Syntactic priming in German-English bilinguals during sentence comprehension: RT and fMRI studies

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During reading we have to process the syntactic structure of the sentences in front of us. Thus, if we process sentences in two different languages, for example German and English, do we access and use the same syntactic information for both languages if the structures are similar? In this study we show that on the neural level sentences in the first and in the second language (L1 and L2) are processed in the same neural areas in left inferior frontal and left temporal regions indicating a shared sentence processing system. Moreover, we use a syntactic priming paradigm in comprehension to establish interaction between the L1 and L2. We find behavioural evidence of syntactic priming in comprehension within the L2 as well as a possible word-order effect from L2 into L1. At the neural level we are not able to demonstrate syntactic priming. Possible implications of this negative finding are discussed.

Keywords: Syntactic priming, Bilingualism, Sentence Comprehension, fMRI adaptation

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1. Introduction

In order to communicate in two languages we have to acquire or learn the grammar of the first language (L1) as well as the grammar of the second language (L2). At present, little is known about how these two syntactic systems are organised in bilinguals, although there are different hypotheses about it. Syntactic processing in the L2 could either be fully independent of the L1 syntactic system, or alternatively the L2 could be built up on the existing L1 system, either completely or in an intermediate way. In the intermediate case, only some parts of the L1 syntactic processor are shared, depending on, for example, the syntactic overlap between the two languages.

In the brain, syntactic processing in the L1 activates parts of the general language processing system that is mainly located in the frontal and temporal areas of the left hemisphere, and more specifically in middle and superior temporal lobes as well as inferior frontal regions around Broca's area (Indefrey, 2004, to appear; Kaan & Swaab, 2002).

To date, there is little clear evidence for some form of a shared syntactic system between L1 and L2. Several neuroimaging studies of L2 sentence comprehension give some indication that L2 sentence and syntactic processing at least roughly activate the same brain areas as L1 processing (Chee et al., 1999; Indefrey, 2006).

However, the studies reviewed in these articles use an L1-L2 subtraction logic, where it is investigated whether any areas are significantly more active for L2 compared to L1 processing and vice versa. Due to inherent limitations of this approach, only roughly similar areas of activity can be shown. It is still possible that at a lower level the activity is separated into different sub-areas that show different activity patterns for L1 and L2. Subtractive logic would not be able to reveal neural activity that is shared or common between the L1 and L2.

It is therefore important to develop new methods and paradigms to investigate whether L1 and L2 syntactic processing interact. In our experiment we will be using syntactic priming to directly investigate the degree to which syntactic processes are shared between the L1 and L2.

1.1 Priming

Generally in the field of cognition, priming is seen either as a facilitating effect that occurs after repetition of two related stimuli or as the likelihood to reuse a certain pattern which was just encountered. Priming can be found behaviourally in the form of faster reaction times or as an increased likelihood to give a certain response and it is found in all kinds of modalities and areas of cognition. Specifically in language, priming effects have been shown at semantic, phonological and syntactic processing levels (Klein et al., 2006; Noppeney & Price, 2004; Rastle & Brysbaert, 2006). In terms of brain imaging studies a number of functional magnetic resonance imaging (fMRI) studies have found decreases in brain activation as a result of priming (Henson & Rugg, 2003; Schacter & Buckner, 1998). It is generally assumed that these neural and behavioural effects are closely related. (Henson & Rugg, 2003, however see (Ganel et al., 2006) for a different opinion).

1.2 Behavioural Syntactic Priming

Behaviourally, syntactic priming is a well studied psycholinguistic paradigm both in monolingual production (Bock, 1986; Branigan, Pickering, Liversedge, Stewart, & Urbach, 1995) and comprehension (Branigan, Pickering, & McLean, 2005; Frazier, Taft, Roeper, Clifton, & Ehrlich, 1984; Luka & Barsalou, 2005) as well as in bilingual production (Hartsuiker, Pickering, & Veltkamp, 2004; Loebell & Bock, 2003; Meijer & Fox Tree, 2003; Schoonbaert, Hartsuiker, & Pickering, 2007). Most of the monolingual studies quoted above were conducted in English. However, there is some research on other, mainly Germanic languages; production priming effects were shown in Dutch (Hartsuiker & Kolk, 1998) and German (Scheepers, 2003).

Syntactic priming paradigms typically consist of prime and target sentences. Priming occurs when prime and target have the same grammatical structure in comparison to a target sentence that is preceded by a sentence of a different structure. The majority of syntactic priming studies (e.g. Bock, 1986, Pickering & Branigan, 1998) focus on two types of grammatical alternations. One of them being the dative alternation, which consists of the double-object dative structure (e.g.*"The boy baked the girl a cake.";* Agent-Verb-Goal-Patient) and the prepositional dative structure (e.g.*"The boy baked a cake for the girl.";* Agent-Verb-Patient-Prep-Goal). The other being the passive alternation, which comprises the active (e.g. *"The woman opened the door.";* Agent-Verb-Patient) and the passive structure (e.g. *"The door was opened by the woman.";* Patient-Aux-Past participle-by-Agent). The advantage of these alternations is that the semantics of the sentences broadly stays the same, while the grammatical structure changes.

The most important finding in these production studies is that the syntactic priming effects are of a structural nature and can be independent of the lexical or semantic content of the sentences (Bock, 1986; Bock & Griffin, 2000; Pickering & Branigan, 1999), as the effects were found even if there was no overlap of lexical and semantic content between prime and target. The claim that the syntactic priming effect is structural in nature is supported by the finding that even locative constructions like "*The construction worker was digging by the bulldozer*", where the by-phrase describes the location of an action, can prime a passive sentence like "*The 747 was alerted by the airport's control tower.*", where the by-phrase describes the agent (Bock & Loebell, 1990) of an action. On a semantic level these sentences are different, while the sentence structure is similar and can thus be primed. While there is a purely structural syntactic priming effect independent of lexical content, a boosting effect is found in the case of verb repetition (Pickering & Branigan, 1998) indicating some lexical influence.

