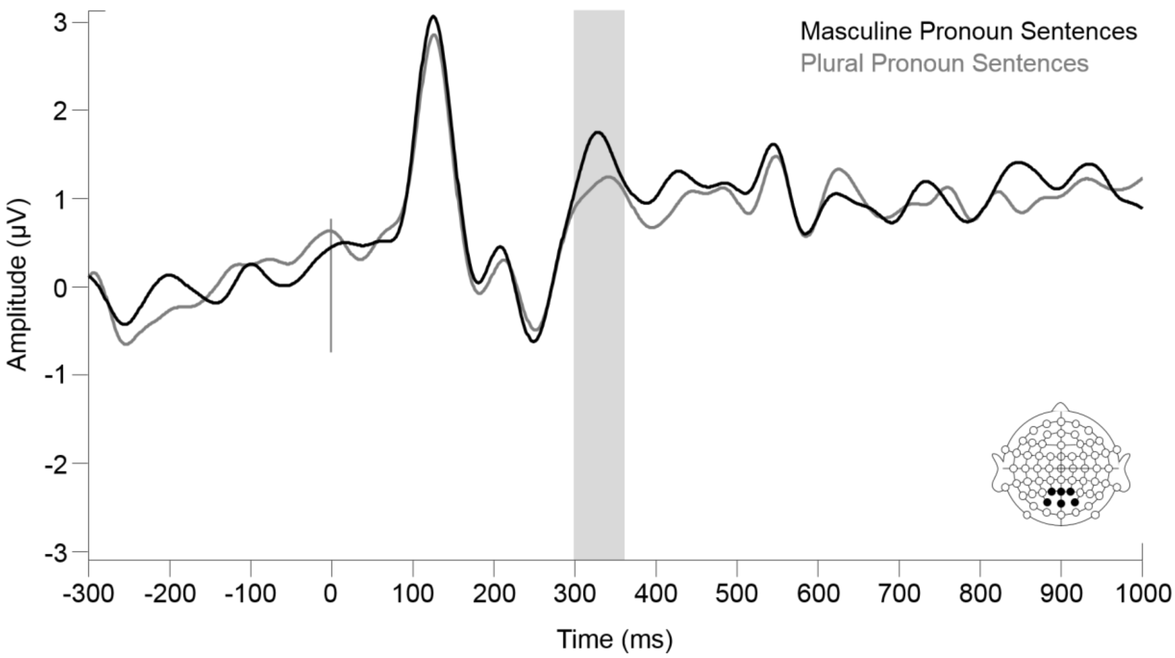

Figure 6. ERPs elicited by mutated nonwords collapsed across masculine and plural antecedents. The plain grey box indicates the window of analysis in which mean ERP amplitudes significantly differed between conditions (300-360 ms post-stimulus).

Our findings in relation to the P3 component indicate that the English masculine pronoun 'his'– which provides gender specific information – was sufficient to elicit activation of the Welsh soft mutation rule on the target word. Importantly, the P3 is considered to reflect an evaluative process, in which a comparison occurs between a stimulus and the information currently held in working memory (Kok, 2001; Polich, 2007). When the stimulus is perceived to be congruent with the information held in working memory, a shift of attention occurs, reflected in an increase in mean amplitudes. Here, we suggest that the presented stimulus (mutated nonword) was perceived to be congruent with the information held in working memory (the preceding sentence context), but only when the preceding sentence context included a masculine pronoun. No analogous modulation of the P3 was found when the preceding sentence context included a masculine antecedent, which is the process by which application of the soft mutation rule would be determined in Welsh. Taken together, our findings suggest not only that bilinguals' syntactic systems are co-active, they can also be fully interactive.

Our results provide strong support for theories of syntactic co-activation (e.g. Hatzidaki et al., 2011; Sanoudaki & Thierry, 2014; Vaughan-Evans et al., 2014), and further elucidate the nature of syntactic co-activation in bilingual individuals. Additionally, our results support previous suggestions that syntactic co-activation is not constrained by syntactic similarities between languages (Ganushchak et al., 2011; Lemhöfer et al., 2008; Sanoudaki & Thierry, 2014; Scheutz & Eberhard, 2004; Vaughan-Evans et al., 2014), and go further still in showing that syntactic co-activation is not dependent on equivalent message-level information between languages. Thus, syntactic co-activation between languages does not appear to occur via automatic activation of translation equivalents and their corresponding syntactic representations. Rather, our findings suggest the more fascinating possibility that bilinguals' syntactic systems are interactive to the extent that a syntactic system can operationalize a rule, even when that rule is foreign; belonging as it does to a different language.

The use of ERPs in the current study enabled measurement of the implicit and unconscious processes underpinning syntactic co-activation. Whilst behavioural methods offer valuable insight into overt, conscious performance, one could argue that they lack the sensitivity to reveal possible dissociations between implicit and explicit effects. Previous studies have reported electrophysiological effects in the absence of behavioural effects when investigating language co-activation (e.g. Thierry, Athanasopoulos, Wiggett, Dering & Kuipers, 2009; Thierry & Wu, 2007), indicating that the underlying processes of language co-activation are not necessarily reflected in behavioural measures. Additionally, online measures such as ERPs provide the opportunity to investigate language co-activation in real time, and provide a continuous measurement of language processing from the initial onset of a target word. As such, it becomes possible to determine the processing stages affected by the experimental manipulations. Such a detailed measurement of language processing cannot be obtained via behavioural measurements. In the current study, processing of Welsh mutations embedded in the English language could only be measured implicitly, via online methods such as ERPs, and, arguably, would not easily be observed in a behavioural paradigm.

Future research is required to ascertain whether these effects occur only in the direction of L1 to L2 (cf. Hatzidaki et al., 2011), and whether second language proficiency could influence this effect (e.g. Hartsuiker & Bernolet, in press; Sanoudaki & Thierry, 2015). It is possible that the integration of the Welsh morphosyntactic rule into English syntax occurs only in highly proficient bilinguals, such as the participants who took part in the current study. Hartsuiker and Bernolet (in press) posited a similar theory, in which they demonstrated that the extent to which syntactic representations interact between languages varies as a function of second language proficiency. Based on their model, we would perhaps not expect the syntactic structures of both languages to be fully integrated in non-proficient bilinguals. However, we might expect syntactic co-activation to occur via automatic activation of lexical representations in the non-operational language, even in non-proficient bilinguals, and for the strength of this effect to increase as a function of proficiency.

To conclude, the current study was designed to further probe the mechanism by which syntactic co-activation occurs in bilinguals. We considered the possibility that whilst co-activation occurs, the two syntactic systems remain functionally independent from one another. An alternative hypothesis described a system in which morphosyntactic rules from the non-operational language could be integrated into the syntactic system of the operational language, where appropriate. Our results support the latter hypothesis, suggesting that bilinguals' syntactic systems are not only co-active, they are also fully interactive. Future studies will investigate the extent to which this effect is modulated by factors such as language proficiency and direction of transfer. An investigation is also required into the occurrence of syntactic co-activation in more naturalistic settings, in which mutated English nonwords are presented covertly.

Chapter 5

Syntactic Co-activation in Natural Reading

Abstract

Recent evidence suggests that bilingual individuals co-activate the syntactic rules of both languages, even when such rules exist in only one language, yet the extent to which syntactic co-activation occurs during natural reading is currently unknown. To address this issue, we measured bilinguals' eye-movements as they read English sentences. Target words embedded in each sentence were manipulated to create nonwords that were consistent or inconsistent (aberrant) with the rules of Welsh soft mutation (a morphosyntactic process that alters the initial consonant of words when placed in specific contexts). Crucially, nonwords were only visible in parafoveal preview, and an explicit fixation triggered the presentation of the normal English word. Linear mixed effects analyses revealed a robust parafoveal preview benefit for identity previews (e.g. **t**elevision) compared with mutated (e.g. **d**elevision) and aberrant previews (e.g. **b**elevision). Our linguistic manipulation moreover affected measures associated with re-analysis, such that mutation preview trials yielded longer regression path durations and re-reading times compared with identity preview trials, but importantly, only in sentence contexts that would elicit a mutation in Welsh. This effect was only statistically reliable during trials in which the English target word and its Welsh translation equivalent shared an initial consonant. Our findings show that when bilinguals engage in natural sentence reading, syntactic rules are co-activated, and emerge as a result of cross-linguistic lexical associations.

A key aim in psycholinguistics research is to elucidate the way in which bilinguals represent each of their languages, with debate centring on whether each language is represented and accessed separately, or whether both languages interact. Specifically, during comprehension or production, do bilinguals only activate the representations of the language in which they are currently operating? Or are properties of the apparently silent (non-operational) language also co-activated? In the domain of lexical processing, the debate on 'language selective' vs 'language nonselective' access has generated a substantial amount of research, and whilst early research favoured a language selective account (e.g. Gerard & Scarborough, 1989; Soares & Grosjean, 1984), the weight of evidence currently falls in favour of language nonselective access (e.g. Duyck, 2005; Jared & Kroll, 2001; Lemhöfer & Dijkstra, 2004; Thierry & Wu, 2007; Van Assche, Duyck, Hartsuiker & Diependaele, 2009; see Dijkstra & Van Heuven, 1998; van Heuven, Dijkstra & Grainger, 1998, for a model of bilingual lexical access that can account for both language selective and language nonselective data).

The intense focus on lexical access in bilinguals stands in stark contrast with the relatively few studies that have investigated whether *syntactic* representations are language selective or nonselective in bilinguals. The evidence obtained to date suggests that bilinguals' syntactic systems do interact: Cross-linguistic syntactic priming studies show that bilinguals are more likely to produce a specific grammatical construction having been recently exposed to the same construction. Crucially, this priming effect occurs irrespective of whether the prime language is the same or different from the response language (e.g. Hartsuiker, Pickering & Veltkamp, 2004). Specific limits on the extent of interactivity between language systems have also been identified, imposed by the syntactic similarity between a bilingual's languages (Bernolet, Hartsuiker & Pickering, 2007; see Pickering & Hartsuiker, 2008, for a review), in addition to factors such as language proficiency (Bernolet, Hartsuiker &

Pickering, 2013; Hartsuiker & Bernolet, in press), immersion (Morales, Paolieri, Cubelli & Bajo, 2014), exposure (Kaushanskaya & Smith, in press), and verbal fluency (Sanoudaki & Thierry, 2015). However, recent data cast doubt on the extent of these limits. Findings from electrophysiological studies show that syntactic co-activation can occur when syntactic structures differ between languages (Sanoudaki & Thierry, 2014). Moreover, syntactic co-activation can occur in the most unfavourable of circumstances: when the syntactic rule exists only in the non-operational language and is therefore completely aberrant in the language of operation (Vaughan-Evans, Kuipers, Thierry & Jones, 2014). Thus, online measures afford a window into bilinguals' representation of syntax that is arguably more sensitive than traditional behavioural measures, in which explicit presentation of both languages occurs (see Grosjean, 1998, for a discussion on the influence of bilingual contexts on language co-activation). A picture is therefore beginning to emerge of a fully interactive, nonselective syntactic system. However, current ERP data is also impeachable, due to the explicit presentation of nonwords (Vaughan-Evans et al., 2014), which have been found to influence the extent to which co-activation occurs (e.g. Soares & Grosjean, 1984). In this study, we conduct the 'acid test' of syntactic interactivity, examining the extent to which bilinguals co-activate the syntactic rules of both languages in a purely monolingual context, in natural sentence reading.

The Current Study

In the current study, we collected eye-tracking data during silent sentence reading. A monolingual reading context was created via the use of the boundary paradigm (Rayner, 1975): manipulated target words were presented in the parafovea (an area 2-6 degrees of visual angle from the focal point of a given fixation), but appeared as normal English words upon fixation. As such, manipulated target words only appeared prior to explicit fixation (and therefore were not consciously processed).

Our experimental conditions included English target words that were manipulated according to the Welsh rules of soft mutation (cf. Vaughan-Evans et al., 2014). Soft mutation is a morphosyntactic process that alters the initial consonants of Welsh words when placed in specific syntactic contexts (Ball & Müller, 1992; Harlow, 1989). For example, the feminine Welsh noun '*cannwyll'* (candle) mutates after the definite article '*y' (*the; '*y **g**annwyll'* – the candle), whereas the masculine noun '*teledu*' (television) does not (*'y **t**eledu'* - the television). The initial consonant of English target words were therefore manipulated in a way that adhered to the soft mutation rules (e.g. **t**elevision → **d**elevision*:* the initial consonant 't' always mutates to 'd') or were aberrant with respect to the soft mutation rules (e.g. **t**elevision → **b**elevision*:* the initial consonant 't' never mutates to 'b'). Parafoveal previews thus consisted of a) identity previews (e.g. **t**elevision), b) mutated previews (e.g. **d**elevision) or c) aberrant previews (e.g. **b**elevision). Furthermore, the syntactic context of experimental sentences was manipulated such that they would, or would not elicit a mutation in Welsh. Importantly, the syntactic context was manipulated via a single change of the pre-target word (e.g. from the personal pronoun 'his' to the definite article 'the').

Experiment 1.a.

In Experiment 1a, we examined whether syntactic co-activation occurs during English sentence reading when the English target words and their Welsh translation equivalents shared an initial consonant (lexical overlap between languages). Thus, our targets included words with identical word-initial consonants, such as 'television' (*teledu* in Welsh). Our experimental conditions therefore comprised the following items, presented in parafoveal preview in mutation and no mutation context sentences: the English word '**t**elevision' (identity preview), a nonword conforming to the rules of soft mutation, '**d**elevision' (mutated preview), or a nonword that did not conform to the rules of soft mutation, '**b**elevision' (aberrant preview; see Table 3).

Table 3

Experimental design and stimulus examples

	No mutation context sentences
Identity preview	Steve was allowed to watch the television after completing his homework
Mutated preview	Steve was allowed to watch the **d**elevision after completing his homework
Aberrant preview	Steve was allowed to watch the **b**elevision after completing his homework
Welsh translation	*Cafodd Steve wylio'r teledu wedi iddo orffen ei waith cartref*
	Mutation context sentences
Identity preview	Steve was allowed to watch his television after completing his homework
Mutated preview	Steve was allowed to watch his **d**elevision after completing his homework
Aberrant preview	Steve was allowed to watch his **b**elevision after completing his homework
Welsh translation	*Cafodd Steve wylio ei* ***d****eledu wedi iddo orffen ei waith cartref*

Note. Welsh translations are included for illustrative purposes only.

Previous studies implementing the boundary paradigm have consistently reported a preview benefit for items that remain identical in preview and upon fixation, compared with items that differ between preview and fixation (see Rayner, 2009, for a review). We therefore predicted shorter fixation durations on the target word for identity preview trials (**t**elevision) compared with the nonword preview trials (**d**elevision; **b**elevision). Based on our previous findings (in which activation of the non-operational syntax facilitated the processing of mutated nonwords; Vaughan-Evans et al., 2014), we anticipated that parafoveal previews of mutated nonwords would facilitate reading times, but only during mutation context sentences. Should facilitation similarly occur during no mutation context sentences, our data would indicate a frequency effect elicited by the consistent phoneme change in Welsh, rather than a syntactic effect. Eye-tracking measures moreover enabled us to assess whether effects occurred during ‘early’ processing, associated with prediction of phonological information (in which case the effect of our linguistic manipulation would manifest in the pre-target region, and during first pass inspection of the target), or on ‘later’ processing, associated with re-analysis and integration of the lexical item with the syntactic context (in which case the effect of our linguistic manipulation would manifest only on second pass measures on the target, and on the post-target region).

Methods

Participants. Fifty-four Welsh-English bilinguals participated in this study. Of this sample, six participants were excluded due to poor performance on an offline task measuring their knowledge of the Welsh soft mutation rule (test score < 58%). A further four participants were removed, having detected more than three display changes during the experiment. Thus, forty-four participants (3 male, 41 female; Mean age = 21.8 years; *SD* = 4.6) were included in the final analysis, all of which self-reported that they had learnt English from an early age (*M* = 4 years; *SD* = 2.8). All participants possessed normal or corrected to normal vision. Ethical approval was obtained from Bangor University Psychology Ethics Committee, and all participants provided written consent.

Apparatus. An SR Research Eyelink 1000 eye-tracking system with a sampling rate of 1000 Hz was used to track participants’ eye movements. Sentences were presented in black monospaced Courier font on a grey background. The font size was controlled such that, at a viewing distance of 70 cm, 1 degree of visual angle was occupied by three characters. Sentences were presented on a single line on a CRT monitor with a refresh rate of 100 Hz.

Materials and design. Forty-eight English target words were selected, and two sentences were constructed for each target word. These sentences were identical with the exception of the pre-target word, however one would elicit a soft mutation had it been presented in Welsh (henceforth referred to as 'mutation context'), and one would not elicit a soft mutation had it been presented in Welsh (henceforth referred to as 'no mutation context'). Word frequencies were obtained from the English lexicon project (Balota et al., 2007) and reflect log transformed word frequencies from the Hyperspace Analogue to Language (HAL) norming study (Lund & Burgess, 1996). Pre-target words were controlled for written frequency (M = 13.8) and word length (M = 3.42 characters), and did not differ significantly between conditions (mutation context frequency: M = 13.5; no mutation context frequency: M = 14.11; p = .79; mutation context length: M = 3.29 characters; no mutation context length: M = 3.54 characters, p = .264).

Our manipulated words were presented only in parafoveal preview, and comprised identity, mutated and aberrant previews, appearing in mutation and no mutation context sentences. Note that English target words were specifically selected to create *nonwords* in mutated and aberrant word conditions (e.g., the word 'park' was excluded, since its mutated equivalent produces the real English word 'bark'). Thus, our experiment comprised a 3 (word preview; identity, mutated, aberrant) x 2 (sentence context; mutation, no mutation) design. Six counterbalancing lists were created; each list included the 48 target items in one of the six experimental conditions. A Latin square counterbalancing procedure ensured that each item appeared only once in each counterbalancing list (corresponding to one experimental procedure). Each counterbalancing list included an equal number of trials from each experimental condition. The 48 experimental sentences were presented along with 120 filler items. A proportion of these filler items (48) were part of another experiment (experiment 1b), and another proportion (48) were part of a separate boundary paradigm study.

In a separate pre-test, the cloze probability and plausibility of all test sentences was measured. Twenty monolingual English speakers were presented with incomplete versions of the test sentences, and were asked to provide a semantically and syntactically appropriate word to complete the sentences. Responses were given a score of 1 if the completions matched our experimental sentences, and all other answers received a score of 0. If a target word was never generated, or was not the most predictable completion, it was removed from the stimulus list. Whilst overall probability was low (M = .41), no difference was observed between mutation context sentences (M = .41) and no mutation context sentences (M = .40; p = .824). Participants were then presented with the actual test sentences, and were asked to rate them on a scale of 1 (not plausible at all) to 7 (very plausible). Plausibility ratings were high overall (M = 6.73), and did not differ between conditions (mutation context sentences: M = 6.75; no mutation context sentences: M = 6.71; p = .69).

Procedure. During the experimental session, participants were seated in front of a desk-mounted eye-tracker, with their forehead resting against a headrest. The headrest was positioned approximately 70 cm from the CRT monitor, and was used for stabilization purposes. Upon reading the task instructions, a brief three-point calibration procedure was initiated. During this procedure, an acceptance criterion of an average error below 0.3 degrees was set. Once the calibration process was complete, participants were presented with ten practice trials. Each trial began with a drift correction in the form of a small circle, placed in the same position as the beginning of the first word of the experimental sentences. Once the participant fixated on the circle, the experimenter pressed a button, and the trial began. If participants did not fixate on the circle, or if the degree of error was greater than 0.35, they were recalibrated. Participants were instructed to read for comprehension, and comprehension questions requiring yes/no responses were included after a third of all trials. To reduce fatigue, participants were instructed to take small breaks during the experiment (typically after reading 40 sentences). Participants were recalibrated after each break, and as such, each participant was recalibrated at least four times during the experiment (thus reducing the chance of drift). Upon reading half of the experimental sentences, participants were asked to complete a language history questionnaire.

Post-tests. Having completed the experiment, participants were asked to complete an online sentence completion task designed to measure their knowledge of the soft mutation rule. In this task, participants were presented with a subset of the experimental sentences, translated into Welsh. The Welsh target words were presented at the top of the screen, and the experimental sentences were presented underneath, with a blank space in place of the target word. Participants were instructed to type the target word in its grammatically correct form in the context of the sentence (i.e., mutated or not mutated). Correct responses were given a score of 1, and participant performance was calculated by averaging across all test sentences. Participants included in the final analysis obtained an average score of 81.91% (*SD* = 12.86%) on the mutation task.

Results

Data analysis. Data were analysed using linear mixed effects models (a regression-based analysis that allows multi factorial comparisons whilst avoiding data aggregation) using the lme4.0 package (Bates, Maechler & Bolker, 2012) in R (R Development Core Team, 2013). In comparison with traditional analyses such as analyses of variance, linear mixed effects models are appropriate for use with unbalanced data sets (in which each condition does not yield an equal amount of data), which is often the case with eye-tracking data. Furthermore, the option to specify multiple random factors in these models allows for a purer measure of the experimental conditions, having accounted for variance attributable to error.

