Understanding same subject-verb agreement differently: ERP evidence for flexibility in processing representations involved in French subject-verb agreement

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Abstract

In an ever-changing environment such as a situation with a variety of linguistic information, individuals have to adapt by selecting the most relevant and appropriate information. In event-related potential studies that manipulated the syntactic agreement between a subject and a verb, it was shown that morphosyntactic features (e.g., number or person feature) are used to compute syntactic dependencies. Furthermore, statistical language information seemed to play a role in the production of subject-verb agreement. We thus investigated flexibility in the processing of morphosyntactic features and co-occurrence frequency between a subject and its verbal inflection. Pronoun primes and verbal targets were presented auditorily and the flexibility of the representations in French subject-verb agreement was studied by manipulating the task to be performed on the target. In Experiment 1, the task was a lexical decision task to induce the use of co-occurrence frequency between a subject and its verbal inflection; in Experiment 2, the task was a grammatical categorization task to amplify the use of morphosyntactic features. Results showed that statistical information affected the processing of the verb earlier than the use of morphosyntactic features, whose violation produced the classic biphasic reaction with negativity followed by positivity. Our findings suggest that there is flexibility in the use of both statistical and abstract morphosyntactic feature representations, although the flexibility of the use of features depends more on task strategies.

Count: 225 words

Keywords: Subject-verb agreement, flexibility, morphosyntactic features, associative representations, statistical properties, event-related potentials.

1. Introduction

When exposed to a large flow of words delivered in a sentence, comprehenders compute the grammatical relationships between words in order to assign thematic roles, such as “who does the action” and “what is the action". Recognizing subject-verb agreement is essential to successfully assigning thematic roles and understanding the meaning of a sentence. However, it is unknown how goals and cognitive strategies can affect the processing of subject-verb agreement by adapting the access to representations necessary for the computation of the subject-verb relationship. It has generally been suggested that to process subject-verb agreement, the cognitive system needs to extract syntactic features from morphological marks provided by a subject and a verb (Chomsky, 1995; Harley & Ritter, 2002; Pearlmutter, 2000). Syntactic features in grammatical agreement are expressed in terms of number, person and gender features in many languages (Corbett, 1979; Harley & Ritter, 2002; Silverstein, 1985), and words sharing the same syntactic features are syntactically related. For instance, [1a] is a syntactically correct sentence as both subject and verb share the same syntactic features (i.e., person and number); in contrast, [1b] is not in correct agreement as subject and verb do not share the same person and number features.

[1] a. *Elle*$_{\text{3rd person singular}}$ *lit*$_{\text{3rd person singular}}$ *un*$_{\text{masculin}}$ *livre*$_{\text{masculin}}$ – She reads a book

[1] b. *Elle*$_{\text{3rd person singular}}$ *lisons*$_{\text{1st person plural}}$ *un*$_{\text{masculin}}$ *livre*$_{\text{masculin}}$ – She read a book

Many previous studies exploring subject-verb agreement used the electrophysiological (EEG) technique, which measures online brain processing at a millisecond-range time resolution (for a review, Molinaro, Barber, & Carreiras, 2011). Moreover, these studies introduced morphosyntactic violations between a subject and a verb and then analyzed event-related potentials (ERP) after such morphosyntactic violations time-locked to the verb target. Two ERP components were found to be related to subject-verb agreement processing when a morphosyntactic anomaly is detected: left anterior negativity (LAN) and late positivity over the posterior sites, usually called P600 (Angrilli et al., 2002; Brunellière, 2011; Dube, Kung, Peter, Brock, & Demuth, 2016; Isel & Kail, 2018; Mancini, Molinaro, Rizzi, & Carreiras, 2011a, 2011b; Nevins, Dillon, Malhotra, & Phillips, 2007; Palolahti, Leino, Jokela, Kopra, & Paavilainen, 2005; Rossi, Gugler, Hahne, & Friederici, 2005; Tanner, 2019; Vincenzi et al., 2003). These two event-related components (ERP) associated with subject-verb agreement processing are known to occur in two different time intervals. The negative deflection, called LAN, is usually observed between 300 and 500 ms; it is then followed by a positive wave arising about 600 ms after verb onset (for a review, Molinaro et al., 2011). Although the functional role of these two components is debated, it appears that the negative deflection is a first response elicited by morphosyntactic violations, and that the positive deflection can be seen as a process of reanalysis and/or integration of verbal inflection with the previous fragment (for a review, Molinaro et al., 2011). However, some authors also found a more central negativity resembling N400 instead of LAN after morphosyntactic violations (e.g., Gunter & Friederici, 1999; Schacht, Sommer, Shmuilovich, Martíenz, & Martín-Loeches, 2014; Zawiszewski, Santesteban, & Laka, 2016) or anterior negativity (e.g., Barber & Carreiras, 2003; Roll, Gosselke, Lindgren, & Horne, 2013; Silva-Pereyra & Carreiras, 2007). Although it has been observed in studies on morphosyntactic processing, N400 is a component that is commonly found in linguistic studies as an index of lexical processing (Brown & Hagoort, 1993; Chwilla, Brown, & Hagoort, 1995; Gomes, Ritter, Tartter, Vaughan, & Rosen, 1997; Thornhill & Van Petten, 2012).

Moreover, Mancini et al. (2011a) pointed out ERP differences in accessing number and person features that were reflected in the amplitude of P600, in which violation of person feature induced greater amplitude compared with violation of number feature. Such ERP differences suggest that abstract morphosyntactic feature representations are accessed during agreement processing, as number feature and person feature are processed separately. Like Mancini et al.