1.3 Syntactic priming in comprehension

While most of the syntactic priming studies investigated production, a number of comprehension priming studies have come out recently. Branigan et al. (2005) used a picture matching paradigm and found priming effects for relative clause-attachment ambiguities. The participants were more likely to opt for a picture depicting a scene with a high-attachment interpretation after a prime with a high-attachment interpretation (e.g. when presented with the ambiguous sentence "*The waitress prodding the clown with the umbrella",* subjects were more likely to choose the picture depicting the scenario where the waitress uses an umbrella to prod the clown instead of a scene with the other interpretation where the clown has the umbrella in his hand after seeing the prime *"The policeman prodding the doctor with the gun"*, where the policeman has the gun and prods the doctor). These priming effects were restricted to the verb repetition condition. Moreover, in an eye-tracking study (Arai, van Gompel, & Scheepers, 2007), syntactic priming effects in a visual world paradigm were only found in case of verb repetition. In this paradigm, subjects see a visual scene depicting objects, including those that are part of the sentence that they hear. Eye-movements are recorded while the subjects listen to the sentence revealing which words they are expecting to come up. The important role of verb repetition is supported by a recent ERP study on syntactic priming in comprehension (Ledoux, Traxler, & Swaab, 2007). The necessity of verb repetition is further emphasized by another recent ERP study (Tooley, Traxler, & Swaab, under review) that shows that even if the verbs in prime and target sentences are synonyms and thus closely related in meaning, the priming effect only occurs in case of true verb repetition.

In a very early study Frazier et al. (1984) looked for structural facilitation which can be seen as being identical to syntactic priming. Besides other types of structures susceptible to priming they found that also the passive structure could be primed. This effect could be linked to the verb as well, as most of the prime and target sentences contained the same verb. More recently, Noppeney and Price (2004), found mean faster reading times for primed target sentences using four types of structures (late and early closure clause boundary ambiguity sentences as well as simple active and reduced relative clause sentences). They did not repeat any semantic content, including no verb repetition between prime and target. However, one factor that might have made the priming effect appear despite the absence of verb repetition is that priming effects were calculated over blocks of 5 sentences of a similar structure compared to blocks with sentences of a dissimilar structure, thus potentially boosting any otherwise weak effects.

Summarising these studies, it seems that in comprehension verb repetition is a very important factor in inducing any syntactic priming effect which raises the question in how far these effects are still structurally independent or whether they are lexically driven.

1.4 Cross-linguistic syntactic priming

To answer the question of whether L1 and L2 syntax interact, the most interesting case is cross-linguistic syntactic priming where the prime and target are in different languages. In several recent behavioural language production studies, cross-linguistic priming effects were found. Loebell and Bock (2003) showed that German-English bilinguals are more likely to produce an English double-object dative sentence (e.g. "*The little boy wrote his pen pal a letter.*") to describe a picture after having produced a sentence of the same structure in German (e.g. "Der *reiche Bauer kaufte seinem Sohn ein Pferd.*") as compared to the alternate prepositional dative construction ("*Der reiche Bauer kaufte ein Pferd für seinen Sohn.* "). These priming effects appeared in both directions from German to English and from English to

German as well as within German. In this study priming of passive sentences with passive sentences as compared to active sentences failed to produce a reliable effect.

However, another study (Hartsuiker et al., 2004) with Spanish-English bilinguals showed a priming effect for passive sentences. One possibility is that the different word-order between the German and English passive structure failed to elicit the effect in the Loebell and Bock (2003) study, a claim that is supported by a recent study (Bernolet & Hartsuiker, accepted) on word-order effects in syntactic priming, showing that the superficial word-order matters. In this study the priming of simple relative clauses between languages was investigated. In the case of Dutch and German which have the same word order in relative clauses, priming did occur, while no priming effect was found between Dutch and English, where the word order differs. However, in a study of relative clause attachments (Desmet & Declercq, 2006), priming effects were found despite of differences in word order. Thus, it remains unclear to what degree the superficial word order is a crucial factor in syntactic priming and whether the effects differ depending on the syntactic structures investigated.

Another study on cross-linguistic priming in this case of the two structures in the dative alternation in Dutch-English bilinguals (Schoonbaert et al., 2007) found syntactic priming effects in all language combinations, in both within-language (L1->L1, L2->L2) as well as in the two cross-linguistic combinations (L1->L2, L2->L1). The introduction of a verb repetition condition (within language) or translation equivalent repetition condition (between languages) resulted in verb boost effects in both within language combinations and a slightly weaker boost from L1 to L2. Although the general syntactic priming effect was found from L2 to L1 the translation equivalent condition did not boost the effect.

1.5 Syntactic Priming at the neural level

Only a few studies investigated syntactic priming at the neural level and found priming effects in monolingual English sentence comprehension (Dehaene-Lambertz et al., 2006; Noppeney & Penny, 2006; Noppeney & Price, 2004). In the first study (Dehaene-Lambertz et al, 2006) the priming effect was located in the superior temporal gyrus as well as in the left middle temporal gyrus. Noppeney and Penny (2006) found decreased activations after priming in a bilateral frontotemporal network that included the left middle temporal gyrus. The study by Noppeney and Price (2004) that investigated the most genuine structural priming effect (as primes and targets were not identical and a priming effect due to lexical content can thus be excluded) found a priming effect in the left temporal pole.

1.6 Current study

While it has been shown that cross-linguistic syntactic priming effects exist in production (Hartsuiker et al., 2004; Loebell & Bock, 2003; Schoonbaert et al., 2007), it is still unclear whether these effects can be shown in comprehension. We will investigate this and the interaction between L1 and L2 processing in a behavioural and an fMRI study.

The current study looks into syntactic priming of the passive sentences testing German-English bilinguals in a visual sentence comprehension paradigm. The behavioural measure is reading time, a measurement that has previously found reliable priming effects in English for passives (Frazier et al., 1984).

The reading time measure has the added advantage that we can compare the verb repetition condition to the no repetition condition while avoiding any further verb repetitions. Previous studies had to rely on a small set of verbs as they needed the verbs to be imageable and thus had to repeat the verbs more often, thus potentially confounding the immediate verb repetition condition between prime and target. (Branigan et al., 2005; Schoonbaert et al., 2007).

1.7 Hypotheses

Late acquisition L2 learners have already acquired the grammar of their native language so we predict that they can and do use this existing knowledge when they start learning a new grammar. (1) Thus, we want to replicate priming effects within the native language and establish these within the L2 as well. (2) Moreover, we predict that we will find cross-linguistic priming effects in comprehension as well, both at the (a) behavioural as well as (b) neural level. (3) Furthermore, we predict that in the brain these syntactic priming effects are located in areas connected to syntactic processing in left frontal and temporal areas and that these will be the same for cross-linguistic and within-language priming. (4) In addition, we expect that any syntactic priming effects will only show up if the verb is repeated between prime and target.