Word preview and sentence context were included as fixed factors, with identity preview words and mutation context sentences set as the baseline. Participants, items and counterbalancing group were included as random effects variables. The ‘items’ and ‘counterbalancing’ variables were modelled as a function of intercept performance, whilst the ‘participant’ variable included the intercept, plus the slope obtained for the additive effects of Word preview + Sentence context conditions. A maximal slope was initially specified for the ‘participant’ variable (Barr, Levy, Scheepers & Tily, 2013), but the model failed to converge. As such, the random effect slope was trimmed until the model reached convergence. For all measures, the formal specification of our model was:

DV ~ Word preview*Sentence context, + (1 + Word preview + Sentence context|Participant) + (1|Item) + (1|Counterbalancing group), data = [dataframe].

The specifications of each model allowed for three contrasts as well as two interaction terms. Contrast 1 compared identity preview trials in mutation and no mutation context sentences. Contrast 2 compared identity preview trials with mutated preview trials during mutation context sentences. Contrast 3 compared identity preview trials with aberrant preview trials during mutation context sentences. Of crucial interest were the two interaction terms. Interaction 1 assessed the extent to which differences in identity vs. *mutated* previews were specifically attributable to mutation context sentences vs. no mutation context sentences. In traditional statistical terms, this interaction term is equivalent to a 2 (preview: identity, mutated) x 2 (context: mutation, no mutation) interaction. Interaction 2 assessed the extent to which differences in identity vs. *aberrant* previews were specifically attributable to mutation context sentences vs. no mutation context sentences. In traditional statistical terms, this interaction term is equivalent to a 2 (preview: identity, aberrant) x 2 (context: mutation, no mutation) interaction.

Pre-processing of data. Prior to data analysis, we excluded trials in which the boundary change was triggered early (prior to the onset of an explicit fixation on the target), or in which participants did not fixate on the target word after the boundary change occurred. We additionally excluded trials in which the boundary change did not occur within 10 ms after fixation onset (e.g. Slattery, Angele & Rayner, 2011), and in which fixations were shorter than 80 ms, or longer than 800 ms. We initially excluded trials in which the pre-target word was not fixated, but this resulted in a large loss of data (> 40% of trials). This was perhaps not surprising, as the pre-target words were typically short function words, which are often skipped during sentence reading (Hautala, Hyönä & Aro, 2011; Rayner & McConkie, 1976; White, 2008). We therefore extended the pre-target region to include both the pre-target word (*n-1*) and the word preceding the pre-target word (*n-2*), resulting in a pre-target area with an average length of 8.19 characters. Crucially, the length of the pre-target region did not differ significantly between conditions (mutation context = 8.1 characters; no mutation context = 8.31 characters; p = .64). Furthermore, as mutation context and no mutation context sentences were identical (with the exception of the pre-target word) the frequency and word length of the word preceding the pre-target were identical across conditions. Trials in which the pre-target region was skipped were not included in the analyses. In total, these exclusions resulted in the loss of 21.07% of all trials.

Analyses were conducted on three interest areas: the pre-target region (*n-1* & *n-2*), the target region (*n*), and the post target region (*n+1*). Two first pass measures were computed for the pre-target region: first fixation duration (the time spent initially fixating on a region) and gaze duration (the time spent fixating on a word before making a saccade to another region). For the target and post target regions, an additional three measures were computed: single fixation duration (the time spent fixating on a region when only one fixation is made), regression path duration (the time spent fixating on the target region and any area preceding the target region before making a forward saccade to a post-target region), and re-reading time (the time spent re-fixating on a target word before making a forward saccade to a post-target region; Liversedge, Paterson & Pickering, 1998). The means and standard deviations are shown in Table 4, and the beta values from the models are displayed in Table 5. With the exception of re-reading time, fixation durations were log-transformed prior to analysis to increase normality (Baayen, Davidson & Bates, 2008).

***Pre-target region*.** A significant effect of word preview was observed: aberrant preview trials yielded shorter first fixation durations as compared with identity preview trials (*Contrast 3*). A similar trend was observed for mutated preview trials, but the effect was not significant (*Contrast 2*). A marginal interaction was also found: aberrant previews yielded shorter gaze durations compared with identity previews during mutation context sentences, but longer gaze durations compared with identity previews during no mutation context sentences (*Interaction 2*). No other significant effects were found.

Table 4

Fixation durations (ms) across all experimental conditions for all target regions

	Mutation context sentences						No mutation context sentences					
	Identity preview		Mutated preview		Aberrant preview		Identity preview		Mutated preview		Aberrant preview	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
First fixation duration												
Pre-target region	240	88	227	72	224	76	236	77	230	78	227	66
Target region	218	63	234	69	233	72	226	76	238	73	235	74
Post target region	232	71	224	70	227	64	231	76	238	80	235	82
Single fixation duration												
Pre-target region	-	-	-	-	-	-	-	-	-	-	-	-
Target region	227	67	251	72	241	63	240	87	246	70	253	65
Post target region	231	63	230	70	230	60	235	69	242	79	242	87
Gaze duration												
Pre-target region	356	213	321	151	335	184	338	172	333	176	362	200
Target region	304	162	323	142	329	136	324	177	337	159	337	144
Post target region	260	104	255	103	248	95	256	98	267	105	270	124
Regression path duration												
Pre-target region	-	-	-	-	-	-	-	-	-	-	-	-
Target region	326	175	402	304	387	211	374	227	389	209	404	227
Post target region	300	187	290	167	307	217	292	179	320	218	304	202
Re-reading time												
Pre-target region	-	-	-	-	-	-	-	-	-	-	-	-
Target region	23	93	81	288	58	172	50	166	54	168	70	194
Post target region	40	149	35	140	60	204	36	156	52	185	34	162

Note. Single fixation duration, regression path duration, and re-reading time measures were not computed for the pre-target region.

Table 5

Fixed effect estimates derived from the linear mixed effects models for all measures across all regions

Factor	First fixation duration	Single fixation duration	Gaze duration	Regression path duration	Re-reading time
			Pre-target region		
Context	-0.01	-	-0.01	-	-
Preview[1]	-0.04	-	-0.06	-	-
Preview[2]	-0.07**	-	-0.05	-	-
Context*Preview[a]	0.01	-	0.03	-	-
Context*Preview[b]	0.04	-	0.09‘	-	-
			Target region		
Context	0.03	0.03	0.05	0.10**	26.84
Preview[1]	0.07**	0.09*	0.09*	0.18***	58.38***
Preview[2]	0.06*	0.05	0.08**	0.16***	38.42*
Context*Preview[a]	-0.01	-0.04	-0.02	-0.10*	-52.93*
Context*Preview[b]	-0.02	0.04	-0.02	-0.06	-18.79
			Post-target region		
Context	0.0004	0.02	-0.01	-0.02	-3.99
Preview[1]	-0.03	-0.004	-0.03	-0.02	0.59
Preview[2]	-0.02	-0.01	-0.04	0.004	26.85
Context*Preview[a]	0.06	0.02	0.07	0.09	19.22
Context*Preview[b]	0.03	0.01	0.08‘	0.03‘	-22.78

Note. Single fixation duration, regression path duration, and re-reading time measures were not computed for the pre-target region.

[1]Refers to the comparison between identity and mutated previews during mutation context sentences.

[2]Refers to the comparison between identity and aberrant previews during mutation context sentences.

[a]Refers to the influence of sentence context on the difference between identity and mutated previews. [b]Refers to the influence of sentence context on the difference between identity and aberrant previews.

‘$t > 1.65$; $p < .1$. *$t > 1.96$; $p < .05$. **$t > 2.56$; $p < .01$. ***$t > 3.29$; $p < .001$.

Target region. A significant effect of word preview was observed: fixation times on the target were longer during mutated and aberrant preview trials, compared with identity preview trials (*Contrasts 2 & 3*). This effect occurred on all measures, with the exception of single fixation duration.

A significant effect of sentence context was also observed: for identity preview trials, longer regression path durations were obtained during no mutation context sentences, compared with mutation context sentences (*Contrast 1*). A similar trend was found on re-reading times, however this effect only approached significance. Importantly, an interaction was observed on regression path duration and re-reading time: longer gaze times on mutated compared with identity preview trials occurred during mutation context sentences, but no difference emerged during no mutation context sentences (*Interaction 1*). The absence of a second interaction suggests that the difference between identity preview and aberrant preview trials was not significantly modulated by sentence context.

Post-target region. No significant effects were observed in this region.

Discussion

The current study investigated the occurrence of syntactic co-activation during natural sentence reading. We manipulated the parafoveal preview of target words in ways that were consistent or inconsistent (aberrant) with the Welsh rules of soft mutation. On the basis of previous findings, we predicted a general preview benefit (reflected in shorter reading times on the target word) for identity preview trials (**t**elevision) compared with mutated (**d**elevision) and aberrant (**b**elevision) preview trials, reflecting the fact that the English word was the most expected item. However, if Welsh soft mutation rules are co-activated during natural sentence reading in English, we also expected that mutated preview trials would facilitate reading times, reflected in shorter reading times, but crucially, in mutation context sentences only. In this section, we discuss our findings relating to the *pre-target*, *target* and *post-target* regions in detail.

Pre-target region. We only expected an effect of our linguistic manipulation in this region if co-activation of Welsh syntax influenced the prediction of phonological information. Aberrant preview trials elicited shorter first fixation durations compared with identity preview trials (a similar, non-significant trend occurred for mutated preview trials). We suggest that, an aberrant preview yielded information that was inconsistent with participant expectations, which may have triggered an early saccade towards the target in an attempt to disambiguate the information presented in parafoveal preview. A different pattern of results was found on the gaze duration measure: aberrant preview trials yielded shorter gaze durations than identity preview trials during mutation context sentences, but longer gaze durations as compared with identity preview trials during no mutation context sentences. In mutation context sentences, we suggest that participants may have co-activated the Welsh syntactic rule to the extent that they were aware that a phoneme change could take place, but computation of the specific phoneme to be applied had not been conducted at this stage. In no mutation context sentences, longer reading times on aberrant preview trials are more difficult to explain. One plausible (if post-hoc explanation) is that a frequency effect applies: neither consonant change is expected according to the syntactic context, but the phoneme change in the mutated preview was not uncommon to Welsh-English bilinguals. The aberrant preview was wholly unexpected, however.

Target region. As predicted, shorter fixation durations were yielded by identity preview trials compared with mutated and aberrant preview trials. Crucially, our linguistic manipulations took effect during measures associated with later processing: mutated preview trials yielded longer regression path durations and re-reading times compared with identity preview trials, but only during mutation context sentences.

Our findings on the target region suggest that Welsh-English bilinguals applied the co-activated rules of Welsh soft mutation during the re-analysis / syntactic integration stage of sentence reading. However, the direction of these results are somewhat surprising. Previous findings showed that syntactic co-activation facilitated the processing of mutated nonwords (Vaughan-Evans et al., 2014), and aided performance on a cognitively demanding task (Sanoudaki & Thierry, 2014). The longer reading times obtained here (indicative of increased processing cost) suggests that participants experienced difficulty integrating the Welsh syntactic rule within a monolingual English sentence context. In retrospect, this seemingly contradictory result is perhaps not surprising. Eye-tracking studies investigating the effect of interlingual homographs (words that are orthographically similar but semantically dissimilar across languages) have revealed similarly prolonged reading times when the non-operational language is co-active. For example, Libben and Titone (2009) reported that interlingual homographs resulted in longer first fixation durations, gaze durations, and total reading times compared with matched controls during reading for comprehension; a finding they ascribed to an inhibitory effect of the non-task language on the task language. With reference to the discrepancy found between the current study and Vaughan-Evans et al. (2014), it is important to note that such inhibitory effects only occurred during low-constraint sentences (which also characterised our sentences), and that no difference was observed between interlingual homographs and their matched control words during high-constraint sentences (which characterises the Vaughan-Evans et al. sentences).

Another important point to make is that the current study investigated syntactic co-activation during natural reading, in which there was no explicit task. Previous indications of facilitation effects can potentially be ascribed to the explicit presentation of both languages. Grosjean (1998) proposed that bilinguals operate in 'language modes' that are sensitive to the linguistic environment. For example, a bilingual operates in a completely monolingual mode whilst reading a monolingual book, whereas they operate in a completely bilingual mode during a conversation in which they are likely to engage in code-switching. As such, co-activation may be stronger during tasks in which both languages are presented; participants would expect a language switch, leading to facilitated performance as a result of syntactic co-activation. Furthermore, in cognitively demanding tasks, such as the processing of nonwords during sentence reading (Vaughan-Evans et al., 2014), and go-no-go tasks (Sanoudaki & Thierry, 2014, 2015), syntactic co-activation may be used as a form of 'conflict resolution', again leading to facilitated performance: Participants may initially rely on the linguistic knowledge of the task language, before subsequently relying on the co-active linguistic knowledge of the non-operational language to aid performance.

An interesting yet unexpected finding emerging from the target region was that identity preview trials consistently yielded shorter regression path durations (and re-reading times) in mutation context sentences, compared with no mutation context sentences. This effect occurred despite the fact that identity preview trials comprised a parafoveal preview of a normal English word, with no phonological manipulation. We suggest the following post-hoc explanation for this finding: In Welsh, mutation context sentences are likely to elicit increased attentional demand, since application of this rule is usually somewhat difficult. Welsh-English bilinguals could be aware that the particular syntactic construction is potentially effortful in Welsh, thus recruiting additional attentional resources to cope with the increased cognitive effort. As such, when the item is entirely expected (a normal English word), it can be processed more quickly than in no mutation context sentences, in which attentional resources are perhaps recruited less for potential problem solving.

Post-target region. No significant effects were found on this region, suggesting that effects on the target word quickly resolve (and do not therefore persist to spill-over regions).

In sum, the findings of Experiment 1a strongly suggest that syntactic co-activation occurs during monolingual, natural reading, leading to momentary conflict between the languages. In this experiment, we used English words that shared an initial consonant with their Welsh translation equivalents. As such, it remains unclear whether syntactic co-activation during natural reading is contingent on lexical overlap between languages. We therefore replicated the current experiment using target words that did not share an initial consonant between languages, in order to assess whether co-activation of syntax occurs even in the absence of a lexical cue (cf. Vaughan-Evans et al., 2014).

Experiment 1.b.

A consistent finding in the bilingual literature is that word recognition and reading times are facilitated for words that are lexically similar in both languages, compared with words that are lexically dissimilar across languages. For example, sentences that include cognates (translation equivalents that are orthographically similar across languages) typically yield faster reading times than sentences that include non-cognates (e.g. Van Assche, Duyck & Hartsuiker, 2012; Van Assche, Duyck, Hartsuiker & Diependaele, 2009; van Hell & de Groot, 2008; see Dijkstra, Grainger & van Heuven, 1999 for similar effects during word recognition tasks). These results have been explained in terms of language nonselective lexical access, during which it is assumed that possible candidates from both languages are activated for selection on the basis of orthography (e.g. van Heuven, Dijkstra & Grainger, 1998). Studies have also found that translation equivalents in the non-operational language are co-activated, irrespective of orthographic similarity (e.g. Thierry & Wu, 2007), suggesting the existence of cross-linguistic lexical associations.

A crucial point to resolve is whether these cross-linguistic lexical associations influence syntactic co-activation. Two recent experimental findings show that syntactic co-activation occurs in the absence of lexical overlap between languages (Kidd, Tennant & Nitschke, 2015; Vaughan-Evans et al., 2014), suggesting the application of an abstract syntactic rule. The validity of this finding in natural monolingual reading is yet to be assessed.

In Experiment 1b target words therefore comprised words that did *not* share an initial consonant with their Welsh translation equivalents (e.g. **p**ancake → **c**rempog). Our experimental conditions therefore comprised the following items in parafoveal preview: the English word '**p**ancake' (identity preview), a nonword conforming to the rules of soft mutation, '**b**ancake' (mutated preview), or a nonword that did not conform to the rules of soft mutation, '**d**ancake' (aberrant preview; see Table 6).

Given our results from Experiment 1a, we predicted shorter fixation durations for identity preview trials compared with mutated and aberrant preview trials. If syntactic co-activation occurs as a result of cross-linguistic lexical associations, we hypothesised that our linguistic manipulation should not influence reading times during the current experiment. If, however, syntactic co-activation occurs via the application of abstract syntactic rules, we expected the current experiment to yield a similar pattern of results as Experiment 1a.

Table 6

Experimental design and stimulus examples

	Mutation context sentences
Identity preview	On Shrove Tuesday, the family ate many **p**ancakes instead of eating supper
Mutated preview	On Shrove Tuesday, the family ate many **b**ancakes instead of eating supper
Aberrant preview	On Shrove Tuesday, the family ate many **d**ancakes instead of eating supper
Welsh translation	*Ar ddydd Mawrth Ynyd, bwytaodd y teulu nifer o grempogau yn lle swper*
	No mutation context sentences
Identity preview	On Shrove Tuesday, the family ate four **p**ancakes instead of eating supper
Mutated preview	On Shrove Tuesday, the family ate four **b**ancakes instead of eating supper
Aberrant preview	On Shrove Tuesday, the family ate four **d**ancakes instead of eating supper
Welsh translation	*Ar ddydd Mawrth Ynyd, bwytaodd y teulu bedwar crempog yn lle swper*

Note. Welsh translations are included for illustrative purposes only.

Methods

The experimental procedure was the same as in Experiment 1a, and the experiment was completed by the same group of participants.

Materials and design. Forty-eight English target words that did not share an initial consonant with their Welsh translation equivalents were selected, and two sentences were constructed for each target word. Pre-target words were controlled for written frequency (M = 13.58) and word length (M = 3.42 characters), and did not differ significantly between conditions (mutation context frequency: M = 13.57; no mutation context frequency: M = 13.59; p = .98; mutation context length: M = 3.31 characters; no mutation context length: M = 3.52 characters, p = .51).

In a separate pre-test, the cloze probability and plausibility of all test sentences was measured. The procedure and scoring method for these pre-tests were identical to those described in Experiment 1a. Whilst overall probability was low (*M* = .30), no difference was observed between mutation context sentences (*M* = .29) and no mutation context sentences (*M* = .31; *p* = .441). Participants were then presented with the actual test sentences, and were asked to rate them on a scale of 1 (not plausible at all) to 7 (very plausible). Plausibility ratings were high overall (*M* = 6.58), and did not differ between conditions (mutation context sentences: *M* = 6.62; no mutation context sentences: *M* = 6.53; *p* = .14).

Results

Data analysis. As in Experiment 1a, data were analysed using linear mixed effects models, and for all measures, the formal specification of our model was:

DV ~ Word preview*Sentence context, + (1 + Word preview + Sentence context |Participant) + (1|Item) + (1|Counterbalancing group), data = [dataframe].

Pre-processing of data. The same data trimming method was implemented as in Experiment 1a. Exclusion of trials in which the pre-target word was not fixated again resulted in a large loss of data (> 40% of trials). Thus, the pre-target region was extended to include the word immediately preceding the pre-target word (*n-1 & n-2*). The average length of the new pre-target area was 8.13, and did not differ significantly between conditions (mutation context = 8.02 characters; no mutation context = 8.23 characters; *p* = .704). Furthermore, as mutation context and no mutation context sentences were identical (with the exception of the pre-target word) the frequency and word length of the word preceding the pre-target was identical across conditions. Trials in which the pre-target region was skipped were not included in the analyses. In total, these exclusions resulted in the loss of 21.64% of trials.

Analyses were conducted on the three interest areas identified in Experiment 1a: the pre-target region (*n-1* & *n-2*), the target region (*n*), and the post target region (*n+1*), and the same eye-movement measures were analysed. The means and standard deviations are shown in Table 7, and the beta values from the models are displayed in Table 8. With the exception of re-reading time, fixation durations were log transformed prior to analysis to increase normality (Baayen, Davidson & Bates, 2008).

Pre-target region. No significant effects were found in this region.

Target region. A significant effect of word preview was observed. Mutated preview trials yielded longer gaze durations and regression path durations compared with identity preview trials (*Contrast 2*), whilst aberrant preview trials yielded longer single fixation durations, gaze durations, and regression path durations compared with identity preview trials (*Contrast 3*). No other significant effects were observed in this region.

Post-target region. No significant effects were observed in this region.