2 .Behavioural Experiment

2.1 Methods

2.1.1 Participants

In the behavioural experiment we tested 14 German-English bilinguals (13 female) of medium English proficiency with German as their native language. They all had a similar language background (see Table 2) and had acquired English at school as their first foreign language at on average 10.85 years (*SD* =0.53) and had formal English lessons for on average 7.85 years (*SD* =1.51). Thus, they were all late acquisition bilinguals. Their proficiency was tested with the Oxford Placement test (mean number of mistakes=9.92, *SD* =4.87).

The participants received course credits (proefpersonenuren) or money for their participation in the experiments.

2.1.2 Stimuli/Design

Half of the sentences were in English, the other half were their translation equivalents in German. A trial was defined as a combination of two sentences, a prime or no-prime and a target. Target sentences were always of a passive structure as this is the less preferred structure and syntactic priming effects are more reliably detected for these (Bock, 1986; Bock & Griffin, 2000; Chang, Dell, & Bock, 2006). Prime sentences were passive sentences as well, while sentences from the no-prime condition had an active sentence structure (see Table 1 for stimulus examples).

The stimuli were created in such a way, that instances of all the experimental conditions occurred equally often. The experimental design included the following factors, the language combinations (German-German, English-English, German-English, English-German), the structural combinations (active-passive, passive-passive) and additionally the verb factor (verb repetition between prime and target, or no repetition). For the same-language conditions the verb was exactly the same, while between languages they were translation equivalents, while cognates were avoided. In sum, we created a 4x2x2 design (language-combination x structural-combination x verb).

The stimuli consisted of active sentences of 5 words and passive sentences of 7 words. No verb was repeated except in the verb repetition condition.

In addition, we used 288 filler sentences. The noun phrases of these sentences matched the number of noun phrases of the experimental sentences; the structure of these fillers was different to those of the experimental sentences. In half of the cases the verb was repeated between filler sentences as in the experimental sentences.

14 stimulus lists were created with 288 experimental sentences and the 288 filler sentences in each. Across the stimulus lists, each structural trial combination occurred equally often, the verb was

Table 4. fMRI Subject Information

Subject	Age	Gender	Oxford Placement Score (mistakes out of 50*)	Age of Acquisition English	Years of formal English lessons
1	23	Female	12	11	7
2	23	Female	4	11	8
3	22	Female	7	10	8
4	22	Female	12	11	8
5	21	Female	7	11	8
6	22	Female	14	11	3
7	20	Female	14	11	9
8	23	Female	9	10	8
9	19	Female	7	11	8
10	27	Female	8	11	9
11	23	Female	8	10	9
12	21	Female	3	12	9
13	22	Male	22	11	8
14	21	Female	12	11	8
Average			**9.93**	**10.86**	**7.86**
SD			**4.87**	**0.53**	**1.51**

*0-9 mistakes: advanced, 10-19 mistakes: good, 20-29 mistakes: satisfactory

Table 1. Examples of experimental trials for the same target sentence

Condition	Prime/Noprime	Target
1. German-German verb shared	Der Baum wurde von dem Künstler gemalt.	Der Mond wurde von den Mädchen gemalt.
	Der Künstler malte den Baum.	
2. German-German verb not shared	Die Böden wurden von dem Hausmeister gereinigt.	Der Mond wurde von den Mädchen gemalt.
	Der Hausmeister reinigte die Böden.	
3. English-English verb shared	The tree was painted by the artist.	The moon was painted by the girls.
	The artist painted the tree.	
4. English-English verb not shared	The floors were cleaned by the janitor.	The moon was painted by the girls.
	The janitor cleaned the floors.	
5. German-English verb shared	Der Baum wurde von dem Künstler gemalt.	The moon was painted by the girls.
	Der Künstler malte den Baum.	
6. German-English verb not shared	Die Böden wurden von dem Hausmeister gereinigt.	The moon was painted by the girls.
	Der Hausmeister reinigte die Böden.	
7. English-German verb shared	The tree was painted by the artist.	Der Mond wurde von den Mädchen gemalt.
	The artist painted the tree.	
8. English-German verb not shared	The floors were cleaned by the janitor.	Der Mond wurde von den Mädchen gemalt.
	The janitor cleaned the floors.	

Note: Conditions in blue were used in the fMRI experiment.

repeated in half of the cases and each target sentence was preceded by both types of structures. Including the filler sentences each language combination occurred equally often, too.

2.1.3 Procedure

The experiments were run using Presentation software (Neurobehavioral Systems, www.neurobs.com). Participants sat in front of a personal computer. Sentences were presented word by word in a self-paced reading paradigm, in white "Arial" font of size 22 on a black background. After reading each word, subjects had to press a button thus providing a measure of reading time. Between sentences a fixation cross was displayed for 1000 ms.

Each participant saw only one of the stimulus lists. Experimental sentences were presented in triplets. The middle sentence of the triplet served as target to the first sentence and as prime to the third. This was done to reduce the number of sentences that were used in the experiment. Experimental triplets were always followed by three filler sentences. The order of the experimental triplets was randomised.

Every experiment was followed immediately by a post task in form of a recognition memory task in which the participants had to make an old-new judgement on a randomised list of 72 sentences (36 old, 36 new). The new sentences had a comparable number of noun phrases to the number of noun phrases in the experimental sentences and half of them corresponded to the experimental sentences in structure.

2.1.4 Data Analysis

To test the hypothesis that reading times are faster for primed versus un-primed sentences we analysed the mean sentence reading times as well as effects on individual words. Outliers (reading times lower than: *mean-2*SD* or *90ms*; and higher than: *mean+2* SD*), were calculated separately for each subject and language over all experimental and filler sentences and were removed.

Any effects of word length were removed by a linear regression for each subject and language individually. This was done by computing a linear regression with string length of each word as the independent variable and reading time as the dependent variable. The regression was computed over all materials (for a more detailed description of the procedure see (Ferreira & Clifton, 1986; Trueswell, Tanenhaus, & Garnsey, 1994)). The expected reading times depending on word length were then subtracted from the original reading times leading to residual reading times. These residual

Table 3. Average Residual Reading Times per language combination

	German-German	English-English	German-English	English-German
Primed	-22.06	-29.85	-18.40	-17.22
Unprimed	-18.92	-20.87	-26.08	-28.66
Average	**-20.49**	**-25.36**	**-22.24**	**-22.94**
Difference	**-3.14**	**-8.98**	**7.68**	**11.45**

reading times are either positive or negative depending on whether the word was read slower or faster than the expected word reading time for a word of that length. The residual reading times reported here are mostly negative, which is probably due to two factors. Firstly, we report results from the third word onwards and generally subjects were speeding up towards the middle of a sentence. Secondly, initially, in the very first part of the experiment, subjects tended to be much slower, once they got the idea of the experiment they speeded up, thus skewing the reading times.

The analysis was performed on the resulting residual reading times. Huynh-Feldt-corrected p-values are reported.

2.2 Behavioural Results

We first report the results of average sentence reading times from the third word onwards were the structure becomes noticeable.

2.2.1 Average sentence reading times

The 4x2x2 (language combinations x verb x priming) ANOVA revealed a marginally significant language-combination by priming interaction, $F(3,39)=2.63$, $p=0.064$ (see Table 3 and Figure 1). None of the other main effects or interactions reached significance.

Separate analyses for the different language combinations showed a significant main effect of priming for the English into German language combination, $F(1,13)=6.82$, $p<0.05$. The effect seems to be in the opposite direction of what was expected. A German passive sentence was read more slowly if it was preceded by an English passive sentence than if it was preceded by an English active sentence. The verb by priming interaction was not significant, neither were the main effects and interaction for the other language combinations.

2.2.2 Word level results

In order to investigate whether priming effects can be found on the word level (see Figure 2), we did a more intricate analysis of the effects on individual words for each language combination.

German-German. At the sixth word (a noun) we found a marginally significant verb by priming interaction, $F(1,13)=3.844$, $p=0.07$. The main effects

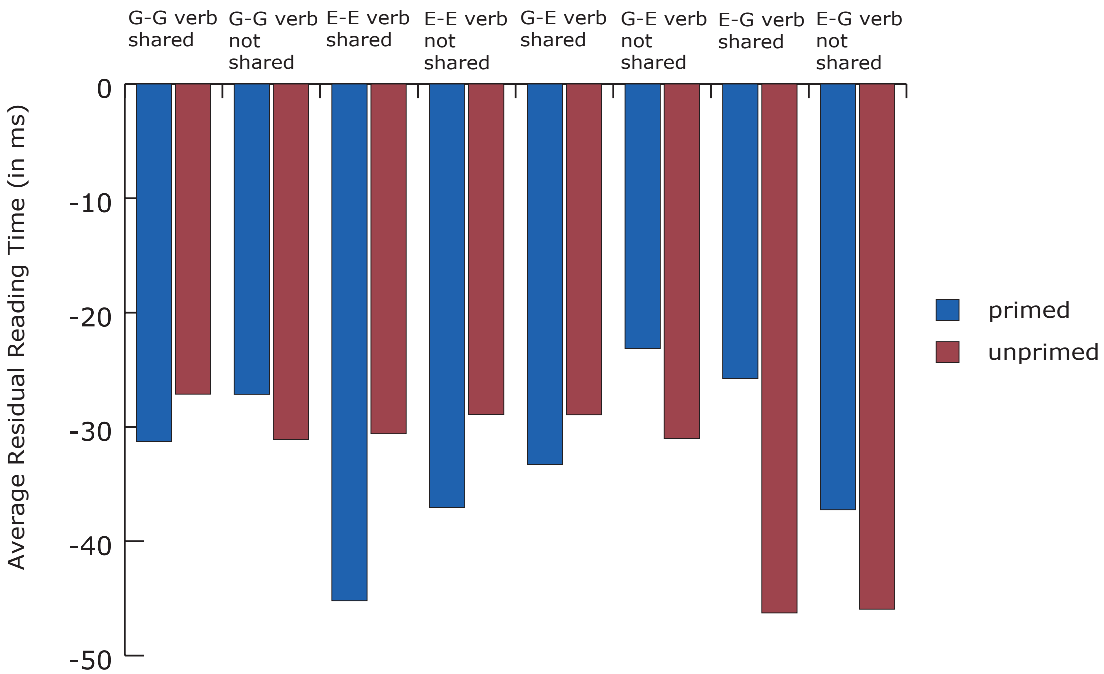

Figure 1. Behavioural results. Average residual reading times per condition.

did not reach significance and the separate analysis of the priming effect for the two verb conditions did not lead to any significant results.

English-English. For this language combination we found marginally significant verb by priming interactions at the 3^{rd} word (*"was"*), F(1,13)=4.59, p=0.052, and at the 5^{th} word (*"by"*), F(1,13)=3.23, p=0.096. None of the other main effects and interactions reached significance.

At the 5^{th} word (*"by"*) we find a significant effect of priming in the verb repetition condition, t(13)=6.035, p<0.05, but not for the condition where the verb differed. At the 3^{rd} word (*"was"*), the separate priming effects for each verb condition did not reach significance.

English-German. For this language combination the main effect of priming was marginally significant at the 3^{rd} (*"wurde"*) and 4^{th} word (*"von"*), F(1,13)=4.24, p=0.06 and F(1,13)=4.033, p=0.066 respectively. None of the other main effects or interactions reached significance.

German-English. For this language combination none of the main effects or interaction reached significance.

2.2.3 Post task

The rate of hits was 59% (*SD* =4.5). The false alarm rate was 21.6% (*SD*=4.3). Thus, it can be assumed that the subjects had read and processed the experimental sentences in depth.