Table 7

Fixation durations (ms) across all experimental conditions for all target regions

	Mutation context sentences						No mutation context sentences					
	Identity preview		Mutated preview		Aberrant preview		Identity preview		Mutated preview		Aberrant preview	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
	First fixation duration											
Pre-target region	236	82	231	72	233	80	239	83	227	72	232	69
Target region	234	76	239	78	244	79	229	69	243	84	250	80
Post target region	225	63	226	67	233	79	234	81	234	81	227	67
	Single fixation duration											
Pre-target region	-	-	-	-	-	-	-	-	-	-	-	-
Target region	238	74	251	67	258	69	240	74	263	87	267	67
Post target region	226	59	231	68	228	60	230	67	241	85	227	60
	Gaze duration											
Pre-target region	366	244	351	197	365	227	362	184	357	207	361	194
Target region	309	158	344	167	367	206	313	140	345	167	341	150
Post target region	254	99	253	95	264	109	263	108	263	108	257	117
	Regression path duration											
Pre-target region	-	-	-	-	-	-	-	-	-	-	-	-
Target region	362	216	401	214	416	255	366	222	383	186	390	206
Post target region	300	213	296	207	308	318	291	168	308	216	383	154
	Re-reading time											
Pre-target region	-	-	-	-	-	-	-	-	-	-	-	-
Target region	56	172	58	167	47	177	48	186	39	129	50	165
Post target region	46	172	44	193	43	293	28	121	45	192	25	96

Note. Single fixation duration, regression path duration, and re-reading time measures were not computed for the pre-target region.

Table 8

Fixed effect estimates derived from the linear mixed effects models for all measures across all regions

Factor	First fixation duration	Single fixation duration	Gaze duration	Regression path duration	Re-reading time
			Pre-target region		
Context	0.01	-	0.04	-	-
Preview[1]	-0.02	-	-0.01	-	-
Preview[2]	-0.02	-	0.01	-	-
Context*Preview[a]	-0.03	-	-0.02	-	-
Context*Preview[b]	-0.003	-	-0.03	-	-
			Target region		
Context	-0.03	0.01	0.01	-0.01	-12.51
Preview[1]	0.02	0.06‘	0.11***	0.12***	4.90
Preview[2]	0.04‘	0.11***	0.17***	0.16***	-5.06
Context*Preview[a]	0.03	0.02	-0.02	-0.04	-11.18
Context*Preview[b]	0.05	0.03	-0.06	-0.05	10.57
			Post-target region		
Context	0.02	0.001	0.02	-0.01	-16.45
Preview[1]	-0.003	0.01	-0.01	-0.01	-2.43
Preview[2]	0.03	0.01	0.03	-0.01	-5.88
Context*Preview[a]	0.01	0.02	0.01	0.05	20.16
Context*Preview[b]	-0.05	-0.01	-0.06	-0.02	1.19

Note. Single fixation duration, regression path duration, and re-reading time measures were not computed for the pre-target region.

[1]Refers to the comparison between identity and mutated previews during mutation context sentences.

[2]Refers to the comparison between identity and aberrant previews during mutation context sentences.

[a]Refers to the influence of sentence context on the difference between identity and mutated previews. [b]Refers to the influence of sentence context on the difference between identity and aberrant previews.

‘$t > 1.65$; $p < .1$. *$t > 1.96$; $p < .05$. **$t > 2.56$; $p < .01$. ***$t > 3.29$; $p < .001$.

Discussion

In this experiment, we tested the parameters of syntactic co-activation during natural reading in order to determine the influence of cross-linguistic lexical associations versus the application of abstract syntactic rules. On the basis of previous findings, we predicted a preview benefit (reflected in shorter reading times on the target word) for identity preview trials (e.g., **p**ancake) compared with mutated (e.g., **b**ancake) and aberrant (e.g., **d**ancake) preview trials. If syntactic co-activation is driven by the application of abstract syntactic rules, we predicted that reading would be inhibited, but only during mutation context sentences (based on the results of Experiment 1a). However, if syntactic co-activation is contingent on lexical overlap between languages, we predicted that our linguistic manipulations would not influence reading times. Given that no significant effects emerged in the pre-target and post-target regions, we restrict the discussion to the target region.

Target region. As predicted, identity preview trials yielded shorter fixation durations compared with mutated preview and aberrant preview trials. However, we found no influence of our linguistic manipulation on any measures, suggesting that participants did not apply the syntactic rules of Welsh soft mutation during this task.

Whilst our linguistic manipulation did not influence sentence reading in a statistically reliable way, some numerical trends were consistent with our hypotheses. In particular, sentence context modulated regression path durations for aberrant and mutated preview trials, with (albeit statistically non-significant) longer regression path durations during mutation context sentences compared with no mutation context sentences. Due to the similarity of the English sentences, such a modulation likely reflects an emergent influence of the non-operational syntax on reading. Furthermore, re-reading times yielded by mutated preview trials were numerically longer during mutation context sentences (58 ms) than no mutation context sentences (39 ms), whereas similar durations emerged for aberrant preview trials across sentence contexts (mutation context sentences: 47 ms; no mutation context sentences: 50 ms). This (non-significant) effect again demonstrates that the syntax of the non-operational language influenced reading to some extent. As such, we suggest that syntactic co-activation may not be entirely contingent on lexical overlap between languages. Rather, syntactic co-activation benefits from a lexical boost, but numerical trends suggest that, under some circumstances, co-activation may be driven by the application of abstract rules.

In sum, the findings of Experiment 1b suggest that the occurrence of syntactic co-activation during monolingual, natural reading is contingent on a degree of lexical overlap between languages. Whilst our linguistic manipulations influenced reading patterns to some extent, these effects were not statistically reliable. As such, we suggest that syntactic co-activation may occur in the absence of lexical overlap between languages, but that co-activation during monolingual sentence reading is stronger when it receives a lexical boost.

General Discussion

In this study, we assessed the occurrence of syntactic co-activation during natural monolingual sentence reading. We also examined the extent to which syntactic co-activation in this reading environment is contingent on lexical overlap between languages versus application of the abstract syntactic rule. In Experiment 1a, we presented participants with English sentences that would or would not elicit a mutation in Welsh (mutation context and no mutation context sentences). Parafoveal previews of the target words - implemented using the boundary paradigm - were manipulated such that participants were presented with an identity preview (the target word in its original form; **t**elevision), a mutated preview (the target word with an initial consonant switch consistent with the rules of soft mutation; **d**elevision) or an aberrant preview (the target word with an initial consonant switch inconsistent with any of the rules of soft mutation; **b**elevision). The same experimental manipulations were used in Experiment 1b, with the sole exception that English target words did not share an initial consonant with their Welsh translation equivalents (e.g. **p**atients → ***c**leifion*). Consistent with previous research, findings from both experiments demonstrated that reading times on the target word were generally facilitated when the word remained the same in preview and upon explicit fixation (e.g. Schotter, Angele & Rayner, 2012), showing that on a basic level, participants were sensitive to the information provided in parafoveal preview.

Crucially, in relation to our linguistic manipulation, we also found evidence of co-activation of Welsh syntax during English sentence reading: In Experiment 1a, mutated previews specifically influenced reading times in mutation context sentences, but not in no mutation context sentences. These effects emerged on later measures, indicating that co-activation occurs during syntactic integration of a lexical item with its context. Surprisingly, this manifested as an inhibitory effect (prolonged durations), but we suggest that this is probably due to the monolingual context and/or the relatively low cloze probability of our sentences. In Experiment 1b, we obtained trends in the data that were overall comparable with Experiment 1a, but the effects of our linguistic manipulation on reading times did not reach significance. These findings stand in direct contrast with our earlier ERP study in which syntactic co-activation occurred irrespective of lexical overlap between languages (Vaughan-Evans et al., 2014). Given the methodological differences between the current experiment and our previous experiment, this contrasting findings may reflect fundamentally different processing strategies driven by specific task demands: In our previous experiment, participants explicitly processed nonwords that did or did not adhere to the rules of soft mutation. As such, the abstraction of syntactic rules may have resulted from a conscious strategy based on the explicit presentation of nonwords: Participants consulted the abstract syntactic rules of the non-operational language in an explicit attempt to resolve a processing conflict. In the current experiment however, manipulated nonwords were *implicitly* processed, and as such, the abstraction of syntactic rules from the non-operational language would be redundant: co-activating the abstract syntactic rules of Welsh would not aid monolingual English reading. We thus propose that syntactic co-activation may primarily involve the activation of lexico-syntactic associations, but that co-activation of an abstract rule can occur under certain task conditions. This proposal is congruent with models of bilingual lexical access, which explicitly note the influence of task demands on lexical selection (e.g. Dijkstra & van Heuven, 2002; Green, 1998), and with theories stressing the dependency of language co-activation on the linguistic environment (e.g. Grosjean, 1998; see also Thierry & Wu, 2010b).

We also note the unexpected but interesting finding that identity preview trials patterned differently in Experiment 1a and 1b. In Experiment 1a, reading times for targets preceded by identity previews were modulated by sentence context, reflected in shorter regression path durations (and marginally shorter re-reading durations) during mutation context sentences compared with no mutation context sentences. In Experiment 1b, no such modulation occurred. We propose that our mutation context sentences prompted increased attentional focus, linked to the cognitive load associated with the application of the soft mutation rule in Welsh. In addition to soft mutation, two other initial consonant mutations are used in Welsh: aspirate mutation and nasal mutation. Thus, not only do Welsh speaking individuals need to attend to the syntactic context to determine the occurrence of a mutation, they also need to determine the appropriateness of a particular consonant change given the context. In Experiment 1a, we propose that lexical overlap between languages (English and Welsh) in the initial consonant of the target word interacted with the heightened attention state, enabling faster processing of the target during mutation context sentences compared with no mutation context sentences. In Experiment 1b, the absence of lexical overlap meant that an analogous effect could not occur.

To conclude, our findings demonstrate syntactic co-activation in the context of natural, monolingual reading. Crucially, co-activation was triggered by the activation of lexico-syntactic associations in the non-operational language (Welsh), and occurred during a relatively late stage of lexical processing, involving integration of the word in the larger syntactic context. Taken together, our findings suggest that co-activation occurs even under the most stringent conditions, and clarify the conditions under which these effects occur: Syntactic co-activation appears to be dependent on lexico-syntactic associations, and influences syntactic integration rather than phonological prediction.

Chapter 6

General Discussion

6.0. Chapter Overview

The primary goal of this thesis was to elucidate the nature of bilinguals' syntactic co-activation during sentence comprehension. In Chapter 1, I summarised the main aims of the thesis as follows:

1. **Whether** bilinguals co-activate idiosyncratic syntactic rules
2. **How** syntactic co-activation occurs
3. **When** syntactic co-activation occurs, focusing on contextual constraints

In this chapter, I will briefly summarise the main findings of the experiments, which aimed to answer the **whether, how** and **when** research questions, before discussing the implications of the reported results for bilingual language processing. I will then describe a proposed theoretical model based on the summarised findings. Finally, I will outline the outstanding theoretical questions, and propose directions for future research.

6.1. Summary and Conclusions

1. **Whether** bilinguals co-activate idiosyncratic syntactic rules

The reported experiments strongly suggest that bilinguals co-activate syntactic rules from both languages during sentence comprehension. In Chapter 3, participants' brain responses were measured as they read English sentences manipulated such that they would (mutation context) or would not (no mutation context) elicit a sentence-final mutation (had they been presented in Welsh). We found that English nonwords 'mutated' according to soft mutation rules (e.g. **d**elevision) were more acceptable than 'aberrant' English nonwords (e.g. **b**elevision), but *only* during sentences that would elicit a sentence final mutation in Welsh. This finding shows that participants co-activated the morphosyntactic rules of soft mutation during English sentence reading, even though they exist only in the non-operational language (Welsh). This conclusion is further supported by the results of Experiment 1a, described in Chapter 5. Here, participants' eye movements were measured as they read sentences in which mutated and aberrant nonwords were presented in parafoveal preview (and thus not explicitly processed). Parafoveal presentation of mutated nonwords during mutation context sentences yielded an inhibitory effect that was modulated as a function of sentence context. Thus, it is clear that syntactic co-activation can occur during monolingual sentence reading.

2. **How** syntactic co-activation occurs

Previous studies investigating the representation of syntax in bilinguals have typically interpreted their findings from a lexicalist perspective (such that the activation of a syntactic representation occurs via the activation of a translation equivalent). The studies presented here were designed to explicitly test whether syntactic co-activation is driven by cross-language lexico-syntactic associations or via the application of abstract syntactic rules. In Chapter 3, this was investigated via the inclusion of English target words that did or did not share an initial consonant with their Welsh translation equivalents. Lexical overlap between languages did not modulate the extent to which co-activation occurred, indicating that participants had activated and applied an abstract syntactic rule from the non-operational language (Welsh) during English sentence reading. The experiment described in Chapter 4 extended the paradigm to investigate whether the morphosyntactic rules of the non-operational language can become embedded within the syntax of the operational language. This experiment examined whether syntactic co-activation could occur via syntactic triggers that are only available in the operational language (i.e., when there is no translation equivalent in Welsh). Participants' brain responses were again measured as they read sentences modified such that the soft mutation rule could be triggered via information from the non-operational language (Welsh), or via information from the operational language (English; the language to which the rule does *not* belong). ERP modulations demonstrated that mutated nonwords were detected as appropriate sentence completions when preceded by triggers specific to the operational language. These results therefore demonstrate that syntactic co-activation is a fully interactive process that is not dependent on the automatic activation of translation equivalents.

3. **When** syntactic co-activation occurs

Taken together, the results provide strong evidence for syntactic co-activation in highly proficient bilinguals, but the effects reported differ somewhat between experiments: In the ERP experiments (Chapters 3 & 4) – in which target words comprised explicit, isolated presentation of nonwords - syntactic co-activation of the soft mutation rules facilitated processing of *mutated* nonwords compared with aberrant nonwords. Furthermore, this effect was not dependent on lexical overlap between languages, and thus involved the application of abstract syntactic rules. Conversely, in the eye-tracking experiments (Chapter 5) - in which target nonwords were processed implicitly in the parafovea - syntactic co-activation inhibited sentence processing: parafoveal previews of mutated nonwords yielded *longer* processing times than aberrant nonwords. Moreover, this effect was specific to conditions in which there was lexical overlap between languages, indicative of a lexical boost effect. I propose that these discrepancies can be attributed to differences in task demands. During the ERP experiments, co-active soft mutation rules allowed easier assimilation of mutated nonwords compared with aberrant nonwords. However, in the eye-tracking experiments, a conflict arose between activation of the Welsh phonology - arising from co-activation of the mutation rule - during parafoveal preview, and the purely English phonology of the target when it was explicitly fixated. Longer processing times likely reflect resolution of this conflict, which is further attested by its occurrence during a post-lexical stage, in which lexical information is integrated in the larger syntactic and semantic sentence structure.

Task differences would also explain differences in the mechanism by which co-activation was triggered. The abstract, non-lexical co-activation of syntactic rules (characteristic of the ERP experiments) likely reflects the non-lexical status of the nonwords. Thus, co-activation occurred via consultation of the abstract syntactic rule. Conversely, the lexical boost effect observed in the eye-tracking experiment likely reflects presentation of a lexical item in the target region. Our findings across different paradigms demonstrates flexibility in the bilingual syntactic system, such that co-activation can occur via abstracted rules or lexico-syntactic associations, depending on the task demands.

6.2. A Proposed Model of Syntactic Co-activation

The results of the thesis provide strong support for syntactic co-activation during sentence comprehension. In this section, I will outline a proposed model of syntactic co-activation in order to account for these findings. Before outlining the specific mechanisms of the model, I will firstly outline some of the key assumptions. Firstly, it is assumed that lexical representations from both languages are co-activated during word-recognition on the basis of semantic, orthographic and phonological information. As such, it is assumed that translation equivalents that are orthographically similar to the input receive a greater amount of activation than translation equivalents that are orthographically dissimilar. In addition, I assume the presence of ‘language nodes’ that are connected only to the lexical representations of their respective language. Furthermore, a spreading activation process is assumed, in which the selection of a lexical candidate automatically activates its respective lemma and combinatorial nodes (whilst this terminology is traditionally used in the production modality, I apply it here for the sake of term consistency and clarity).

Based on the results of the studies described in Chapters 3 and 4, I propose that the combinatorial node specifying the occurrence of a soft mutation during a noun phrase is directly connected to all relevant Welsh lexical representations. Furthermore, I propose that this combinatorial node is also directly linked to the relevant English lexical representations (though the strength of these connections is significantly less than between the combinatorial node and the Welsh lexical representations). As such, the activation of English lexical representations should, to some extent, activate the combinatorial node for a soft mutation noun phrase: In Chapter 4, I suggested that the morphosyntactic rules of Welsh soft mutation become embedded within the syntax of English. The activation of an English lexical item would thus automatically activate the combinatorial node for a soft mutation noun phrase, and as such, the strength of these connections should be unaffected by the orthography of the non-operational language. Crucially, this activation should not be modulated by the degree of lexical overlap between languages: syntactic co-activation occurred even in the absence of lexical overlap between languages in the studies described in Chapters 3 and 4. On the basis of Chapter 5 however (in which syntactic co-activation was influenced by the degree of lexical overlap between languages), it is clear that such a model does not fully encapsulate the underlying mechanism of syntactic co-activation. As such, I propose the addition of a task schema that, via its connection to the language nodes, can inhibit or facilitate the connections between the combinatorial nodes and the lexical candidates. When presented with somewhat artificial contexts, such as the reading of nonwords, or the explicit presentation of both languages, the task schema activates the language nodes of both languages. The activation of these language nodes leads to the activation of their connected representations. As such, in these tasks, the activation of the Welsh language node automatically activates the combinatorial node for a soft mutation noun phrase, which feeds back to the English and Welsh lexical candidates. In this scenario therefore, the combinatorial node for Welsh mutation receives bottom up activation from the Welsh translation equivalents (and to some extent, the English lexical candidates), and top-down activation from the Welsh language node (Figure 7).

When presented with monolingual tasks, however, the task schema only activates the language node of the operational language, leading to the activation of all representations connected to that language node. Thus, during monolingual tasks, the combinatorial node for a soft mutation noun phrase does not receive any top-down activation. That is not to say that the combinatorial node is not activated, however. Despite the monolingual context, I maintain that the lexical representations of the non-operational language are automatically activated, leading to the activation of their connected combinatorial nodes. The combinatorial node for a soft mutation noun phrase therefore receives bottom-up activation, via the activation of translation equivalents (and to some extent, via the activation of the English lexical candidates). Due to the stronger activation of translation equivalents that are orthographically similar to the perceived word, the activation of the combinatorial node for a soft mutation noun phrase is stronger during lexical overlap trials compared with no overlap trials (Figure 8).

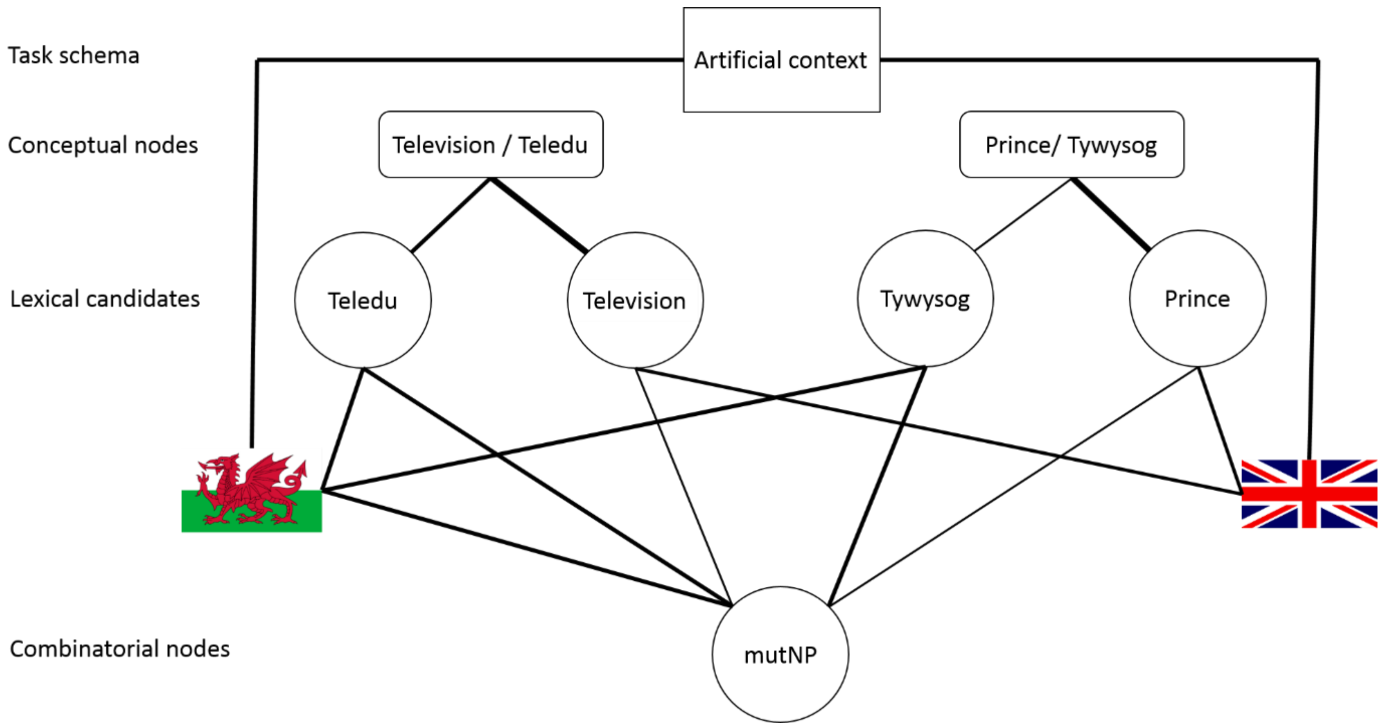

Figure 7. A proposed model depicting the co-activation of Welsh soft mutation rules in artificial contexts. For the sake of clarity, the model is restricted to the representation of conceptual, lexical and combinatorial nodes. Shared conceptual nodes connect to lexical candidates from both languages. Lexical candidates from both languages connect to all combinatorial nodes as well as language-specific language nodes (depicted by the Welsh and British flags). Finally, combinatorial nodes are connected to relevant language nodes. In this case, a connection exists between only the Welsh language node and the combinatorial node. Lines represent the connections between representations, and the strength of these connections is depicted by the thickness of the lines.

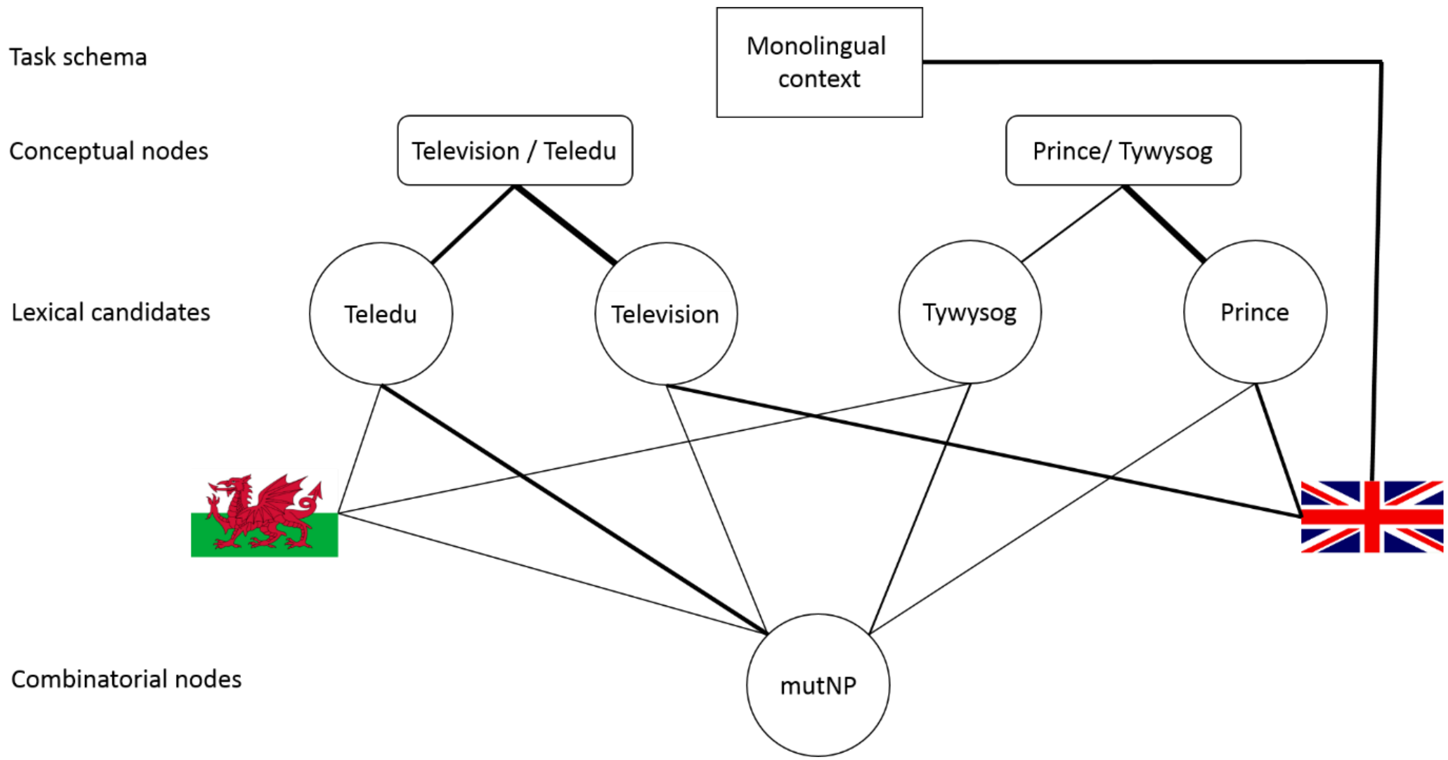

Figure 8. A proposed model depicting the co-activation of Welsh soft mutation rules in monolingual contexts. For the sake of clarity, the model is restricted to the representation of conceptual, lexical and combinatorial nodes. Shared conceptual nodes connect to lexical candidates from both languages. Lexical candidates from both languages connect to all combinatorial nodes as well as language-specific language nodes (depicted by the Welsh and British flags). Finally, combinatorial nodes are connected to relevant language nodes. In this case, a connection exists between only the Welsh language node and the combinatorial node. Lines represent the connections between representations, and the strength of these connections is depicted by the thickness of the lines.

These models demonstrate the interactivity of the bilingual syntactic system: combinatorial nodes are shared between languages, even when such syntactic rules exist only in one language. In this model, I assume stronger connections between idiosyncratic combinatorial nodes and lexical candidates from the language in which the rule exists, than between combinatorial nodes and lexical candidates from the language in which the rule does not exist. It is possible however, that the strength of these connections vary as a function of proficiency, or exposure (I will return to this discussion point in section 6.3.). Furthermore, this model demonstrates the influence of task demands on the co-activation of these rules: During monolingual tasks, the combinatorial nodes receive bottom up activation only, and as such, the stronger connections driven by orthographically similar translation equivalents would result in a form of 'lexical boost'. During more artificial tasks, however, the combinatorial node for a soft mutation noun phrase additionally receives top-down activation from the Welsh language node, which in turn strengthens the connection between the combinatorial node and its connected English lexical representations. Given the strength of the direct link between the English lexical candidate and the combinatorial node for a soft mutation noun phrase, less emphasis is placed on the connection between the combinatorial node and its Welsh lexical candidate. As such, the activation of a combinatorial node during artificial tasks is unaffected by lexical overlap between languages.

6.3. Directions for Future Research

Whilst the data presented here has started to elucidate the nature of syntactic co-activation in bilingual sentence comprehension, a number of empirical questions remain to be investigated. In this thesis, focus was placed exclusively on the influence of L1 syntax during L2 processing in a group of highly proficient bilinguals. However, it is unclear whether the effect also occurs in the opposite direction (whether L2 syntax can influence L1 processing).

Research to date has provided conflicting evidence, with some researchers stipulating that co-activation can be bidirectional (e.g. Van Assche, Duyck, Hartsuiker & Diependaele, 2009), and others stressing the asymmetry of co-activation: co-activation of L1 during L2 processing is typically stronger than the co-activation of L2 during L1 processing (e.g. Weber & Cutler, 2004). In relation to bilingual syntax, there is evidence supporting bidirectional co-activation, but co-activation of L2 syntax during L1 processing is comparatively weaker (Hatzidaki, Branigan & Pickering, 2011), and can be modulated by language exposure (Kaushanskaya & Smith, in press) and age of acquisition (e.g. Hernandez, Bates & Avila, 1994; Hohenstein, Eisenberg & Naigles, 2006). Future studies could extend the research presented in this thesis to investigate the co-activation of L2 syntax during L1 processing. To this end, testing fluent English-Welsh bilinguals on the paradigms described in this thesis would theoretically help elucidate this issue. However, it is important to note that L2 speakers typically learn Welsh in school, and their acquisition of soft mutation rules may never reach 'native' standards due to the lower amount of exposure (Jones, 1992). Evidence from psycholinguistics also shows that L2 processing of complex syntactic rules differs from L1 processing of such rules, even in highly proficient bilinguals (e.g. Clahsen & Felser, 2006). Creating a directionality comparison is therefore fraught with methodological difficulties, stemming from non-equivalence in L1 and L2 acquisition of syntax.

Another avenue for the future of this research topic concerns the developmental trajectory of syntactic co-activation in early bilinguals. In Chapters 1 and 2, I reviewed studies that noted the influence of proficiency on language co-activation, and noted that current models of bilingual syntactic representation may specifically represent balanced bilinguals who are equally proficient in both of their languages. Some studies have investigated the developmental trajectory of bilingual syntax in the context of shared vs separate representations, but they differ in terms of the conclusions drawn. Bernolet, Hartsuiker & Pickering (2013) proposed a developmental model of bilingual syntax in which syntactic representations are initially autonomous and language specific, with shared, language nonspecific syntactic representations developing as a function of proficiency. In contrast, Cantone & Müller (2008) suggested that bilinguals map L2 representations onto pre-existing L1 representations during acquisition, and that separate, language specific representations are developed as a function of second language proficiency. However, it is important to note that both of these studies investigated acquisition of L2 as a much weaker language compared with L1, and as such do not inform the representation of syntax in early, or simultaneous bilinguals, in which the syntactic system of L1 is not yet fully developed. Investigating the co-activation of the Welsh rules of soft mutation provides an opportunity to elucidate this issue. Children in Wales are exposed to English from a very young age, and engage in formal instruction of English by the age of 7. Given that the L1 Welsh syntactic system is still under development, at least until the age of nine (e.g., Thomas & Gathercole, 2007), acquisition of L2 syntactic structures are concurrent with the development of L1 syntax. Investigating syntactic co-activation in Welsh-English bilingual children would thus elucidate the developmental trajectory of syntactic representations. If early, or simultaneous bilinguals acquire and map syntactic representation in an integrated way (such that they aren't explicitly marked for language), it is possible that syntactic co-activation may be more prominent when both syntactic systems are developing. Conversely, if early, or simultaneous bilinguals acquire and map autonomous, language specific syntactic representations, it is possible that syntactic co-activation may not occur. Research into bilingual language acquisition has demonstrated that knowledge of a syntactic structure in one language can aid the acquisition of a similar syntactic structure in the other language (e.g. Gawlitzek-Maiwald & Tracy, 1996), although this transfer effect is typically reported in the direction of the dominant language to the non-dominant language (e.g. Yip and Matthews, 2000). Given the evidence for cross-linguistic influences in bilingual children, it is unlikely that syntactic co-activation would not occur in early, or simultaneous bilingual children. Given the complexity of the Welsh mutation rules however, and the fact that they do not exist in English, an investigation into the co-activation of these rules in Welsh-English bilinguals is necessary.

The two considerations outlined above could be combined in order to investigate the neurodevelopmental constraints of syntactic co-activation. In a recent review of our paper (Vaughan-Evans et al., 2014), Skeide (2014) argued that an adaptation of the experimental paradigm presented in Chapter 4 could provide insight into the effect of age of acquisition (AOA) and directionality on syntactic co-activation. A comparison of English-Welsh bilingual children and adult learners of Welsh would address the empirical question of whether the influence of L2 syntax on L1 is contingent on its acquisition within a critical period of chronological age. Skeide further proposes that the use of functional imaging may further elucidate the nature of syntactic co-activation by identifying whether language specific brain regions are involved in sentence processing (see also van Heuven, Schriefers, Dijkstra & Hagoort, 2008).Whilst these suggestions present interesting research avenues, several of the methodological constraints outlined above are still relevant. In particular, it is first necessary to discover whether syntactic co-activation is a bidirectional process, before investigating the influence of AOA on syntactic co-activation. Furthermore, whilst Skeide suggests that syntactic co-activation may be sensitive to AOA, we suggest that co-activation may me more sensitive to factors such as second language proficiency and immersion (Jones, Kuipers, Vaughan-Evans & Thierry, 2014).

A final consideration is whether the results obtained in this thesis would manifest similarly during production tasks. In the monolingual literature, researchers have suggested that syntactic representations are non-modular, such that common representations are activated during comprehension and production (e.g. Branigan, Pickering & Garrod, 2000;

Pickering & Garrod, 2004; Pickering & Garrod, 2013; but see Friederici & Jacobsen, 1999). So-called representational accounts do not assume that these representations are accessed similarly during comprehension and production however. During sentence production, syntactic *construction* is required so that the speaker can accurately convey the appropriate message-level information. During sentence comprehension however, syntactic *deconstruction* is required so that the reader or listener can accurately *interpret* the appropriate message-level information. It is therefore possible that the underlying mechanisms of syntactic co-activation are fundamentally different in comprehension and production: During comprehension, stronger activation of representations from both languages may occur, as participants need to interpret the appropriate message-level information. During production however, activation of the representations from the non-operational language may be reduced, as participants are aware of the message-level information that they want to produce in a specific language. Thus, syntactic co-activation may be more pronounced in comprehension tasks compared with production tasks. I propose that the experimental paradigms implemented in the current thesis could readily be adapted to investigate syntactic co-activation during production. For example, voice-onset time (VOT) could be measured as participants engage in written language production tasks, reading sentences containing mutated and aberrant nonwords (presented either explicitly or implicitly) out loud. Should syntactic co-activation occur, shorter VOT would be expected for mutated compared with aberrant nonwords during mutation context sentences.

6.4. The Final Summary

In this thesis, I have investigated the parameters of syntactic co-activation in bilinguals' sentence comprehension. In four experiments, I have shown that syntactic co-activation does occur during sentence comprehension in highly proficient Welsh-English bilinguals. I have also demonstrated that linguistic context – the extent to which the task is ostensibly monolingual – plays a significant role in determining when co-activation occurs (cross language lexico-syntactic associations vs abstract syntactic rules), as well as its manifestation (facilitated vs delayed processing). On the basis of these findings, I have proposed a model depicting the processes involved in the co-activation of the rules of soft mutation. Finally, I have outlined outstanding empirical questions, and have discussed the possibility of adapting the experimental paradigms presented in this thesis to investigate such questions.

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Appendix A

Anomalous Transfer of Syntax between Languages

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Behavioral/Cognitive

Anomalous Transfer of Syntax between Languages

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Each human language possesses a set of distinctive syntactic rules. Here, we show that balanced Welsh-English bilinguals reading in English unconsciously apply a morphosyntactic rule that only exists in Welsh. The Welsh soft mutation rule determines whether the initial consonant of a noun changes based on the grammatical context (e.g., the feminine noun *cath*—"cat" mutates into *gath* in the phrase *y gath*—"the cat"). Using event-related brain potentials, we establish that English nouns artificially mutated according to the Welsh mutation rule (e.g., "goncert" instead of "concert") require significantly less processing effort than the same nouns implicitly violating Welsh syntax. Crucially, this effect is found whether or not the mutation affects the same initial consonant in English and Welsh, showing that Welsh syntax is applied to English regardless of phonological overlap between the two languages. Overall, these results demonstrate for the first time that abstract syntactic rules transfer anomalously from one language to the other, even when such rules exist only in one language.

Key words: bilingualism; event-related brain potentials; grammar; language rules

Introduction

Language syntax is an abstract, rule-based mechanism in which combinatorial operations govern the classification and use of words (Chomsky, 1995). It remains unknown, however, which mechanisms underlie the creation of such linguistic rules, and whether syntactic analysis is performed on the basis of lexical-phonological regularities or whether abstract rules are extracted that can be applied through generalization (Plunkett and Marchman, 1993; Elman, 1998). In the current study, we tested the possibility of implicit syntactic transfer between languages in early adult bilinguals to determine whether the implementation of abstract linguistic rules relies on lexical–phonological associations (Thierry and Wu, 2007; Wu and Thierry, 2010; Wu et al., 2013) or syntactic contingencies (Loebell and Bock, 2003; Hartsuiker et al., 2004; Scheutz and Eberhard, 2004; Thierry and Sanoudaki, 2012). This allowed us to characterize the mechanisms by which syntax can generalize across languages.

We recorded electrophysiological brain responses in Welsh-English bilinguals reading English sentences. All test sentences ended in nonwords created by substituting the initial consonant of the final word with a consonant that produced either a mutated or an aberrant form, according to the Welsh mutation rule (e.g., "p" substituted by "b"-mutated, or "g"-aberrant). Syntactic structure was manipulated such that the Welsh translation of the English sentences required a word-final mutation or not. For example, the soft mutation rule in Welsh imposes a change to the initial consonant of a noun following specific syntactic triggers (Ball and Müller, 1992), which can be nonadjacent to the mutated word, and is defined as a morphosyntactically driven process (Harlow, 1989). This allowed us to distinguish between brain processing of expected and unexpected initial consonants of the final noun, depending on the syntactic context. The phonological mismatch negativity (PMN) is an event-related potential (ERP) index that is sensitive to lexical processing modulated by phonological expectation formed on the basis of the initial letter of a word, and peaks between 250 and 300 ms poststimulus (Connolly and Phillips, 1994; Hagoort and Brown, 2000; Diaz and Swaab, 2007). Assuming that Welsh syntactic rules are active during reading in English, we hypothesized that PMN amplitude would be reduced for mutated word forms, but only in sentences that would elicit a soft mutation if they had been encountered in Welsh.

We also manipulated phonological overlap between English and Welsh, such that in half of the experimental trials, the final word and its mutated form shared their initial consonant with their Welsh translations (Table 1). If syntactic transfer between languages occurs as a result of cross-language lexical associations (Thierry and Wu, 2007; Wu and Thierry, 2010; Wu et al., 2013), we expected a PMN reduction only when the English word and its translation in Welsh shared their initial consonant. However, if syntactic transfer occurs as a result of implementing abstract morphosyntactic rules, the PMN reduction should also be observed when there is no overlap between Welsh and English.

Materials and Methods

Participants. Nineteen Welsh-English bilinguals (5 males, 14 females) were included in the analysis on the basis of good knowledge of the Welsh soft mutation rule, which was assessed via a written sentence completion test (cutoff score, >65%), and self-reported that they were native language Welsh speakers, having learned English from an early age (mean age, 4.9

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years; SD, 2.7 years). Five participants were excluded owing to poor mutation performance or self-report of stronger written and oral abilities in English than in Welsh. A further three participants obtained too few epochs per condition. All participants possessed normal or corrected-to-normal vision. Ethical approval was granted by the School of Psychology, Bangor University Research Ethics Committee, and participants gave written consent.

Stimuli and procedure. In 11% of the cases, the sentence ended in the correct, most expected word (fillers), with nonwords completing the remaining 89% of cases.

In a separate pretest, an additional 26 monolingual participants completed sentences with the first word that came to mind. If the completions matched our experimental sentences, they were given a score of 1, and all other answers were scored 0. Cloze probability was calculated by averaging scores across sentences. In the event that the experimental test word was not the most predictable completion, it was removed from the stimulus list. Thus, cloze probability was calculated for all 160 test sentences. The overall probability was 0.66, with no significant differences among any of the experimental conditions (no phoneme overlap/no mutation context, 0.69; no phoneme overlap/mutation context, 0.67; phoneme overlap/no mutation context, 0.63; phoneme overlap/mutation context, 0.64; $p = 0.816$). Target words were controlled for written frequency, word length, and number of syllables. Participants viewed all 360 sentences, resulting in 40 trials per condition and 40 filler trials in a single session. Sentences were presented in a white 18 point font on a black background. The first clause was presented as continuous text and self-paced, followed by individual word presentation (200 ms with a 500 ms interstimulus interval). Presentation order was pseudorandomized, such that two target words never appeared in immediate succession. A third of all sentences were followed by a comprehension question. Participants responded correctly to comprehension questions with an average accuracy of 94% (SD, 4%; range, 83–98%), and their reading time of the first half of each sentence (mean, 2639 ms; SD, 575 ms) did not differ significantly between conditions (mutation context/mutated word, 2676 ms; mutation context/aberrant word, 2635 ms; no mutation context/mutated word, 2617 ms; no mutation context/aberrant word, 2626 ms; $p = 0.374$).

ERP recording. Electrophysiological data were recorded from 64 Ag/AgCl electrodes according to the extended 10–20 convention and were referenced to the Cz site at a rate of 1 kHz. The electroencephalogram (EEG) activity was filtered on-line with a bandpass filter between 0.1 and 200 Hz, and off-line with a low-pass, zero phase-shift digital filter, which was set at 20 Hz. Observed eye blinks in the EEG were corrected mathematically, and remaining artifacts were removed by manually inspecting the data. Epochs ranging from −100 to 1000 ms after the onset of the target word were extracted from the EEG recordings. Epochs with activity exceeding ±75 μV at any electrode site were automatically discarded. There was a minimum of 30 epochs per condition for every participant. Baseline correction was performed in reference to prestimulus activity, and individual averages were digitally rereferenced to the global average reference.

Results

We analyzed ERP amplitudes over six electrodes where the PMN is known to be maximal (linear derivation of FCZ, FC2, FC4, CZ, C2, and C4; Connolly and Phillips, 1994; Fig. 1) by means of a repeated-measures ANOVA with mutation context (mutation vs no mutation), word form (mutated vs aberrant), and phoneme overlap between languages (overlap vs no overlap) as independent variables.