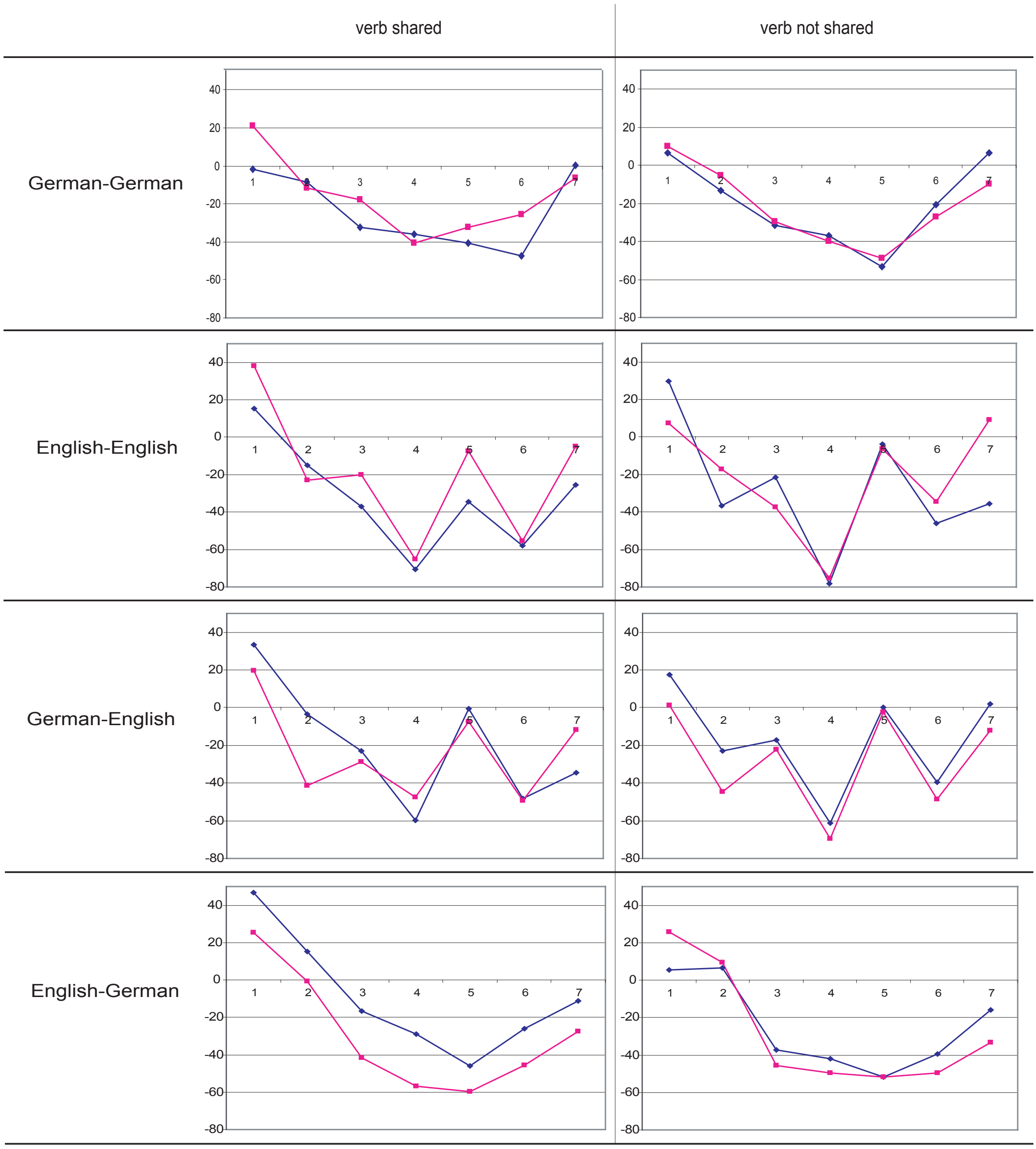

Figure 2. Behavioural results. Residual reading times (in ms) per word. (Blue: primed; Pink: unprimed)

2.3 Discussion

This experiment demonstrated that cross-linguistic priming syntactic effects in comprehension are not as clear-cut as expected. Although we did find syntactic priming effects within the second language and a weak tendency within the first language, the two cross-linguistic conditions showed no priming from German to English and a rather puzzling reverse priming effect from English into German. As expected, all facilitating effects were restricted to the verb repetition condition.

2.3.1 Within language effects

Within the first language, German, the priming effect is not reliable although we find a weak trend. Within English, the second language of our participants, we find a priming effect, thus replicating previous findings of the priming of passive structures in comprehension within English (Frazier et al., 1984). Another study found priming effects from Spanish to English in production (Hartsuiker et al., 2004), where the word order is the same between the two languages. However, to date no priming has been found within German. In one study (Loebell & Bock, 2003), the priming effect is in the right direction but does not reach significance. In this study, the authors claim that this is due to a lack of power, a factor that could have influenced our results as well, as we had comparably few subjects and only 8 items per condition.

Other possibilities should however be considered as well. It might be that the specific structure of the German passive with the sentence final verb weakened any priming effect. In the light of claims that the syntactic priming effect might arise from the priming of verb-subcategorisation frames (Pickering & Branigan, 1998), thus the argument structure information stored with the verb, the late occurrence of the verb in the German passive structure might weaken any priming effect. Similarly, lexicalist models of syntax (MacDonald, Pearlmutter, & Seidenberg, 1994; Vosse & Kempen, 2000) emphasize the special role of lexical items and especially the verb in the parsing of sentences. In lexicalist accounts, the lexical information that is retrieved from the mental lexicon carries syntactic information, for example the obligatory and optional phrases with a specific verb, like the number of and the order of noun and prepositional phrases that are attached to the verb. Thus, one possibility is that what is primed is the verb plus one of its possible argument structures, information on which might be encoded in the lexical frame retrieved from the mental lexicon. In this case, the same argument holds that if the verb is encountered late, any priming effects due to the preactivation of verb argument structures will not manifest themselves in the reading times prior to the encounter of the verb.

These lexicalist models are helpful in explaining the findings from the within L2 results as well. Here, we did find priming effects in the case of verb repetition but not if the verb differed. Thus, if what is primed are verb-subcategorisation frames (Pickering & Branigan, 1998), this might explain why the priming effect only showed up in case of verb repetition. The priming effect we found showed up at the fifth word of the passive sentences (*"by"*), which is the first word after the occurrence of the verb. Thus, if we assume that a certain lexical syntactic frame was retrieved and activated by the processing of the prime sentence, this syntactic frame with the passive argument structure "node" will still be active when the verb of the target sentence is encountered and thus the facilitatory effect will be visible at the first word after the prime that indicates that the same passive argument structure will again be used for processing.

This means that like in previous studies on syntactic priming in comprehension (Arai et al., 2007; Branigan et al., 2005; Ledoux et al., 2007; Tooley et al., under review), this priming effect is restricted to the verb repetition condition. We do not find structural priming that is independent of lexical content.

This effect speaks in favour of lexically-bound accounts of syntax, like in recent lexicalist models (MacDonald et al., 1994; Vosse & Kempen, 2000) and against independent syntax accounts (Chomsky, 1957; Frazier, 1987). The lexical verb frame, the verb-subcategorisation frame, stored in the Mental Lexicon carries with it information on argument structure in form of for example the possible phrases with this particular verb. In case of syntactic priming, these argument structures might be primed and therefore lead to verb-bound priming effects only.

2.3.2 Cross-linguistic effects

There were no significant priming effects from German into English, while the effect from English into German was in the opposite direction (unprimed sentences were read faster than primed ones) to what we had previously predicted. A null result regarding priming effects for passives structures between German and English was previously found in a production study by Loebell and Bock (2003). Inspection of their data shows that similarly to our findings, they found fewer passives produced after a passive prime, especially from English into German. However, these effects did not reach significance.

The effect in the opposite direction might be due to the word order differences between the German and the English passive structure. The effect is similar in both the verb repetition and the non-repetition condition. In the German passive structure the verb occurs too late for the effect to be verb-bound, thus indicating, that the effect is not mediated by the verb but rather, that it is a structural effect. A previous study on cross-linguistic priming effects in production had found a syntactic priming effect. Similarly to our study the effect was purely structural, they did not find any boosting effect for the verb repetition condition. Thus, if the argument structures that are linked to the lexical frames not only encode information on the possible phrases but also their word order, this might explain the results we find. If a certain argument structure including a certain word-order was preactivated by the English prime, then the encounter of the word "*von*" does not fit in with the preactivated argument structure, where a verb is expected. Another argument structure candidate has to be chosen and this process, in whichever form it might manifest itself, could slow down the reading of the target sentence. Moreover, as described for the effects within German, the specific word order of the German passive might hinder any priming effects.

Thus, it is still possible, that other structures with a similar word-order in the two languages would lead to cross-linguistic syntactic priming effects in comprehension.

3. FMRI Experiment

In the fMRI experiment we tried to establish syntactic priming within L2 and between L1 and L2 at the neural level.

3.1 Methods

3.1.1 Participants

In the fMRI experiment, 19 German-English bilinguals of medium English proficiency with German as their native language were tested (three of these subjects were later discarded due to too much movement). They all had a similar language background (see Table 4) and had acquired English at school as their first foreign language at on average 10.88 (*SD* =0.96) years of age and had on average 8 years of formal instruction (*SD* =1.29). Thus, they were all late acquisition bilinguals. Their proficiency was tested with the Oxford Placement

Table 4. fMRI Subject Information

Subject	Age	Gender	Oxford Placement Score (mistakes out of 50*)	Age of Acquisition English	Years of formal English lessons
1	21	Male	7	11	8
2	22	Male	3	10	8
3	20	Female	8	10	9
4	23	Female	15	10	8
5	22	Female	15	12	9
6	21	Female	9	11	8
7	23	Female	26	10	9
8	23	Female	14	11	9
9	21	Female	12	12	9
10	20	Female	20	10	8
11	26	Female	6	13	5
12	22	Female	13	10	9
13	26	Female	7	10	8
14	29	Female	5	11	9
15	26	Male	24	11	9
16	27	Male	16	12	8
Average			**12.13**	**10.88**	**8.06**
SD			**6.93**	**0.96**	**1.29**

*0-9 mistakes: advanced, 10-19 mistakes: good, 20-29 mistakes: satisfactory test on which they made 12.13 mistakes on average (*SD* =6.93). The participants received course credits (proefpersonenuren) or money for their participation in the experiments.

3.1.2 Stimuli/Design

The same experimental materials as in the behavioural experiment were used. In order to increase the number of stimuli per condition we limited the number of conditions to those that had given the best and strongest results behaviourally. We focused on the verb repetition condition (the verb between prime and target was either identical or a translation equivalent) from German to English and within English only (see stimulus examples of the fMRI experiment in Table 1 in blue). Thus, three quarters of the experimental sentences were in English. This was counterbalanced with the filler sentences so that in total half of the sentences were in English, half were in German. The sentences were arranged in experimental trials consisting of the prime and no-prime (passive and active structures respectively) and the target, which always had a passive structure. These trials were alternated with 1 to 3 filler sentences. The order of the experimental trials was randomised. As a baseline condition we inserted 6 to 10 consonant string sentences after every 20 sentences.

There were 36 trials per condition. Eight stimulus lists were created that counterbalanced the languages and the structures that preceded a target stimulus.

3.1.3 fMRI data acquisition

The fMRI data was acquired on a 3 Tesla Siemens Trio scanner. A functional T2* weighted EPI-BOLD fMRI scan was performed (TR = 3 sec, TE = 35 ms), with a flip angle of 90°. 35 slices with a voxel size of 3.5*3.5*3.5 mm were acquired. The field of view was 224*224 mm for each slice. The slices were acquired in an interleaved manner in ascending order. The anatomical images were acquired using a T1 weighted GRAPPA sequence with a 1*1*1 mm resolution.

3.1.4 Procedure

The stimuli were presented using Presentation software (Neurobehavioral Systems). The general procedure was comparable to the one in the behavioural experiment. Participants were lying the scanner and saw the stimuli via mirrors just above their head. In contrast to the behavioural experiment, the stimulus sentences were presented at a fixed presentation time of 350 ms per word. The length of the inter-stimulus interval between sentences in which a fixation cross was displayed was jittered between 1.5 and 4.5 s. Following 20% of the filler sentences a grammaticality decision had to be made by pressing one of two buttons.

8 stimulus lists were created, each participant saw only one of these. Each stimulus list was divided into 4 runs, thus 4 fMRI scans. There was a short break between every scan and the anatomical T1 images were acquired after half of the experiment.

3.1.5 Data analysis

The fMRI data were preprocessed and analysed using SPM5 (Wellcome Neuroimaging Laboratory, London, UK). The first five image volumes were discarded to ensure that transient non-saturation effects did not affect the analysis. All volumes were first slice-time corrected and then realigned. The subjects' mean functional images were coregistered to the subjects' anatomical T1 images. This step was followed by spatial normalisation of the structural and functional images to a T1 template image. As the last step of preprocessing, functional volumes were smoothed with an 8mm FWHM Gaussian kernel.

The fMRI analysis was conducted in two steps. At the first level a single subject analysis was conducted. The contrasts from the first level were then taken to the second level for a random effects group analysis.