We found no main effect of mutation context, word form, or phoneme overlap. However, there was a significant mutation context × word form interaction ($F_{(1,18)} = 6.076$, $p = 0.024$). *Post hoc* paired-samples *t* tests revealed that correctly mutated words elicited less negative PMN amplitudes than aberrant words when presented in a mutation context ($t_{(18)} = 3.066$, $p = 0.007$, Bonferroni correction), and this was not the case in no mutation contexts ($t_{(18)} = -0.09$, $p = 0.926$). No other significant interactions were found. In particular, phoneme overlap between English and Welsh did not interact with the mutation context effect ($F_{(1,18)} = 0.349$, $p = 0.562$). Finally, analyses in earlier time windows (N1 and P2) did not show significant differences in amplitude between experimental conditions.

Table 1. Experimental design and stimulus examples

	Correct form	Mutated form	Aberrant form
Phoneme overlap			
Mutation context			
Each book starts with a page listing its "Dechreuir pob llyfr â thudalen yn rhestru ei	contents gynnwys"	gontents	dontents
No mutation context			
The lid was lifted to examine the "Codwyd y caead er mwyn archwilio'r	contents cynnwys"	gontents	dontents
No phoneme overlap			
Mutation context			
As a doctor she saw a lot of "Fel meddyg, roedd hi'n gweld nifer o	patients gleifion"	batients	datients
No mutation context			
At the hospital he would read to the "Yn yr ysbyty, byddai'n darllen i'r	patients cleifion"	batients	datients

The Welsh translation is shown here for information only. Translation accuracy was independently assessed in a group of 15 balanced Welsh-English bilinguals who did not take part in the study. Participants were presented with whole sentences and were asked to translate the second clause of each sentence (including the mutation trigger). Translations were deemed accurate (score, 1) if they satisfied the following two conditions: (1) that the sentence context appropriately elicited a mutation or not; and (2) that the target word was the same as the item included in the experimental items. Translation agreement was very high (average, 89%) and, critically, did not differ significantly between mutation and nonmutation contexts ($p = 0.131$).

Discussion

Here, we questioned whether syntactic rules of one language may transfer to the other language of bilinguals by testing for a covert influence of Welsh mutations applied to English material. We found that English words mutated into nonwords according to Welsh mutation rules are more easily integrated within a sentence context that requires a mutation in Welsh compared with these same nonwords presented in a nonmutation context.

Implicit transfer of Welsh syntactic mutation rules was indexed by a reduction of mean amplitude in the range of the PMN, an ERP modulation known to be sensitive to phonological expectation and phonetic stimulus properties (Connolly and Phillips, 1994; Hagoort and Brown, 2000; Diaz and Swaab, 2007). It is noteworthy that such phonological expectancy effects are also found in reading tasks (Savill and Thierry, 2011; Savill et al., 2011). If predictions normally applying to the Welsh language were also made in relation to English words, we expected reduced PMN amplitude for mutated relative to aberrant word forms, according to the grammatical context.

Importantly, the effect reported here is not merely an artificial process triggered by the use of nonwords in the experiment, because a PMN modulation can only be elicited when participants make predictions regarding the upcoming final word and, in particular, its first phoneme. If the effect was merely triggered by the encounter of a nonword, there is no reason why participants should expect a particular phoneme rather than another, unless they engaged in syntactic processing governed by the rules of the Welsh language. Also we note that filler sentences ended in a correct English completion word, and therefore that participants did not systemically approach the final word as a nonword.

Crucially, this effect was found regardless of phonological overlap between English words and their Welsh translation equivalents. Indeed, language-nonspecific lexical access (Thierry and Wu, 2007, Wu and Thierry, 2010, Wu et al., 2013) fails to account for the results obtained here. If the effect reported here could be accounted for by nonselective lexical access alone, we would expect it to occur only when the initial phonemes of the

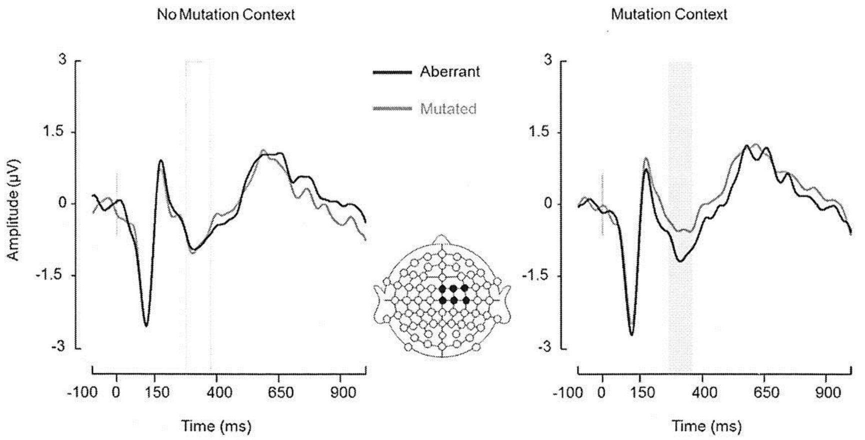

Figure 1. ERPs elicited by mutated and aberrant nonwords collapsed across conditions of phoneme overlap and no phoneme overlap. The plain gray box indicates the window of analysis in which mean ERP amplitude significantly differed between conditions (260–360 ms poststimulus).

word were identical in English and Welsh. The finding that participants appeared to apply the Welsh mutation rule even in the absence of phonological overlap between languages demonstrates that it is based on the implementation of a morphosyntactic rule. Beyond the issue of phonological overlap, the timing of the effect is also incompatible with a lexical mediation account since priming was observed here between 260 and 360 ms, which is considerably earlier than the time period in previous studies of spontaneous access to translation equivalents (Thierry and Wu, 2007). Furthermore, this finding is compatible with results from an electrophysiological study demonstrating word-order transfer in bilinguals (Thierry and Sanoudaki, 2012) and with results from behavioral studies demonstrating cross-linguistic syntactic priming (Hartsuiker et al., 2004).

The use of ERPs in the current study presents an important methodological breakthrough in the investigation of syntactic processing in adult bilinguals, providing unique insights into covert transfer of syntactic rules from one language to another within the same individual (Wu and Thierry, 2013). Our findings therefore provide strong support for theories positing rule-based representation of syntax in proficient adult readers (Opitz and Friederici, 2004; Doeller et al., 2006).

The current study provides the first tangible evidence for spontaneous and anomalous transfer of syntax between languages, even at the level of subtle morphosyntactic changes elicited by a rule alien to English. These data suggest that transfer relies on abstract syntactic representations rather than lexical–phonological associations and lend strong support to theories positing rule-based representation of syntax. Future studies will shed more light on the developmental dynamics of syntactic transfer.

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Appendix B

Experimental sentences used in Chapter 3

	Correct form	Mutated form	Aberrant form
Phoneme Overlap			
Mutation Context			
The criminal provided the detective with information as he was his	contact	gontact	bontact
No Mutation Context			
Over the years the childhood friends had lost	contact	gontact	bontact
Mutation Context			
Each book starts with a page listing its	contents	gontents	dontents
No Mutation Context			
The lid was lifted to examine the	contents	gontents	dontents
Mutation Context			
She wasn't sure if the answer was	correct	gorrect	borrect
No Mutation Context			
He listened to the answer before shouting:	correct	gorrect	borrect
Mutation Context			
The lecturer was popular and the students enjoyed his	course	gourse	bourse
No Mutation Context			
A lot of students had registered on the	course	gourse	bourse
Mutation Context			
The lifeguard worried about the strength of the sea and its	current	gurrent	burrent
No Mutation Context			
Sarah dropped a leaf in the river and watched it float away on the	current	gurrent	burrent
Mutation Context			
It was obvious that the old house needed a coat of	paint	baint	gaint
No Mutation Context			
In the art class the students could use	paint	baint	gaint
Mutation Context			
She looked at the numbers and saw a	pattern	battern	gattern
No Mutation Context			
She was making a quilt and was following a	pattern	battern	gattern
Mutation Context			
They were in the middle of a crowd of	people	beople	deople
No Mutation Context			
He was shy and didn't like interacting with	people	beople	deople
Mutation Context			
The director watched the actor and was happy with his	performance	berformance	derformance
No Mutation Context			
Simon directed a play and was pleased that everyone enjoyed the	performance	berformance	derformance
Mutation Context			
There was one apple on the tree that hadn't been	picked	bicked	gicked
No Mutation Context			
The apples on the tree were ripe and needed to be	picked	bicked	gicked

	Correct form	Mutated form	Aberrant form
Mutation Context			
In a debate about politics she didn't understand his	point	boint	goint
No Mutation Context			
He was being stubborn and wanted to prove a	point	boint	goint
Mutation Context			
He preferred swimming outside in the sea than indoors in his	pool	bool	dool
No Mutation Context			
He decided to relax and go swimming in the	pool	bool	dool
Mutation Context			
There were housing concerns due to an increase in the	population	bopulation	dopulation
No Mutation Context			
A census can be used to estimate the size of a	population	bopulation	dopulation
Mutation Context			
He shopped locally as he thought it was	convenient	gonvenient	bonvenient
No Mutation Context			
They travelled by plane as it was more	convenient	gonvenient	bonvenient
Mutation Context			
On top of the saucer she placed the	cup	gup	dup
No Mutation Context			
She was making tea when she broke the	cup	gup	dup
Mutation Context			
His drink was hot and burnt his	tongue	dongue	gongue
No Mutation Context			
They were learning about taste buds on the	tongue	dongue	gongue
Mutation Context			
The pirate was certain that nobody would find his	treasure	dreasure	greasure
No Mutation Context			
The book was about big ships, pirates and	treasure	dreasure	greasure
Mutation Context			
The naughty boy always got his best friends into	trouble	drouble	brouble
No Mutation Context			
The car engine broke down leaving the family in	trouble	drouble	brouble
Mutation Context			
He came home early to feed the dog and the	cat	gat	dat
No Mutation Context			
She didn't like dogs but she did like	cats	gats	dats
Mutation Context			
During the picnic the sun was covered by a	cloud	gloud	bloud
No Mutation Context			
She could tell it was about to rain by looking up at the	cloud	gloud	bloud
Mutation Context			
If John behaves well, his dad lets him watch sports on his	television	delevision	belevision
No Mutation Context			
After supper, the children are allowed to watch	television	delevision	belevision

	Correct form	Mutated form	Aberrant form
Mutation Context			
As he did his homework, Paul could play games on his	computer	gomputer	bomputer
No Mutation Context			
Tom's work was lost because someone deleted the files on the	computer	gomputer	bomputer
Mutation Context			
The IT procedure seemed very basic and not too	technical	dechnical	bechnical
No Mutation Context			
She avoided computers, since she didn’t understand	technology	dechnology	bechnology
Mutation Context			
He finished the screenplay but couldn't think of a	title	ditle	gitle
No Mutation Context			
They were looking for a specific film but couldn't remember the	title	ditle	gitle
Mutation Context			
Most serious illnesses can't be cured without	treatment	dreatment	greatment
No Mutation Context			
At the vet's, the dog was receiving	treatment	dreatment	greatment
Mutation Context			
She had met a man and enjoyed his	company	gompany	bompany
No Mutation Context			
He was in a bad mood and didn't want	company	gompany	bompany
Mutation Context			
They worked very hard and won the	competition	gompetition	bompetition
No Mutation Context			
The two choirs liked performing against each other as they enjoyed	competing	gompeting	bompeting
Mutation Context			
They submitted the work once it had been	completed	gompleted	dompleted
No Mutation Context			
The work was daunting with so many tasks to	complete	gomplete	domplete
Mutation Context			
Her hair was very brittle so she tried to improve its	condition	gondition	bondition
No Mutation Context			
She bought an item online but was unhappy with the	condition	gondition	bondition
Mutation Context			
After months, the phone line still had not been	connected	gonnected	donnected
No Mutation Context			
They could speak at last because the phone lines were	connected	gonnected	donnected
Mutation Context			
In the music lesson, she learned that Motzart's music was called	classical	glassical	blassical
No Mutation Context			
The popular old TV show was referred to as a	classic	glassic	blassic
Mutation Context			
The restaurant had to close after receiving many	complaint	gomplaint	bomplaint
No Mutation Context			
Bill was unhappy with his purchase and decided to make a	complaint	gomplaint	bomplaint

	Correct form	Mutated form	Aberrant form
Mutation Context			
The shop sold chocolates and packets of	crisps	grisps	brips
No Mutation Context			
If you fry thinly sliced potatoes, you can make	crisps	grisps	brips
Mutation Context			
She was giving an important lecture so she was sure to	prepare	brepare	drepare
No Mutation Context			
In the exam he realised he had not	prepared	brepared	drepared
Mutation Context			
He struck a match after the power cut and went to light the	candles	gandles	bandles
No Mutation Context			
They had no electricity so they lit some	candles	gandles	bandles
Mutation Context			
After moving the fallen branches the path was	clear	glear	blear
No Mutation Context			
After a long sleep, she was thinking more	clearly	glearly	blearly
Mutation Context			
Dan was fussy and wouldn't clean the spill without a	cloth	gloth	dloth
No Mutation Context			
After spilling milk on the counter she fetched a	cloth	gloth	dloth
Mutation Context			
In music lessons, she learned that Bach was a	composer	gomposer	bomposer
No Mutation Context			
People who write musical pieces are often referred to as	composers	gomposers	bomposers
Mutation Context			
Being a novice, she used a recipe whilst	cooking	gooking	dooking
No Mutation Context			
He worked as a chef and enjoyed	cooking	gooking	dooking
Mutation Context			
After dating for several months, they decided to call themselves a	couple	gouple	douple
No Mutation Context			
The boy and girl went to the party as a	couple	gouple	douple

	Correct form	Mutated form	Aberrant form
No Phoneme Overlap			
Mutation Context			
She wore her sister's dress without asking for	permission	bermission	dermission
No Mutation Context			
He used the equipment without getting their	permission	bermission	dermission
Mutation Context			
The farmer bought a bull to mate with the	cow	gow	dow
No Mutation Context			
On the farm, she was milking a	cow	gow	dow
Mutation Context			
After he was sentenced he was taken to a	prison	brison	drison
No Mutation Context			
She was interviewing dangerous criminals inside the	prison	brison	drison
Mutation Context			
He broke a vase and was about to be	punished	bunished	dunished
No Mutation Context			
Carl and Peter were in trouble and were waiting to be	punished	bunished	dunished
Mutation Context			
At the child's party he had a piece of	cake	gake	pake
No Mutation Context			
She went home early to bake a	cake	gake	pake
Mutation Context			
At the doctors she found out she was	pregnant	bregnant	gregnant
No Mutation Context			
The husband was thrilled to hear about her	pregnancy	bregnancy	gregnancy
Mutation Context			
Over the summer he lived in his	cottage	gottage	dottage
No Mutation Context			
They went on holiday in the hills and stayed in a	cottage	gottage	dottage
Mutation Context			
Despite not being sentenced everyone thought he was a	criminal	griminal	briminal
No Mutation Context			
As a police officer, he dealt a lot with	criminals	griminals	briminals
Mutation Context			
Phillip was prescribed medicine for his cold, but he could not stop his	coughing	goughing	boughing
No Mutation Context			
He swallowed water the wrong way and couldn't stop	coughing	goughing	boughing
Mutation Context			
He liked the topping of sugar and lemon on his	pancakes	bancakes	dancakes
No Mutation Context			
She bought flour and milk on Shrove Tuesday to make	pancakes	bancakes	dancakes

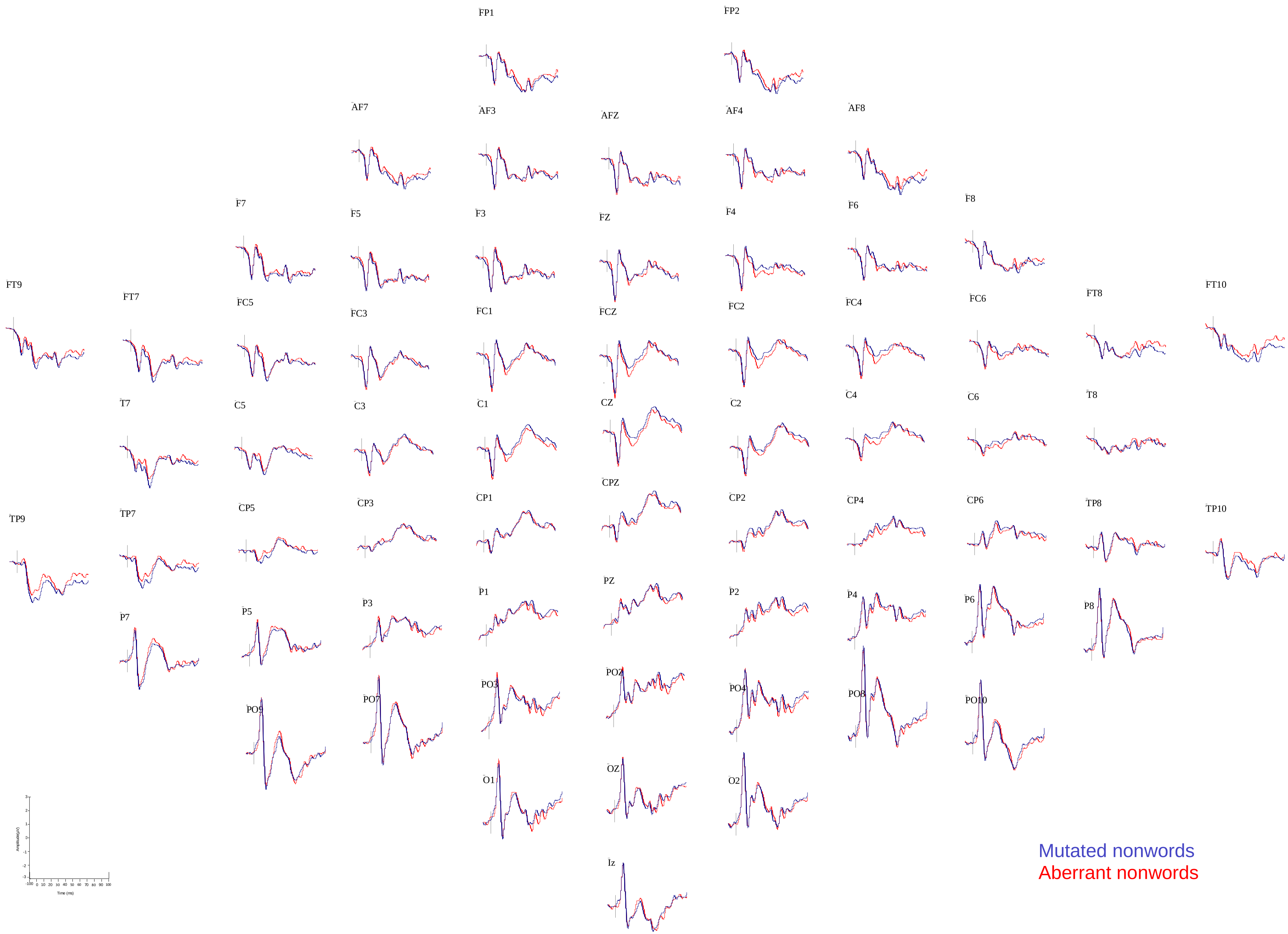
	Correct form	Mutated form	Aberrant form
Mutation Context			
To improve your vision you should eat more	carrots	garrots	darrots
No Mutation Context			
At Christmas, the reindeer liked to eat	carrots	garrots	darrots
Mutation Context			
For the presentation he connected the computer to his	projector	brojector	grojector
No Mutation Context			
To show slides in his presentation, he needed to find a	projector	brojector	grojector
Mutation Context			
He remembered his login but forgot his	password	bassword	dassword
No Mutation Context			
She couldn't log in because she had forgotten the	password	bassword	dassword
Mutation Context			
In the forest she stepped on a	twig	dwig	gwig
No Mutation Context			
To make their nests the birds were collecting	twigs	dwigs	gwigs
Mutation Context			
On the high-street most of the birds were	pigeons	bigeons	digeons
No Mutation Context			
On the city streets, she threw seeds at the	pigeons	bigeons	digeons
Mutation Context			
They didn't understand the foreign text so they had it	translated	dranslated	branslated
No Mutation Context			
She knew many languages and worked as a	translator	dranslator	branslator
Mutation Context			
Compared to the elephant the mouse was	tiny	diny	giny
No Mutation Context			
Being a fan of extremes, he bought something large and something	tiny	diny	giny
Mutation Context			
To end the war they signed a	treaty	dreaty	breaty
No Mutation Context			
The governments of both countries were happy with the	treaty	dreaty	breaty
Mutation Context			
To get better results they needed data from more	participants	barticipants	darticipants
No Mutation Context			
In the experiment she was one of the	participants	barticipants	darticipants
Mutation Context			
The smallest unit of Sterling currency is the	penny	benny	denny
No Mutation Context			
He bought a book for one pound and one	penny	benny	denny
Mutation Context			
His scheme didn't work as everybody knew about his	plan	blan	dlan
No Mutation Context			
Before writing an essay it's important to make a	plan	blan	dlan