The design matrix for each individual subject included regressors that modelled the sentence conditions from the third word onwards, the point in time where the sentence structure became apparent, to the final word in the sentence. There were four regressors modelling the experimental conditions of interest, English targets that were preceded by a German prime (GEP), English targets that were preceded by an English prime (EEP), English targets preceded by a German non-prime (GEU) and English targets preceded by an English non-prime (EEU). Moreover, we had sentence regressors that modelled the four types of primes and non-primes (GP, EP, GU, EU) and the filler sentences in German and English (FILG, FILE). The first two words of all experimental and filler sentences were modelled together as a separate regressor (Wo). The consonant string sentences were modelled by a regressor from the third string as well (Con) and the first two strings were modelled as a separate regressor (WCon). This was done in order to make the consonant string sentences regressor comparable to the experimental regressors. The explanatory variables were then convolved with a haemodynamic response function with time derivatives. Furthermore, the realignment parameters for movement artefact correction were included in the design matrix.

Whole brain analysis. For this conventional whole brain analysis we generated single-subject contrast images for filler (FILE, FILG) and prime sentences (EP, GP, EU, GU) combined relative to the consonant string sentences baseline (Con) in both English and German. These were then taken into a random effect ANOVA with the factor language. In addition, we added the Oxford Placement scores as a covariate of second language proficiency.

Region of Interest analysis. In order to be able to detect potentially weak priming effects that might be lost in a whole brain analysis we conducted a region of interest analysis (ROI) at the group level. As it can be assumed that any syntactic priming effect will be located in areas that are involved in general sentence processing, we took the activation results from main effect of condition of the whole brain analysis as the functional region of interest. A region of interest analysis was then performed using the Marsbar toolbox for SPM ((Brett, Anton, Valbregue, & Poline, 2002), http://marsbar.sourceforge.net), looking for the priming effects within the ROI with a 2x2 ANOVA (priming (primed; not primed) x language combination (English-English; German-English)). This ANOVA was based on single-subject contrast images for the priming conditions (GEP, EEP, GEU, EEU) with consonant string sentences (Con) as a baseline.

3.2 Results

3.2.1 Whole brain analysis (Table 5)

For this analysis we used a voxel-level threshold of 0.05 with family-wise error correction for multiple comparisons. A main effect of condition (the effect of reading sentences versus consonant string sentences) revealed increased activation in the left middle temporal gyrus, $t=7.82$, $p=0.001$, and the left inferior frontal gyrus, $t=6.43$, $p<0.05$ (see Table 3 and Figure 3 for the exact activation locations). The main effect of language did not reveal any activations, neither did the interaction effect, at a 0.001 uncorrected threshold level, indicating that there were no regions more active for English than for German and vice versa.

3.2.2 Region of interest analysis

The ROI analysis did not reveal any significant main effects of priming in the region of interest that was defined by the main effect of condition in the whole brain analysis at a 0.001 uncorrected threshold level.

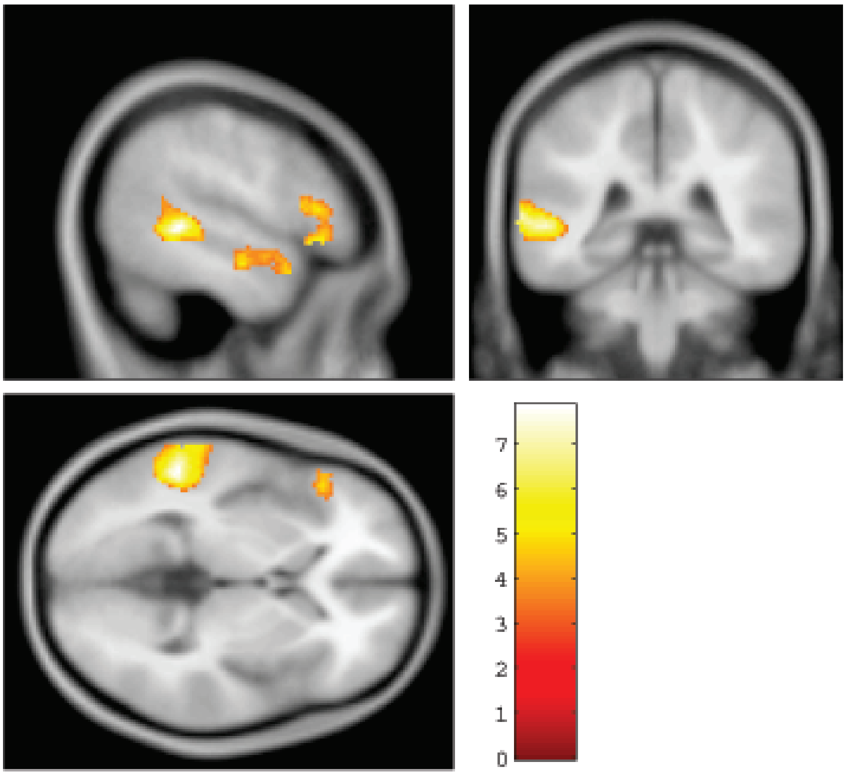

Figure 3. Whole brain analysis. Filler and Prime Sentences > Consonant string sentences. A 0.001 uncorrected threshold level with a spatial extend threshold of k = 10 is used for illustration purposes.

Table 5. Filler and Prime Sentences versus consonant string sentences

Region	BA	Cluster size	Voxel T^{29} value	x	y	z
Left middle temporal gyrus	22	149	7.82	-52	-42	2
	22		7.07	-62	-40	2
Left inferior frontal gyrus (pars triangularis)	45	3	6.43	-56	28	12

Note: significant activation peaks>8mm apart ($p<0.05$ FWE corrected). BA=Broodman Area, x, y, z-coordinates are given in MNI space

3.2.3 Grammaticality Judgement Task

The participants failed to respond to only 0.005% of the task stimuli (*SD* =0.7). The hit rate, subject correctly judging a sentence as being correct, was 44.63% (*SD*=1.7). The false alarm rate was 14.69% (*SD*=4.63*)*. This level of performance is to be expected as some of the violations might be hard to detect in our fast presentation mode. Thus, one can assume that the participants generally attended to all the experimental stimuli and processed them in depth.