	Correct form	Mutated form	Aberrant form
Mutation Context			
William Wordsworth wrote verses and was a	poet	boet	doet
No Mutation Context			
They had to learn poems by more than one	poet	boet	doet
Mutation Context			
He was working hard but seeing very little	progress	brogress	drogress
No Mutation Context			
The kind teacher said the student was making	progress	brogress	drogress
Mutation Context			
He worked on his paper for it to be	published	bublished	dublished
No Mutation Context			
Many of her better papers had been	published	bublished	dublished
Mutation Context			
They were all nervous and afraid of speaking	publically	bublically	dublically
No Mutation Context			
She hoped to talk somewhere that was less	public	bublic	dublic
Mutation Context			
The dog was running around chasing its	tail	dail	cail
No Mutation Context			
Dogs have one head, four legs and one	tail	dail	cail
Mutation Context			
After the overnight journey on the plane she was	tired	dired	gired
No Mutation Context			
You could see from their worn-out faces that they were	tired	dired	gired
Mutation Context			
The energetic children enjoyed climbing up the	tree	dree	gree
No Mutation Context			
The cat had become stuck up a	tree	dree	gree
Mutation Context			
He walked home drunk from the	pub	bub	gub
No Mutation Context			
After finishing work they went to the	pub	bub	gub
Mutation Context			
His back was hurting after carrying a sack of	potatoes	botatoes	gotatoes
No Mutation Context			
She worked in a kitchen and was peeling	potatoes	botatoes	gotatoes
Mutation Context			
The film was about a princess and her brother, who was a	prince	brince	grince
No Mutation Context			
The royals had two children; one princess and one	prince	brince	grince
Mutation Context			
The food was set out on a	table	dable	bable
No Mutation Context			
The hot plates left marks on the	table	dable	bable

	Correct form	Mutated form	Aberrant form
Mutation Context			
She didn't like the soup because of its	taste	daste	gaste
No Mutation Context			
The soup looked delicious but she didn't want a	taste	daste	gaste
Mutation Context			
John did the sum but was unhappy with his	total	dotal	botal
No Mutation Context			
The restaurant's earnings didn't add up so they recalculated the	total	dotal	botal
Mutation Context			
The food standards agency came to the farm to assess his	produce	broduce	droduce
No Mutation Context			
David and Kathy were dairy farmers and were happy with their	produce	broduce	droduce
Mutation Context			
Bill won the vote and became chair of a	committee	gommittee	dommittee
No Mutation Context			
She was active in chapel and was on the	committee	gommittee	dommittee
Mutation Context			
To get to the bar in the busy pub they pushed through the	crowd	growd	browd
No Mutation Context			
She was claustrophobic, and panicked when in the middle of a	crowd	growd	browd
Mutation Context			
He dropped the book and lost his	page	bage	tage
No Mutation Context			
He took the boring manual and read down one	page	bage	tage
Mutation Context			
He had already spent the month's wage and couldn't wait to be	paid	baid	gaid
No Mutation Context			
They put the shopping in the trolley before	paying	baying	gaying
Mutation Context			
As a doctor she saw a lot of	patients	batients	datients
No Mutation Context			
At the hospital he would read to the	patients	batients	datients

Appendix C

ERPs elicited by mutated and aberrant nonwords in mutation context sentences, as described in Chapter 3


FP1
FP2
AF7
AF3
AFZ
AF4
AF8
F7
F5
F3
FZ
F4
F6
F8
FT9
FT7
FC5
FC3
FC1
FCZ
FC2
FC4
FC6
FT8
FT10
T7
C5
C3
C1
CZ
C2
C4
C6
T8
TP9
TP7
CP5
CP3
CP1
CPZ
CP2
CP4
CP6
TP8
TP10
P7
P5
P3
P1
PZ
P2
P4
P6
P8
PO9
PO7
PO3
POZ
PO4
PO8
PO10
O1
OZ
O2
Iz
Mutated nonwords
Aberrant nonwords

Appendix D

ERPs elicited by mutated and aberrant nonwords in no mutation context sentences, as described in Chapter 3


Mutated nonwords
Aberrant nonwords
FP1*
FP2*
AF7*
AF3*
AFZ*
AF4*
AF8*
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Appendix E

Experimental sentences used in Chapter 4

	Masculine antecedent	Plural antecedent
Total		
Masculine pronoun	Steven recalculated the sum as he didn't trust his dotal	Steven and Jane recalculated the sum as they didn't trust his dotal
Plural pronoun	Steven recalculated the sum as he didn't trust their dotal	Steven and Jane recalculated the sum as they didn't trust their dotal
Page		
Masculine pronoun	After Andrew dropped the book mark he could not find his bage	After Andrew and Beth dropped the book mark they could not find his bage
Plural pronoun	After Andrew dropped the book mark he could not find their bage	After Andrew and Beth dropped the book mark they could not find their bage
Patients		
Masculine pronoun	Eric was a conscientious doctor so he always cared for his batients	Eric and Sarah were conscientious doctors so they always cared for his batients
Plural pronoun	Eric was a conscientious doctor so he always cared for their batients	Eric and Sarah were conscientious doctors so they always cared for their batients
Plans		
Masculine pronoun	Mark started building the extension after he finished drawing up his blans	Mark and Kerry started building the extension after they finished drawing up his blans
Plural pronoun	Mark started building the extension after he finished drawing up their blans	Mark and Kerry started building the extension after they finished drawing up their blans
Produce		
Masculine pronoun	David was a dairy farmer and he was happy with his broduce	David and Kathy were dairy farmers and they were happy with his broduce
Plural pronoun	David was a dairy farmer and he was happy with their broduce	David and Kathy were dairy farmers and they were happy with their broduce
Production		
Masculine pronoun	As Carl was working backstage, he could not watch his broduction	As Carl and Lilly were working backstage, they could not watch his broduction
Plural pronoun	As Carl was working backstage, he could not watch their broduction	As Carl and Lilly were working backstage, they could not watch their broduction
Public		
Masculine pronoun	As Ian was the democratic party's presidential candidate he would often address his bublic	As Ian and Suzan were the democratic party's presidential candidates they would often address his bublic
Plural pronoun	As Ian was the democratic party's presidential candidate he would often address their bublic	As Ian and Suzan were the democratic party's presidential candidates they would often address their bublic
Coughing		
Masculine pronoun	Phillip prescribed medicine for colds, but he could not stop his goughing	Phillip and Lauren prescribed medicine for colds, but they could not stop his goughing
Plural pronoun	Phillip prescribed medicine for colds, but he could not stop their goughing	Phillip and Lauren prescribed medicine for colds, but they could not stop their goughing
Confusion		
Masculine pronoun	After Liam read the simple book he could not understand his gonfusion	After Liam and Ann read the simple book they could not understand his gonfusion
Plural pronoun	After Liam read the simple book he could not understand their gonfusion	After Liam and Ann read the simple book they could not understand their gonfusion

	Masculine antecedent	Plural antecedent
Presentation		
Masculine pronoun	Roy was watching the talk and he was enjoying his bresentation	Roy and Cheryl were watching the talk and they were enjoying his bresentation
Plural pronoun	Roy was watching the talk and he was enjoying their bresentation	Roy and Cheryl were watching the talk and they were enjoying their bresentation
Password		
Masculine pronoun	Noah couldn't log on to the shared system because he had forgotten his bassword	Noah and Lauren couldn't log on to the shared system because they had forgotten his bassword
Plural pronoun	Noah couldn't log on to the shared system because he had forgotten their bassword	Noah and Lauren couldn't log on to the shared system because they had forgotten their bassword
Penny		
Masculine pronoun	Lucas decided to flip a coin so he asked to use his benny	Lucas and Patricia decided to flip a coin so they asked to use his benny
Plural pronoun	Lucas decided to flip a coin so he asked to use their benny	Lucas and Patricia decided to flip a coin so they asked to use their benny
Percentage		
Masculine pronoun	Paul was delegating company shares to staff and he was satisfied with his bercentage	Paul and Sophie were delegating company shares to staff and they were satisfied with his bercentage
Plural pronoun	Paul was delegating company shares to staff and he was satisfied with their bercentage	Paul and Sophie were delegating company shares to staff and they were satisfied with their bercentage
Prison		
Masculine pronoun	As Henry was a ruthless criminal he was feared at his brison	As Henry and Rebecca were ruthless criminals they were feared at his brison
Plural pronoun	As Henry was a ruthless criminal he was feared at their brison	As Henry and Rebecca were ruthless criminals they were feared at their brison
Pottery		
Masculine pronoun	Ed moulded the clay, so that he could make his bottery	Ed and Jane moulded the clay, so that they could make his bottery
Plural pronoun	Ed moulded the clay, so that he could make their bottery	Ed and Jane moulded the clay, so that they could make their bottery
Concern		
Masculine pronoun	As Zack was usually a laid back person, he could not understand his goncern	As Zack and Bella were usually laid back people, they could not understand his goncern
Plural pronoun	As Zack was usually a laid back person, he could not understand their goncern	As Zack and Bella were usually laid back people, they could not understand their goncern
Topic		
Masculine pronoun	Gregory became a teaching assistant as he thoroughly enjoyed his dopic	Gregory and Sophia became teaching assistants as they thoroughly enjoyed his dopic
Plural pronoun	Gregory became a teaching assistant as he thoroughly enjoyed their dopic	Gregory and Sophia became teaching assistants as they thoroughly enjoyed their dopic
Permit		
Masculine pronoun	Jake was in trouble after parking the car as he did not display his bermit	Jake and Ellie were in trouble after parking the car as they did not display his bermit
Plural pronoun	Jake was in trouble after parking the car as he did not display their bermit	Jake and Ellie were in trouble after parking the car as they did not display their bermit

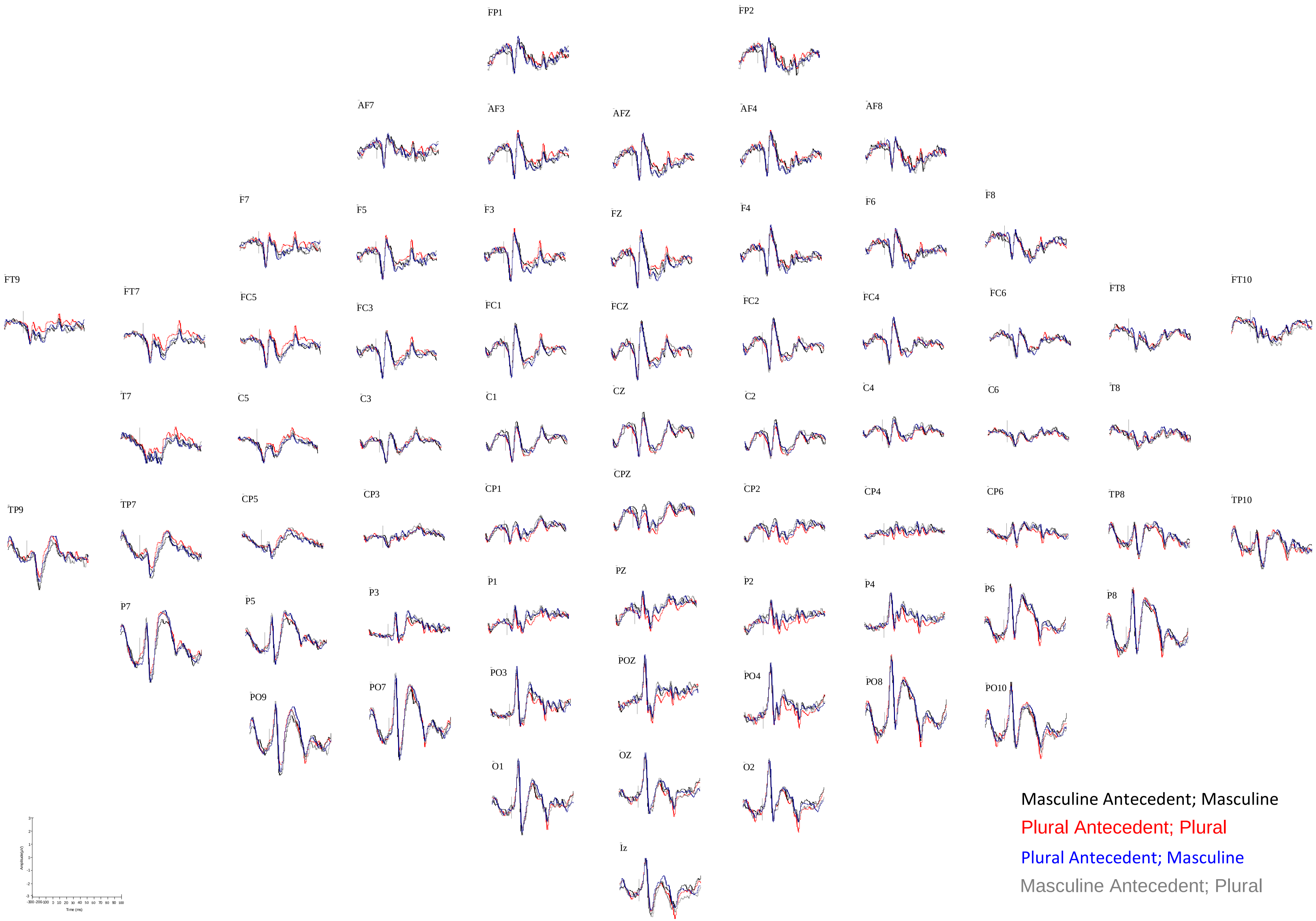
	Masculine antecedent	Plural antecedent
Calmness		
Masculine pronoun	Andy was usually very stressed, so he was surprised at his galmness	Andy and Chloe were usually very stressed, so they were surprised at his galmness
Plural pronoun	Andy was usually very stressed, so he was surprised at their galmness	Andy and Chloe were usually very stressed, so they were surprised at their galmness
Transport		
Masculine pronoun	Colin used a new car lease company, and he was pleased with his dransport	Colin and Margaret used a new car lease company, and they were pleased with his dransport
Plural pronoun	Colin used a new car lease company, and he was pleased with their dransport	Colin and Margaret used a new car lease company, and they were pleased with their dransport
Test		
Masculine pronoun	If Paul revises he will pass his dest	If Paul and Hannah revise they will pass his dest
Plural pronoun	If Paul revises he will pass their dest	If Paul and Hannah revise they will pass their dest
Payment		
Masculine pronoun	Josh was a banker so he could authorise his bayment	Josh and Elizabeth were bankers so they could authorise his bayment
Plural pronoun	Josh was a banker so he could authorise their bayment	Josh and Elizabeth were bankers so they could authorise their bayment
Publication		
Masculine pronoun	Charles was a journal editor and he was impressed with his bublication	Charles and Gemma were journal editors and they were impressed with his bublication
Plural pronoun	Charles was a journal editor and he was impressed with their bublication	Charles and Gemma were journal editors and they were impressed with their bublication
Committee		
Masculine pronoun	If Julian wins the vote, he will chair his gommittee	If Julian and Judy win the vote, they will chair his gommittee
Plural pronoun	If Julian wins the vote, he will chair their gommittee	If Julian and Judy win the vote, they will chair their gommittee
Pub		
Masculine pronoun	Tommy was a bartender and he drank in his bub	Tommy and Laura were bartenders and they drank in his bub
Plural pronoun	Tommy was a bartender and he drank in their bub	Tommy and Laura were bartenders and they drank in their bub
Carrots		
Masculine pronoun	Ben was told he could see in the dark if he ate all his garrots	Ben and Sally were told they could see in the dark if they ate all his garrots
Plural pronoun	Ben was told he could see in the dark if he ate all their garrots	Ben and Sally were told they could see in the dark if they ate all their garrots
Translator		
Masculine pronoun	Ethan doesn't speak English so he relies on his dranslator	Ethan and Miranda don't speak English so they rely on his dranslator
Plural pronoun	Ethan doesn't speak English so he relies on their dranslator	Ethan and Miranda don't speak English so they rely on their dranslator

	Masculine antecedent	Plural antecedent
Participants		
Masculine pronoun	If Christopher finishes the stimuli he can test his barticipants	If Christopher and Pamela finish the stimuli they can test his barticipants
Plural pronoun	If Christopher finishes the stimuli he can test their barticipants	If Christopher and Pamela finish the stimuli they can test their barticipants
Cakes		
Masculine pronoun	Robert attended a baking class and he enjoyed tasting his gakes	Robert and Vicky attended a baking class and they enjoyed tasting his gakes
Plural pronoun	Robert attended a baking class and he enjoyed tasting their gakes	Robert and Vicky attended a baking class and they enjoyed tasting their gakes
Pillows		
Masculine pronoun	Craig was the most skilled textile student so he designed covers for his billows	Craig and Becky were the most skilled textile students so they designed covers for his billows
Plural pronoun	Craig was the most skilled textile student so he designed covers for their billows	Craig and Becky were the most skilled textile students so they designed covers for their billows
Table		
Masculine pronoun	Hugh was angry at the restaurant so he threw food across his dable	Hugh and Amy were angry at the restaurant so they threw food across his dable
Plural pronoun	Hugh was angry at the restaurant so he threw food across their dable	Hugh and Amy were angry at the restaurant so they threw food across their dable
Capital		
Masculine pronoun	When Simon visited Cardiff he was impressed with his gapital	When Simon and Deborah visited Cardiff they were impressed with his gapital
Plural pronoun	When Simon visited Cardiff he was impressed with their gapital	When Simon and Deborah visited Cardiff they were impressed with their gapital
Progress		
Masculine pronoun	William was surveying the building work and he was happy with his brogress	William and Izabella were surveying the building work and they were happy with his brogress
Plural pronoun	William was surveying the building work and he was happy with their brogress	William and Izabella were surveying the building work and they were happy with their brogress
Tortoise		
Masculine pronoun	Alexander was in the pet shop as he needed food for his dortoise	Alexander and Jenny were in the pet shop as they needed food for his dortoise
Plural pronoun	Alexander was in the pet shop as he needed food for his dortoise	Alexander and Jenny were in the pet shop as they needed food for their dortoise
Pipe		
Masculine pronoun	Harry often bought tobacco when visiting friends, and he smoked it in his bipe	Harry and Linda often bought tobacco when visiting friends, and they smoked it in his bipe
Plural pronoun	Harry often bought tobacco when visiting friends, and he smoked it in their bipe	Harry and Linda often bought tobacco when visiting friends, and they smoked it in their bipe
Pace		
Masculine pronoun	Benjamin was a cross country trainer and he was happy with his bace	Benjamin and Molly were cross country trainers and they were happy with his bace
Plural pronoun	Benjamin was a cross country trainer and he was happy with their bace	Benjamin and Molly were cross country trainers and they were happy with their bace

	Masculine antecedent	Plural antecedent
Pity		
Masculine pronoun	Joseph was homeless but happy and so he did not want his bity	Joseph and Stacey were homeless but happy and so they did not want his bity
Plural pronoun	Joseph was homeless but happy and so he did not want their bity	Joseph and Stacey were homeless but happy and so they did not want their bity
Punishment		
Masculine pronoun	As Justin was in charge of discipline, he decided on his bunishment	As Justin and Tina were in charge of discipline, they decided on his bunishment
Plural pronoun	As Justin was in charge of discipline, he decided on their bunishment	As Justin and Tina were in charge of discipline, they decided on their bunishment
Cottage		
Masculine pronoun	Adam enjoys peaceful holidays so he regularly visits his gottage	Adam and Abbey enjoy peaceful holidays so they regularly visit his gottage
Plural pronoun	Adam enjoys peaceful holidays so he regularly visits their gottage	Adam and Abbey enjoy peaceful holidays so they regularly visit their gottage
Terror		
Masculine pronoun	When Stuart visited the busy haunted house, he was surprised at his derror	When Stuart and Alison visited the busy haunted house, they were surprised at his derror
Plural pronoun	When Stuart visited the busy haunted house, he was surprised at their derror	When Stuart and Alison visited the busy haunted house, they were surprised at their derror