3.3 Discussion

In this experiment we aimed at investigating the interaction between the L1 and the L2 syntactic processing systems by looking at syntactic priming effects in the brain during reading comprehension. The approach was to first identify the areas involved in sentence comprehension in a conventional whole brain analysis and then to look for syntactic priming effects within these areas.

3.3.1 L1 and L2 sentence processing

The results of the whole brain analysis show that English and German sentences are processed in the same neural areas of left inferior frontal and temporal regions. These findings are in accordance with other neuroimaging studies on second language processing, which claim that essentially the same areas are used in the first and in the second language (Chee et al., 1999; Indefrey, 2006). Considering that the baseline condition was made up of consonant string sentences, we can assume that the activated areas are involved in word or sentence level processing. These regions are similar to those areas linked to syntactic processing in L1 in meta-analyses (Indefrey, 2006, to appear; Kaan & Swaab, 2002).

3.3.2 Null result of priming

The priming analysis was conducted within a region of interest consisting of areas in the left inferior frontal gyrus and left middle temporal lobe and did not lead to any significant activation or deactivation. This ROI was based on a sentences versus consonant string sentences baseline. Thus, it does not mean that had we used more complex sentences we would not have been able to replicate Noppeney and Price (2004).

Moreover, there are several factors that influenced our results and might have made a potential priming effect undetectable. Firstly, we are investigating second language processes and it is a reasonable assumption to assume that L2 processing although roughly located in the same areas as L1 processing is still more variable across subjects depending on such factors as proficiency level, age of acquisition and manner of learning (Clahsen & Felser, 2006; Opitz & Friederici, 2004; Wartenburger et al., 2003). Although we did ensure that subjects had a similar language background in terms of age of acquisition and manner of learning (in school settings), it was not possible due to practical limitations to have a homogeneous subject group in terms of proficiency levels (see Table 4). This might mean that the second language processing is fundamentally different in different subjects even though the whole brain analysis yielded a common activation patterns. Thus, the priming effects might be located in different areas across subjects thus not resulting in any significant group effects. This is a reasonable explanation, especially in the light of claims that the more proficient one gets in a second language, the more automatised and procedural the processing becomes, thus potentially making L2 processing fundamentally different between different subjects in our study (Clahsen & Felser, 2006; Opitz & Friederici, 2004; Ullman, 2006).

3.3.3 Future analyses

To substantiate the claim that the lack of a neural priming effect is due to the variability between subjects we will have to conduct further analyses. One approach would be to take the inter-subject variability into account and do the ROI specification on the single subject level. For every subject an individual ROI based on the sentences versus consonant string sentences contrast would be defined and those clusters with the highest activation would then be taken into the ROI analysis of the priming effect for each subject separately. The resulting contrast values could then be further analysed in a group analysis.

4. General Discussion

This study investigated the interaction between L1 and L2 syntax in a behavioural and an fMRI experiment on visual sentence comprehension using a syntactic priming paradigm.

4.1 Shared syntactic processor

The behavioural as well as the neuroimaging experiment provide some evidence that at least parts of the L1 and L2 syntactic processing system are shared and thus interact. Firstly, we did find an effect of reading times on German sentences that were preceded by English sentences. This effect is in the opposite direction to the syntactic priming effect we expected and it does not rely on the repetition of translation equivalent verbs. The effect is found in a situation were a verb-mediated effect is not possible due to the structure of the German passive with the sentence final verb. It shows that between languages a purely structural interaction is possible. This means that at least part of the structural representation is shared between languages. This might be in the form of a common store of lexical frames including argument structure and word-order. In this case, the preactivation of a certain word-order in English might lead to a slow down in the reading times of the primed target sentence in German with a different word-order.

Secondly, although we did not find direct evidence of interaction at the neural level in the form of a cross-linguistic priming effect in language specific brain areas, we found that the same neural areas of left inferior frontal and temporal lobes are active for L1 as well as L2 processing. As the two languages are processed in the same areas one might assume that the same processing mechanisms are involved in both languages although we are lacking any direct evidence of language interaction at the neural level. Moreover, the areas that we found activated in both languages are those that studies and meta-analyses on reading comprehension find implicated in syntactic processing (Indefrey, to appear; Kaan & Swaab, 2002).

4.2 The verb effect within L2

Within the L2, the priming effect is carried by the repeated verb. The restriction of the effect to the verb repetition condition replicates other studies on syntactic priming in comprehension (Arai et al., 2007; Branigan et al., 2005; Ledoux et al., 2007). As we do not find any lexically independent priming effects within the L2 condition (i.e. all significant differences in reading times are linked to the verb), it is questionable whether any independent syntax account (Chomsky, 1957; Frazier, 1987) would be able to account for these effects. Much rather, the results can be explained in terms of lexicalist models (Hagoort, 2005; MacDonald et al., 1994; Vosse & Kempen, 2000) in which the locus of information lies in the syntactic frames that are stored in the mental lexicon. These carry syntactic information, for example the argument structures, for each individual word. Consequently, if syntactic representations are lexically specific, syntactic priming effects will be lexically-driven as well.

In sum, we find lexically-driven, verb-bound effects within the L2 and lexically-independent structural effects from L2 to L1. Taking into consideration lexicalist models of syntactic processing at a neural level (Hagoort, 2005), one could suggest that lexically driven priming effects in the brain would should show up in left temporal regions and lexically independent priming effects in the left inferior frontal gyrus. In this sense neuroimaging results could give a further dimension to language research on which relevant effects can be found. Firstly, to find interactions between L1 and L2 syntactic processing and secondly to provide evidence for sentence processing models.

5. Conclusion

The results of the present experiment indicate that syntactic priming effects in comprehension for passive structures can be detected within the L2 if the verb is repeated between prime and target. Additionally, we find cross-linguistic effects, most likely due to word-order, which indicate that there may be shared structural representations. As the behavioural priming effect we found were rather weak, future experiments on syntactic priming in comprehension should increase the power by using more subjects and more experimental items per condition.

The neuroimaging results also favour the idea of a shared syntactic processor, as shown by an analysis using subtraction logic. So far, the priming analysis at the neural level did not show any cross-linguistic or within L2 priming effects. However, due to the variability in subject proficiency we can assume that the variability in L2 neural representation and processing is too high between subjects to show any reliable effects at the group level. Thus, future analyses should approach the question from a slightly different angle and a region of interest analysis on the single subject level should be conducted, thus minimizing inter-subject variability.

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