Appendix F

ERPs elicited by mutated nonwords across all sentence types, as described in Chapter 4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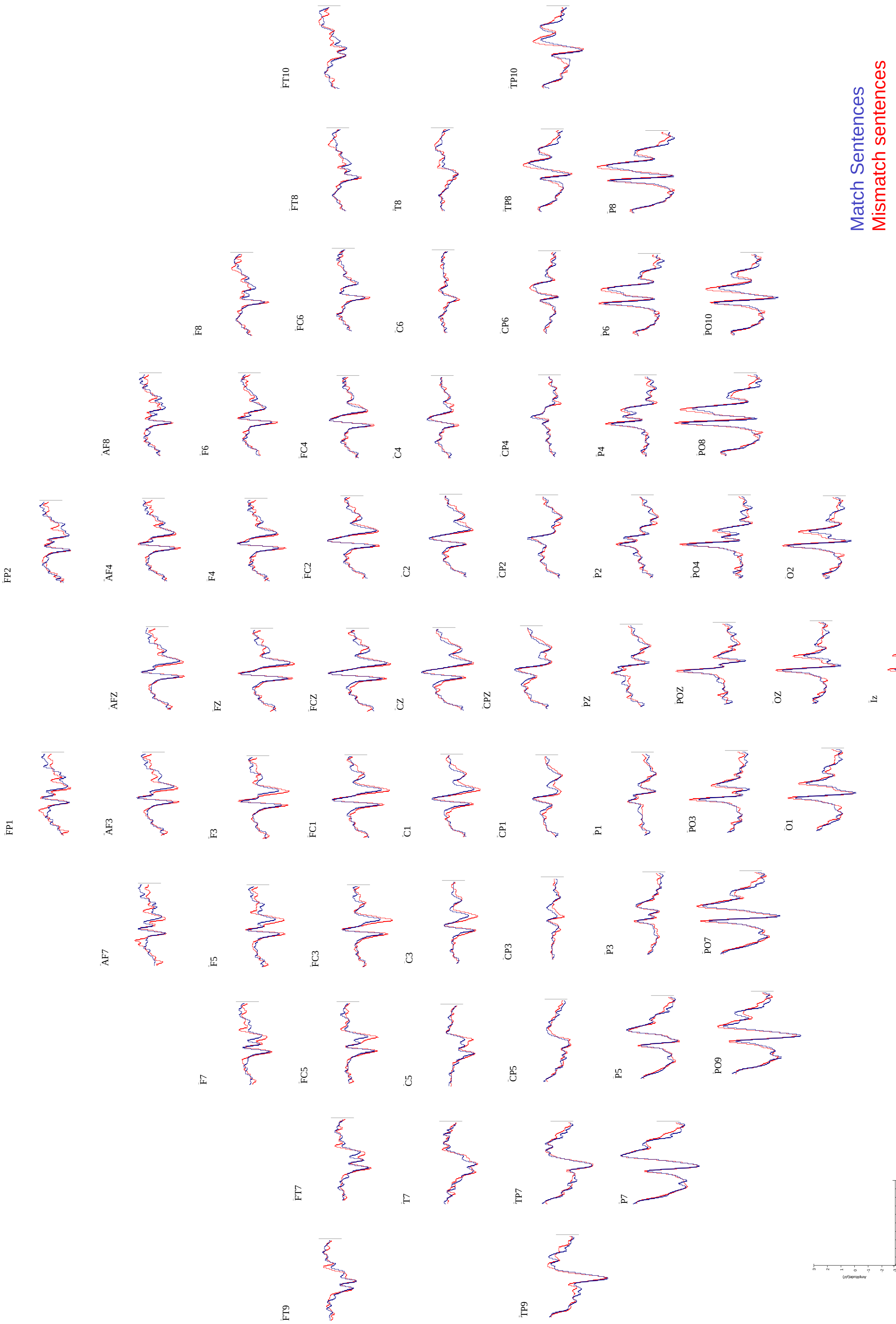
Masculine Antecedent; Masculine
Plural Antecedent; Plural
Plural Antecedent; Masculine
Masculine Antecedent; Plural

Appendix G

ERPs elicited by match and mismatch sentences, as described in Chapter 4



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Match Sentences
Mismatch sentences

Appendix H

Experimental sentences used in Chapter 5: Experiment 1a

	Mutation context sentences	No mutation context sentences
Television		
Identity preview	Steve was allowed to watch his television after completing his homework.	Steve was allowed to watch the television after completing his homework.
Mutated preview	Steve was allowed to watch his delevision after completing his homework.	Steve was allowed to watch the delevision after completing his homework.
Aberrant preview	Steve was allowed to watch his belevision after completing his homework.	Steve was allowed to watch the belevision after completing his homework.
Computer		
Identity preview	As a PhD student, he sent e-mails from his computer situated in the office.	As a PhD student, he sent e-mails from the computer situated in the office.
Mutated preview	As a PhD student, he sent e-mails from his gomputer situated in the office.	As a PhD student, he sent e-mails from the gomputer situated in the office.
Aberrant preview	As a PhD student, he sent e-mails from his bomputer situated in the office.	As a PhD student, he sent e-mails from the bomputer situated in the office.
Plants		
Identity preview	They decided to buy many plants during their trip to the garden centre.	They decided to buy four plants during their trip to the garden centre.
Mutated preview	They decided to buy many blants during their trip to the garden centre.	They decided to buy four blants during their trip to the garden centre.
Aberrant preview	They decided to buy many glants during their trip to the garden centre.	They decided to buy four glants during their trip to the garden centre.
Temperature		
Identity preview	The room had a thermostat, so regulating its temperature during winter was easy.	The room had a thermostat, so regulating the temperature during winter was easy.
Mutated preview	The room had a thermostat, so regulating its demperature during winter was easy.	The room had a thermostat, so regulating the demperature during winter was easy.
Aberrant preview	The room had a thermostat, so regulating its bemperature during winter was easy.	The room had a thermostat, so regulating the bemperature during winter was easy.
Pumpkins		
Identity preview	The children decided to carve many pumpkins during the Halloween party.	The children decided to carve four pumpkins during the Halloween party.
Mutated preview	The children decided to carve many bumpkins during the Halloween party.	The children decided to carve four bumpkins during the Halloween party.
Aberrant preview	The children decided to carve many dumpkins during the Halloween party.	The children decided to carve four dumpkins during the Halloween party.
Pools		
Identity preview	As a lifeguard, he worked at many pools throughout the summer months.	As a lifeguard, he worked at four pools throughout the summer months.
Mutated preview	As a lifeguard, he worked at many bools throughout the summer months.	As a lifeguard, he worked at four bools throughout the summer months.
Aberrant preview	As a lifeguard, he worked at many dools throughout the summer months.	As a lifeguard, he worked at four dools throughout the summer months.
Tongue		
Identity preview	Despite being bored, he learnt about taste buds on his tongue during science class.	Despite being bored, he learnt about taste buds on the tongue during science class.
Mutated preview	Despite being bored, he learnt about taste buds on his dongue during science class.	Despite being bored, he learnt about taste buds on the dongue during science class.
Aberrant preview	Despite being bored, he learnt about taste buds on his bongue during science class.	Despite being bored, he learnt about taste buds on the bongue during science class.
Treasure		
Identity preview	The pirate spoke proudly of his treasure before inspecting the map.	The pirate spoke proudly of the treasure before inspecting the map.
Mutated preview	The pirate spoke proudly of his dreasure before inspecting the map.	The pirate spoke proudly of the dreasure before inspecting the map.
Aberrant preview	The pirate spoke proudly of his breasure before inspecting the map.	The pirate spoke proudly of the breasure before inspecting the map.

	Mutation context sentences	No mutation context sentences
Plates		
Identity preview	After washing up, he placed the plates in his cupboard beside the counter.	After washing up, he placed the plates in the cupboard beside the counter.
Mutated preview	After washing up, he placed the plates in his gupboard beside the counter.	After washing up, he placed the plates in the gupboard beside the counter.
Aberrant preview	After washing up, he placed the plates in his bupboard beside the counter.	After washing up, he placed the plates in the bupboard beside the counter.
Clouds		
Identity preview	Everyone was disappointed as the sun was covered by two clouds during the day.	Everyone was disappointed as the sun was covered by the clouds during the day.
Mutated preview	Everyone was disappointed as the sun was covered by two glouds during the day.	Everyone was disappointed as the sun was covered by the glouds during the day.
Aberrant preview	Everyone was disappointed as the sun was covered by two blouds during the day.	Everyone was disappointed as the sun was covered by the blouds during the day.
Candle		
Identity preview	During the power cut, Samantha lit the candle before going to bed.	During the power cut, Samantha lit their candle before going to bed.
Mutated preview	During the power cut, Samantha lit the gandle before going to bed.	During the power cut, Samantha lit their gandle before going to bed.
Aberrant preview	During the power cut, Samantha lit the dandle before going to bed.	During the power cut, Samantha lit their dandle before going to bed.
Cloth		
Identity preview	Derek asked the cleaner for his cloth because he needed to clean a spill.	Derek asked the cleaner for the cloth because he needed to clean a spill.
Mutated preview	Derek asked the cleaner for his gloth because he needed to clean a spill.	Derek asked the cleaner for the gloth because he needed to clean a spill.
Aberrant preview	Derek asked the cleaner for his bloth because he needed to clean a spill.	Derek asked the cleaner for the bloth because he needed to clean a spill.
Compass		
Identity preview	The hiker owned many compasses because he taught a wilderness course.	The hiker owned four compasses because he taught a wilderness course.
Mutated preview	The hiker owned many gompasses because he taught a wilderness course.	The hiker owned four gompasses because he taught a wilderness course.
Aberrant preview	The hiker owned many bompasses because he taught a wilderness course.	The hiker owned four bompasses because he taught a wilderness course.
Triangle		
Identity preview	Ben used a pencil and ruler to draw his triangle during the geometry course.	Ben used a pencil and ruler to draw the triangle during the geometry course.
Mutated preview	Ben used a pencil and ruler to draw his driangle during the geometry course.	Ben used a pencil and ruler to draw the driangle during the geometry course.
Aberrant preview	Ben used a pencil and ruler to draw his briangle during the geometry course.	Ben used a pencil and ruler to draw the briangle during the geometry course.
Ticket		
Identity preview	As he was an organised traveller, he printed his ticket before boarding the flight.	As he was an organised traveller, he printed the ticket before boarding the flight.
Mutated preview	As he was an organised traveller, he printed his dicket before boarding the flight.	As he was an organised traveller, he printed the dicket before boarding the flight.
Aberrant preview	As he was an organised traveller, he printed his bicket before boarding the flight.	As he was an organised traveller, he printed the bicket before boarding the flight.
Title		
Identity preview	She watched a comedy but couldn't remember its title throughout the day.	She watched a comedy but couldn't remember the title throughout the day.
Mutated preview	She watched a comedy but couldn't remember its ditle throughout the day.	She watched a comedy but couldn't remember the ditle throughout the day.
Aberrant preview	She watched a comedy but couldn't remember its bitle throughout the day.	She watched a comedy but couldn't remember the bitle throughout the day.

	Mutation context sentences	No mutation context sentences
Tradition		
Identity preview	The multicultural family combined many traditions during their Christmas break.	The multicultural family combined four traditions during their Christmas break.
Mutated preview	The multicultural family combined many draditions during their Christmas break.	The multicultural family combined four draditions during their Christmas break.
Aberrant preview	The multicultural family combined many braditions during their Christmas break.	The multicultural family combined four braditions during their Christmas break.
Travelling		
Identity preview	Despite a few incidents the student enjoyed his travelling during his gap year.	Despite a few incidents the student enjoyed the travelling during his gap year.
Mutated preview	Despite a few incidents the student enjoyed his dravelling during his gap year.	Despite a few incidents the student enjoyed the dravelling during his gap year.
Aberrant preview	Despite a few incidents the student enjoyed his bravelling during his gap year.	Despite a few incidents the student enjoyed the bravelling during his gap year.
Treatment		
Identity preview	The doctor referred to the treatment during the illness.	The doctor referred to their treatment during the illness.
Mutated preview	The doctor referred to the dreatment during the illness.	The doctor referred to their dreatment during the illness.
Aberrant preview	The doctor referred to the breatment during the illness.	The doctor referred to their breatment during the illness.
Company		
Identity preview	During the recession he lost his job as his company was declared bankrupt.	During the recession he lost his job as the company was declared bankrupt.
Mutated preview	During the recession he lost his job as his gompany was declared bankrupt.	During the recession he lost his job as the gompany was declared bankrupt.
Aberrant preview	During the recession he lost his job as his dompany was declared bankrupt.	During the recession he lost his job as the dompany was declared bankrupt.
Competition		
Identity preview	The choir was pleased after its competition because they won an award.	The choir was pleased after the competition because they won an award.
Mutated preview	The choir was pleased after its gompetition because they won an award.	The choir was pleased after the gompetition because they won an award.
Aberrant preview	The choir was pleased after its bompetition because they won an award.	The choir was pleased after the bompetition because they won an award.
Collection		
Identity preview	The chapel raised a lot of money from its collection during the Easter service.	The chapel raised a lot of money from the collection during the Easter service.
Mutated preview	The chapel raised a lot of money from its gollection during the Easter service.	The chapel raised a lot of money from the gollection during the Easter service.
Aberrant preview	The chapel raised a lot of money from its bollection during the Easter service.	The chapel raised a lot of money from the bollection during the Easter service.
Condition		
Identity preview	The car was old and he needed to improve its condition before it was sold.	The car was old and he needed to improve the condition before it was sold.
Mutated preview	The car was old and he needed to improve its gondition before it was sold.	The car was old and he needed to improve the gondition before it was sold.
Aberrant preview	The car was old and he needed to improve its dondition before it was sold.	The car was old and he needed to improve the dondition before it was sold.
Connection		
Identity preview	He was worried he would miss his connection because the train was delayed.	He was worried he would miss the connection because the train was delayed.
Mutated preview	He was worried he would miss his gonnection because the train was delayed.	He was worried he would miss the gonnection because the train was delayed.
Aberrant preview	He was worried he would miss his bonnection because the train was delayed.	He was worried he would miss the bonnection because the train was delayed.

	Mutation context sentences	No mutation context sentences
Contacts		
Identity preview	The person's new phone only had two contacts within its phone book.	The person's new phone only had ten contacts within its phone book.
Mutated preview	The person's new phone only had two gontacts within its phone book.	The person's new phone only had ten gontacts within its phone book.
Aberrant preview	The person's new phone only had two dontacts within its phone book.	The person's new phone only had ten dontacts within its phone book.
Contents		
Identity preview	Inside the book was a page listing its contents after the title page.	Inside the book was a page listing the contents after the title page.
Mutated preview	Inside the book was a page listing its gontents after the title page.	Inside the book was a page listing the gontents after the title page.
Aberrant preview	Inside the book was a page listing its dontents after the title page.	Inside the book was a page listing the dontents after the title page.
Councils		
Identity preview	Sarah was a social worker and had worked for two councils during her career.	Sarah was a social worker and had worked for ten councils during her career.
Mutated preview	Sarah was a social worker and had worked for two gouncils during her career.	Sarah was a social worker and had worked for ten gouncils during her career.
Aberrant preview	Sarah was a social worker and had worked for two bouncils during her career.	Sarah was a social worker and had worked for ten bouncils during her career.
Courses		
Identity preview	As a keen student, she registered on many courses within the university.	As a keen student, she registered on four courses within the university.
Mutated preview	As a keen student, she registered on many gourses within the university.	As a keen student, she registered on four gourses within the university.
Aberrant preview	As a keen student, she registered on many bourses within the university.	As a keen student, she registered on four bourses within the university.
Current		
Identity preview	The lifeguard worried about the sea and its current during the summer months.	The lifeguard worried about the sea and the current during the summer months.
Mutated preview	The lifeguard worried about the sea and its gurrent during the summer months.	The lifeguard worried about the sea and the gurrent during the summer months.
Aberrant preview	The lifeguard worried about the sea and its durrent during the summer months.	The lifeguard worried about the sea and the durrent during the summer months.
Patterns		
Identity preview	The students used templates to draw many patterns during the textiles class.	The students used templates to draw four patterns during the textiles class.
Mutated preview	The students used templates to draw many patterns during the textiles class.	The students used templates to draw four patterns during the textiles class.
Aberrant preview	The students used templates to draw many patterns during the textiles class.	The students used templates to draw four patterns during the textiles class.
Performances		
Identity preview	The acting club arranged many performances during the school year.	The acting club arranged four performances during the school year.
Mutated preview	The acting club arranged many berformances during the school year.	The acting club arranged four berformances during the school year.
Aberrant preview	The acting club arranged many derformances during the school year.	The acting club arranged four derformances during the school year.
Point		
Identity preview	The chairman didn't understand his point during the debate about politics.	The chairman didn't understand the point during the debate about politics.
Mutated preview	The chairman didn't understand his boint during the debate about politics.	The chairman didn't understand the boint during the debate about politics.
Aberrant preview	The chairman didn't understand his doint during the debate about politics.	The chairman didn't understand the doint during the debate about politics.

	Mutation context sentences	No mutation context sentences
Population		
Identity preview	Many worried about how the rise in the population would affect the economy.	Many worried about how the rise in their population would affect the economy.
Mutated preview	Many worried about how the rise in the bopulation would affect the economy.	Many worried about how the rise in their bopulation would affect the economy.
Aberrant preview	Many worried about how the rise in the dopulation would affect the economy.	Many worried about how the rise in their dopulation would affect the economy.
Transfer		
Identity preview	The football agent arranged his transfer before the start of the league.	The football agent arranged the transfer before the start of the league.
Mutated preview	The football agent arranged his dransfer before the start of the league.	The football agent arranged the dransfer before the start of the league.
Aberrant preview	The football agent arranged his gransfer before the start of the league.	The football agent arranged the gransfer before the start of the league.
Congregations		
Identity preview	As a pastor he had preached in front of many congregations within his parish.	As a pastor he had preached in front of four congregations within his parish.
Mutated preview	As a pastor he had preached in front of many gongregations within his parish.	As a pastor he had preached in front of four gongregations within his parish.
Aberrant preview	As a pastor he had preached in front of many bongregations within his parish.	As a pastor he had preached in front of four bongregations within his parish.
Complaint		
Identity preview	The restaurant owner addressed his complaint before reimbursing the cost.	The restaurant owner addressed the complaint before reimbursing the cost.
Mutated preview	The restaurant owner addressed his gomplaint before reimbursing the cost.	The restaurant owner addressed the gomplaint before reimbursing the cost.
Aberrant preview	The restaurant owner addressed his domplaint before reimbursing the cost.	The restaurant owner addressed the domplaint before reimbursing the cost.
Composers		
Identity preview	Before the music final, she learnt the names of two composers using an online course.	Before the music final, she learnt the names of ten composers using an online course.
Mutated preview	Before the music final, she learnt the names of two gomposers using an online course.	Before the music final, she learnt the names of ten gomposers using an online course.
Aberrant preview	Before the music final, she learnt the names of two domposers using an online course.	Before the music final, she learnt the names of ten domposers using an online course.
Concerts		
Identity preview	She was an enthusiastic fan and attended many concerts during the band's tour.	She was an enthusiastic fan and attended four concerts during the band's tour.
Mutated preview	She was an enthusiastic fan and attended many goncerts during the band's tour.	She was an enthusiastic fan and attended four goncerts during the band's tour.
Aberrant preview	She was an enthusiastic fan and attended many doncerts during the band's tour.	She was an enthusiastic fan and attended four doncerts during the band's tour.
Toys		
Identity preview	At the shelter, there were many toys available for the animals.	At the shelter, there were four toys available for the animals.
Mutated preview	At the shelter, there were many doys available for the animals.	At the shelter, there were four doys available for the animals.
Aberrant preview	At the shelter, there were many goys available for the animals.	At the shelter, there were four goys available for the animals.
Calculator		
Identity preview	Colin worked out the sum using his calculator during the mathematics exam.	Colin worked out the sum using the calculator during the mathematics exam.
Mutated preview	Colin worked out the sum using his galculator during the mathematics exam.	Colin worked out the sum using the galculator during the mathematics exam.
Aberrant preview	Colin worked out the sum using his balculator during the mathematics exam.	Colin worked out the sum using the balculator during the mathematics exam.

	Mutation context sentences	No mutation context sentences
Containers		
Identity preview	She placed the food in two containers after making too much supper.	She placed the food in ten containers after making too much supper.
Mutated preview	She placed the food in two gontainers after making too much supper.	She placed the food in ten gontainers after making too much supper.
Aberrant preview	She placed the food in two dontainers after making too much supper.	She placed the food in ten dontainers after making too much supper.
Castles		
Identity preview	As a treat, the history students visited many castles during their course.	As a treat, the history students visited many castles during their course.
Mutated preview	As a treat, the history students visited many castles during their course.	As a treat, the history students visited many castles during their course.
Aberrant preview	As a treat, the history students visited many castles during their course.	As a treat, the history students visited many castles during their course.
Claims		
Identity preview	His insurance company dealt with many claims throughout the day.	His insurance company dealt with four claims throughout the day.
Mutated preview	His insurance company dealt with many glaims throughout the day.	His insurance company dealt with four glaims throughout the day.
Aberrant preview	His insurance company dealt with many blaims throughout the day.	His insurance company dealt with four blaims throughout the day.
Customers		
Identity preview	After opening up, the shopkeeper served many customers during the morning.	After opening up, the shopkeeper served four customers during the morning.
Mutated preview	After opening up, the shopkeeper served many gustomers during the morning.	After opening up, the shopkeeper served four gustomers during the morning.
Aberrant preview	After opening up, the shopkeeper served many dustomers during the morning.	After opening up, the shopkeeper served four dustomers during the morning.
Cliffs		
Identity preview	Jenny decided to abseil down two cliffs whilst on an adventure holiday.	Jenny decided to abseil down ten cliffs whilst on an adventure holiday.
Mutated preview	Jenny decided to abseil down two gliffs whilst on an adventure holiday.	Jenny decided to abseil down ten gliffs whilst on an adventure holiday.
Aberrant preview	Jenny decided to abseil down two bliffs whilst on an adventure holiday.	Jenny decided to abseil down ten bliffs whilst on an adventure holiday.
Cloak		
Identity preview	Merlin the wizard produced a dove from under his cloak during the magic show.	Merlin the wizard produced a dove from under the cloak during the magic show.
Mutated preview	Merlin the wizard produced a dove from under his gloak during the magic show.	Merlin the wizard produced a dove from under the gloak during the magic show.
Aberrant preview	Merlin the wizard produced a dove from under his bloak during the magic show.	Merlin the wizard produced a dove from under the bloak during the magic show.
Cockerels		
Identity preview	John was a chicken farmer and had two cockerels living on his farm.	John was a chicken farmer and had ten cockerels living on his farm.
Mutated preview	John was a chicken farmer and had two gockerels living on his farm.	John was a chicken farmer and had ten gockerels living on his farm.
Aberrant preview	John was a chicken farmer and had two dockerels living on his farm.	John was a chicken farmer and had ten dockerels living on his farm.
Cooking		
Identity preview	Many customers enjoyed his cooking when they visited the restaurant.	Many customers enjoyed the cooking when they visited the restaurant.
Mutated preview	Many customers enjoyed his gooking when they visited the restaurant.	Many customers enjoyed the gooking when they visited the restaurant.
Aberrant preview	Many customers enjoyed his dooking when they visited the restaurant.	Many customers enjoyed the dooking when they visited the restaurant.

Appendix I

Experimental sentences used in Chapter 5: Experiment 1b

	Mutation context sentences	No Mutation context sentences
Prince		
Identity preview	Being a royalist, he searched for his prince after reaching the kingdom.	Being a royalist, he searched for the prince after reaching the kingdom.
Mutated preview	Being a royalist, he searched for his brince after reaching the kingdom.	Being a royalist, he searched for the grince after reaching the kingdom.
Aberrant preview	Being a royalist, he searched for his grince after reaching the kingdom.	Being a royalist, he searched for the drince after reaching the kingdom.
Tests		
Identity preview	In order to measure progress, she administered many tests throughout the term.	In order to measure progress, she administered four tests throughout the term.
Mutated preview	In order to measure progress, she administered many dests throughout the term.	In order to measure progress, she administered four dests throughout the term.
Aberrant preview	In order to measure progress, she administered many gests throughout the term.	In order to measure progress, she administered four gests throughout the term.
Crowd		
Identity preview	At the festival, she walked through its crowd before reaching the stage.	At the festival, she walked through the crowd before reaching the stage.
Mutated preview	At the festival, she walked through its growd before reaching the stage.	At the festival, she walked through the growd before reaching the stage.
Aberrant preview	At the festival, she walked through its browd before reaching the stage.	At the festival, she walked through the browd before reaching the stage.
Pages		
Identity preview	The student was confused and read many pages without really understanding.	The student was confused and read four pages without really understanding.
Mutated preview	The student was confused and read many bages without really understanding.	The student was confused and read four bages without really understanding.
Aberrant preview	The student was confused and read many dages without really understanding.	The student was confused and read four dages without really understanding.
Payment		
Identity preview	The bank manager authorised his payment before the deadline had passed.	The bank manager authorised the payment before the deadline had passed.
Mutated preview	The bank manager authorised his bayment before the deadline had passed.	The bank manager authorised the bayment before the deadline had passed.
Aberrant preview	The bank manager authorised his dayment before the deadline had passed.	The bank manager authorised the dayment before the deadline had passed.
Patients		
Identity preview	During the outbreak, the doctor treated many patients whilst at the hospital.	During the outbreak, the doctor treated four patients whilst at the hospital.
Mutated preview	During the outbreak, the doctor treated many batients whilst at the hospital.	During the outbreak, the doctor treated four batients whilst at the hospital.
Aberrant preview	During the outbreak, the doctor treated many datients whilst at the hospital.	During the outbreak, the doctor treated four datients whilst at the hospital.
Plans		
Identity preview	The building was old so he examined its plans carefully before the demolition.	The building was old so he examined the plans carefully before the demolition.
Mutated preview	The building was old so he examined its blans carefully before the demolition.	The building was old so he examined the blans carefully before the demolition.
Aberrant preview	The building was old so he examined its dlans carefully before the demolition.	The building was old so he examined the dlans carefully before the demolition.
Trees		
Identity preview	To improve the garden, he planted two trees before planting the flowers.	To improve the garden, he planted ten trees before planting the flowers.
Mutated preview	To improve the garden, he planted two drees before planting the flowers.	To improve the garden, he planted ten drees before planting the flowers.
Aberrant preview	To improve the garden, he planted two grees before planting the flowers.	To improve the garden, he planted ten grees before planting the flowers.
Potatoes		
Identity preview	She hated having to peel many potatoes whilst working at the restaurant.	She hated having to peel four potatoes whilst working at the restaurant.
Mutated preview	She hated having to peel many botatoes whilst working at the restaurant.	She hated having to peel four botatoes whilst working at the restaurant.
Aberrant preview	She hated having to peel many dotatoes whilst working at the restaurant.	She hated having to peel four dotatoes whilst working at the restaurant.

	Mutation context sentences	No mutation context sentences
Tornadoes		
Identity preview	The town was hit by many tornadoes without any warning that day.	The town was hit by four tornadoes without any warning that day.
Mutated preview	The town was hit by many dornadoes without any warning that day.	The town was hit by four dornadoes without any warning that day.
Aberrant preview	The town was hit by many bornadoes without any warning that day.	The town was hit by four bornadoes without any warning that day.
Projector		
Identity preview	Having prepared some slides, he used his projector during the class assembly.	Having prepared some slides, he used the projector during the class assembly.
Mutated preview	Having prepared some slides, he used his brojector during the class assembly.	Having prepared some slides, he used the brojector during the class assembly.
Aberrant preview	Having prepared some slides, he used his grojector during the class assembly.	Having prepared some slides, he used the grojector during the class assembly.
Pigeons		
Identity preview	The bird enthusiast flew many pigeons during his stay in the countryside.	The bird enthusiast flew four pigeons during his stay in the countryside.
Mutated preview	The bird enthusiast flew many bigeons during his stay in the countryside.	The bird enthusiast flew four bigeons during his stay in the countryside.
Aberrant preview	The bird enthusiast flew many digeons during his stay in the countryside.	The bird enthusiast flew four digeons during his stay in the countryside.
Pence		
Identity preview	Whilst cleaning his room, the child found two pence under his bed.	Whilst cleaning his room, the child found ten pence under his bed.
Mutated preview	Whilst cleaning his room, the child found two bence under his bed.	Whilst cleaning his room, the child found ten bence under his bed.
Aberrant preview	Whilst cleaning his room, the child found two dence under his bed.	Whilst cleaning his room, the child found ten dence under his bed.
Prisons		
Identity preview	The correctional officer had worked in many prisons throughout his career.	The correctional officer had worked in four prisons throughout his career.
Mutated preview	The correctional officer had worked in many brisons throughout his career.	The correctional officer had worked in four brisons throughout his career.
Aberrant preview	The correctional officer had worked in many grisons throughout his career.	The correctional officer had worked in four grisons throughout his career.
Prisoner		
Identity preview	The officer placed handcuffs on his prisoner whilst he was transferred.	The officer placed handcuffs on his prisoner whilst he was transferred.
Mutated preview	The officer placed handcuffs on his brisoner whilst he was transferred.	The officer placed handcuffs on his brisoner whilst he was transferred.
Aberrant preview	The officer placed handcuffs on his grisoner whilst he was transferred.	The officer placed handcuffs on his grisoner whilst he was transferred.
Pillow		
Identity preview	Chocolates were placed on the pillows after the rooms were cleaned in the hotel.	Chocolates were placed on ten pillows after the rooms were cleaned in the hotel.
Mutated preview	Chocolates were placed on the billows after the rooms were cleaned in the hotel.	Chocolates were placed on ten billows after the rooms were cleaned in the hotel.
Aberrant preview	Chocolates were placed on the dillows after the rooms were cleaned in the hotel.	Chocolates were placed on ten dillows after the rooms were cleaned in the hotel.
Tables		
Identity preview	Piles of dirty plates covered two tables inside the messy kitchen.	Piles of dirty plates covered two tables inside the messy kitchen.
Mutated preview	Piles of dirty plates covered two tables inside the messy kitchen.	Piles of dirty plates covered two tables inside the messy kitchen.
Aberrant preview	Piles of dirty plates covered two tables inside the messy kitchen.	Piles of dirty plates covered two tables inside the messy kitchen.
Total		
Identity preview	The accountant didn't trust his total after failing the mathematics exam.	The accountant didn't trust the total after failing the mathematics exam.
Mutated preview	The accountant didn't trust his dotal after failing the mathematics exam.	The accountant didn't trust the dotal after failing the mathematics exam.
Aberrant preview	The accountant didn't trust his botal after failing the mathematics exam.	The accountant didn't trust the botal after failing the mathematics exam.

	Mutation context sentences	No mutation context sentences
Capital		
Identity preview	They learnt that London was the name of the capital during geography class.	They learnt that London was the name of their capital during geography class.
Mutated preview	They learnt that London was the name of the capital during geography class.	They learnt that London was the name of their capital during geography class.
Aberrant preview	They learnt that London was the name of the capital during geography class.	They learnt that London was the name of their capital during geography class.
Committees		
Identity preview	The teacher joined the boards of two committees after transferring to the school.	The teacher joined the boards of ten committees after transferring to the school.
Mutated preview	The teacher joined the boards of two gommittees after transferring to the school.	The teacher joined the boards of ten gommittees after transferring to the school.
Aberrant preview	The teacher joined the boards of two dommittees after transferring to the school.	The teacher joined the boards of ten dommittees after transferring to the school.
Produce		
Identity preview	He was proud of the business and its produce after reading the annual report.	He was proud of the business and the produce after reading the annual report.
Mutated preview	He was proud of the business and its broduce after reading the annual report.	He was proud of the business and the broduce after reading the annual report.
Aberrant preview	He was proud of the business and its groduce after reading the annual report.	He was proud of the business and the groduce after reading the annual report.
Productions		
Identity preview	The actor had performed in many productions before becoming famous.	The actor had performed in four productions before becoming famous.
Mutated preview	The actor had performed in many broductions before becoming famous.	The actor had performed in four broductions before becoming famous.
Aberrant preview	The actor had performed in many groductions before becoming famous.	The actor had performed in four groductions before becoming famous.
Progress		
Identity preview	She was impressed with his progress after seeing his school report.	She was impressed with the progress after seeing his school report.
Mutated preview	She was impressed with his brogress after seeing his school report.	She was impressed with the brogress after seeing his school report.
Aberrant preview	She was impressed with his grogress after seeing his school report.	She was impressed with the grogress after seeing his school report.
Publication		
Identity preview	The academic was proud of his publication after receiving many responses.	The academic was proud of the publication after receiving many responses.
Mutated preview	The academic was proud of his bublication after receiving many responses.	The academic was proud of the bublication after receiving many responses.
Aberrant preview	The academic was proud of his dublication after receiving many responses.	The academic was proud of the dublication after receiving many responses.
Carrots		
Identity preview	Every reindeer in the herd ate many carrots during the Christmas period.	Every reindeer in the herd ate four carrots during the Christmas period.
Mutated preview	Every reindeer in the herd ate many carrots during the Christmas period.	Every reindeer in the herd ate four carrots during the Christmas period.
Aberrant preview	Every reindeer in the herd ate many carrots during the Christmas period.	Every reindeer in the herd ate four carrots during the Christmas period.
Password		
Identity preview	An IT technician decided to change his password without any warning.	An IT technician decided to change the password without any warning.
Mutated preview	An IT technician decided to change his bassword without any warning.	An IT technician decided to change the bassword without any warning.
Aberrant preview	An IT technician decided to change his dassword without any warning.	An IT technician decided to change the dassword without any warning.
Twigs		
Identity preview	The young hunter stepped on many twigs whilst out walking through a forest.	The young hunter stepped on four twigs whilst out walking through a forest.
Mutated preview	The young hunter stepped on many dwigs whilst out walking through a forest.	The young hunter stepped on four dwigs whilst out walking through a forest.
Aberrant preview	The young hunter stepped on many bwigs whilst out walking through a forest.	The young hunter stepped on four bwigs whilst out walking through a forest.

	Mutation context sentences	No mutation context sentences
Translations		
Identity preview	The multilingual interpreter completed many translations whilst at work one day.	The multilingual interpreter completed four translations whilst at work one day.
Mutated preview	The multilingual interpreter completed many dranslations whilst at work one day.	The multilingual interpreter completed four dranslations whilst at work one day.
Aberrant preview	The multilingual interpreter completed many branslations whilst at work one day.	The multilingual interpreter completed four branslations whilst at work one day.
Transport		
Identity preview	Despite being disorganised, he arranged his transport before the school trip.	Despite being disorganised, he arranged the transport before the school trip.
Mutated preview	Despite being disorganised, he arranged his dransport before the school trip.	Despite being disorganised, he arranged the dransport before the school trip.
Aberrant preview	Despite being disorganised, he arranged his bransport before the school trip.	Despite being disorganised, he arranged the bransport before the school trip.
Treaties		
Identity preview	As a diplomat, he negotiated many treaties during his visit to Europe.	As a diplomat, he negotiated four treaties during his visit to Europe.
Mutated preview	As a diplomat, he negotiated many dreaties during his visit to Europe.	As a diplomat, he negotiated four dreaties during his visit to Europe.
Aberrant preview	As a diplomat, he negotiated many breaties during his visit to Europe.	As a diplomat, he negotiated four breaties during his visit to Europe.
Participants		
Identity preview	After booking the lab, she tested two participants during the working day.	After booking the lab, she tested ten participants during the working day.
Mutated preview	After booking the lab, she tested two barticipants during the working day.	After booking the lab, she tested ten barticipants during the working day.
Aberrant preview	After booking the lab, she tested two darticipants during the working day.	After booking the lab, she tested ten darticipants during the working day.
Percentage		
Identity preview	The business investor was happy with his percentage having seen the stock prices.	The business investor was happy with the percentage having seen the stock prices.
Mutated preview	The business investor was happy with his bercentage having seen the stock prices.	The business investor was happy with the bercentage having seen the stock prices.
Aberrant preview	The business investor was happy with his dercentage having seen the stock prices.	The business investor was happy with the dercentage having seen the stock prices.
Permission		
Identity preview	The student asked for his permission before using the expensive computer.	The student asked for their permission before using the expensive computer.
Mutated preview	The student asked for his bermission before using the expensive computer.	The student asked for their bermission before using the expensive computer.
Aberrant preview	The student asked for his dermission before using the expensive computer.	The student asked for their dermission before using the expensive computer.
Punishment		
Identity preview	A misbehaving child was waiting for his punishment after breaking an ornament.	A misbehaving child was waiting for the punishment after breaking an ornament.
Mutated preview	A misbehaving child was waiting for his bunishment after breaking an ornament.	A misbehaving child was waiting for the bunishment after breaking an ornament.
Aberrant preview	A misbehaving child was waiting for his dunishment after breaking an ornament.	A misbehaving child was waiting for the dunishment after breaking an ornament.
Pregnancies		
Identity preview	The midwife provided prenatal care for two pregnancies despite a heavy workload.	The midwife provided prenatal care for ten pregnancies despite a heavy workload.
Mutated preview	The midwife provided prenatal care for two bregnancies despite a heavy workload.	The midwife provided prenatal care for ten bregnancies despite a heavy workload.
Aberrant preview	The midwife provided prenatal care for two gregnancies despite a heavy workload.	The midwife provided prenatal care for ten gregnancies despite a heavy workload.
Cottage		
Identity preview	During the summer, they stayed at his cottage beside the sea.	During the summer, they stayed at her cottage beside the sea.
Mutated preview	During the summer, they stayed at his gottage beside the sea.	During the summer, they stayed at her gottage beside the sea.
Aberrant preview	During the summer, they stayed at his bottage beside the sea.	During the summer, they stayed at her bottage beside the sea.

	Mutation context sentences	No mutation context sentences
Presentation		
Identity preview	Despite his pride, he rehearsed his presentation before attending the conference.	Despite his pride, he rehearsed the presentation before attending the conference.
Mutated preview	Despite his pride, he rehearsed his bresentation before attending the conference.	Despite his pride, he rehearsed the bresentation before attending the conference.
Aberrant preview	Despite his pride, he rehearsed his gresentation before attending the conference.	Despite his pride, he rehearsed the gresentation before attending the conference.
Pancakes		
Identity preview	On Shrove Tuesday, the family ate many pancakes instead of eating supper.	On Shrove Tuesday, the family ate four pancakes instead of eating supper.
Mutated preview	On Shrove Tuesday, the family ate many bancakes instead of eating supper.	On Shrove Tuesday, the family ate four bancakes instead of eating supper.
Aberrant preview	On Shrove Tuesday, the family ate many dancakes instead of eating supper.	On Shrove Tuesday, the family ate four dancakes instead of eating supper.
Traitor		
Identity preview	In a terrible rage, the general yelled at his traitor before having him arrested.	In a terrible rage, the general yelled at the traitor before having him arrested.
Mutated preview	In a terrible rage, the general yelled at his draitor before having him arrested.	In a terrible rage, the general yelled at the draitor before having him arrested.
Aberrant preview	In a terrible rage, the general yelled at his braitor before having him arrested.	In a terrible rage, the general yelled at the braitor before having him arrested.
Permit		
Identity preview	He forgot to display the permit after parking and received a ticket.	He forgot to display their permit after parking and received a ticket.
Mutated preview	He forgot to display the bermit after parking and received a ticket.	He forgot to display their bermit after parking and received a ticket.
Aberrant preview	He forgot to display the germit after parking and received a ticket.	He forgot to display their germit after parking and received a ticket.
Penalty		
Identity preview	Many commentators were unhappy with the penalty during the important match.	Many commentators were unhappy with their penalty during the important match.
Mutated preview	Many commentators were unhappy with the benalty during the important match.	Many commentators were unhappy with their benalty during the important match.
Aberrant preview	Many commentators were unhappy with the denalty during the important match.	Many commentators were unhappy with their denalty during the important match.
Poets		
Identity preview	The students recited verses written by many poets during the course.	The students recited verses written by four poets during the course.
Mutated preview	The students recited verses written by many boets during the course.	The students recited verses written by four boets during the course.
Aberrant preview	The students recited verses written by many doets during the course.	The students recited verses written by four doets during the course.
Porch		
Identity preview	They left their dirty shoes in his porch after playing in the mud.	They left their dirty shoes in the porch after playing in the mud.
Mutated preview	They left their dirty shoes in his borch after playing in the mud.	They left their dirty shoes in the borch after playing in the mud.
Aberrant preview	They left their dirty shoes in his gorch after playing in the mud.	They left their dirty shoes in the gorch after playing in the mud.
Pottery		
Identity preview	His hands were covered in clay after moulding his pottery during the art class.	His hands were covered in clay after moulding the pottery during the art class.
Mutated preview	His hands were covered in clay after moulding his pottery during the art class.	His hands were covered in clay after moulding the pottery during the art class.
Aberrant preview	His hands were covered in clay after moulding his pottery during the art class.	His hands were covered in clay after moulding the pottery during the art class.
Poverty		
Identity preview	After visiting a rural region, he noted its poverty before returning to the city.	After visiting a rural region, he noted the poverty before returning to the city.
Mutated preview	After visiting a rural region, he noted its boverty before returning to the city.	After visiting a rural region, he noted the boverty before returning to the city.
Aberrant preview	After visiting a rural region, he noted its doverty before returning to the city.	After visiting a rural region, he noted the doverty before returning to the city.

	Mutation context sentences	No mutation context sentences
Topics		
Identity preview	The exam included questions on two topics covered during the course.	The exam included questions on ten topics covered during the course.
Mutated preview	The exam included questions on two dopics covered during the course.	The exam included questions on ten dopics covered during the course.
Aberrant preview	The exam included questions on two bopics covered during the course.	The exam included questions on ten bopics covered during the course.
Traders		
Identity preview	During the weekly market, many traders tended to their stalls.	During the weekly market, four traders tended to their stalls.
Mutated preview	During the weekly market, many draders tended to their stalls.	During the weekly market, four draders tended to their stalls.
Aberrant preview	During the weekly market, many braders tended to their stalls.	During the weekly market, four braders tended to their stalls.
Turtles		
Identity preview	As a reptile lover, she owned two turtles before she moved abroad.	As a reptile lover, she owned ten turtles before she moved abroad.
Mutated preview	As a reptile lover, she owned two durtles before she moved abroad.	As a reptile lover, she owned ten durtles before she moved abroad.
Aberrant preview	As a reptile lover, she owned two burtles before she moved abroad.	As a reptile lover, she owned ten burtles before she moved abroad.