(2011a), other ERP studies (Nevins et al., 2007 ; Silva-Pereyra, & Carreiras, 2007 ; Zawisewski et al., 2016) have also indicated that person and number features are processed as distinct components of the subject-verb agreement computation. Albeit, Silva-Pereyra & Carreiras (2007) and Zawisewski et al. (2016) did not find difference between violations of number feature and of person feature per se rather they demonstrated that double and single feature violation were processed differently wherein double feature violation elicited larger amplitude in comparison to single feature (number feature or person feature in Silva-Pereyra & Carreiras, 2007; number feature in Zawisewski et al., 2016). All differences that were observed between type of features (number feature vs. person feature) or number of features (single feature vs. double feature) suggest that abstract morphosyntactic feature representations are used during the computation of subject-verb agreement.

Furthermore, it has been assumed that language processing does not solely rely on abstract representations such as morphosyntactic features, because the system also uses information that comes from probabilities between words (Seidenberg & Macdonald, 1999; Trueswell & Tanenhaus, 1994). Regarding grammatical agreement, some behavioral studies (Haskell & MacDonald, 2003; Haskell, Thornton, & MacDonald, 2010) have shown that this statistical information is used during the production of subject-verb agreement. For instance, Haskell et al. (2010) investigated whether statistical language properties affect the number of agreement errors in the production of sentences, which were composed of collective nouns denoting a group of people or things. Collective nouns were used as subject primes followed by a number feature manipulation on verbs. There were thus three different modalities: singular prime, where a collective noun was followed by a singular verb (e.g., was); plural prime, where a collective noun was followed by a plural verb (e.g., were); and neutral prime, where a collective noun was followed by a verb that did not have a number marker (e.g., had). For example, the following sentence fragment “After getting off the phone with Carol, a jumble of wonderful possibilities” followed either with “was already” (singular prime condition), “were already” (plural prime condition) or with “had already started” (neutral prime condition)”. Participants were then asked to complete the following target sentence; “Every year, a series of concerts…”. It was observed that the use of plural verbs following collective nouns probed more use of plural verbs during the target sentence completion task. This suggests that statistical language properties based on prior experience shape the system of agreement production (Haskell & MacDonald, 2003, 2005; Thornton & MacDonald, 2003). We therefore wanted to know whether statistical information also affects subject-verb agreement processing by exploring the impact of co-occurrence frequency between a subject and its verbal inflection. It has already been suggested that subject-verb agreement is processed by sequence detectors linking the representations of morphemes that are likely to occur in succession (Pulvermüller, 2003). In subject-verb agreement, this statistical information can refer to associative representations between morphemic units, wherein co-occurrence frequency between a subject and its inflection is encoded (e.g., in French, the subject *‘nous’*-‘we’ referring to 1^{rst} plural person and its regular inflection ‘-/ɔ̃/’). A subject may have a high or low co-occurrence frequency with one specific verbal inflection in language use, mainly due to the statistical regularity of inflections encountered after a subject.

Therefore, if abstract morphosyntactic features and associative representations are involved in the processing of subject-verb agreement, it is interesting to investigate whether there is flexibility in accessing these two representations depending on goals and cognitive strategy, like task demands. Although abstract morphosyntactic features operate at syntactic levels, the use of associative representations, in which co-occurrence frequency between a subject and its inflection is encoded, should occur more at the lexical level. Regarding flexibility, previous studies in language processing have suggested that lexical processing is task-dependent (e.g., Balota et al., 1999; Balota & Yap, 2006). However, little is known about flexibility in subject-verb agreement processing. To our knowledge, only one ERP study (Gunter & Friederici, 1999) on subject-verb agreement has investigated the impact of task demands between a grammatical judgment task and a physical task. Gunter & Friederici (1999) measured ERP responses elicited by word category and subject-verb violations in either a physical task, where participants had to judge whether a word in a sentence was printed in upper case, or a grammatical task, where they had to judge whether a sentence was syntactically correct. The ERP responses elicited by subject-verb violations were more strongly reduced in the physical task than in the grammatical task. As this reduction was not as significant for word category violations, these findings were interpreted as reflecting more an automatic processing of word category information than as inflectional information. Even though this study claims in favor of a flexibility in subject-verb processing, it remains elusive whether this flexibility is related to the use of specific representations that are involved in the computation of subject-verb agreement.

In the current study, we investigated ERP responses associated with the access to morphosyntactic features and associative representations involved in the French spoken subject-verb agreement and to what extent there is flexibility in accessing such representations. To this end, we used two different experimental tasks as we hypothesized that the flexibility in accessing morphosyntactic features and associative representations are probed by the nature of the task (i.e. the goal of the task). In both experiments, the same stimuli were taken from the Lexique database (New, Brysbaert, Veronis, & Pallier, 2007) and they were presented with a grammatical priming paradigm: the subject pronoun acted as a prime, while the verb acted as a target. To probe the putative influence of goal-oriented to specific representations involved in subject-verb agreement, we used a lexical decision task (LDT) and a grammatical categorization task for which responses had to be given on the target. In the go/no-go LDT, participants were asked to make a response if they heard a nonword target, while in the grammatical categorization task, they were asked to make a response if they heard a noun target. We hypothesized that the LDT would shift the access to associative representations as this task requires participants to focus on the lexical information. In contrast, the grammatical categorization task is related to grammatical information, as participants need to determine whether the target stimulus is a noun or not. Therefore, it would induce the use of abstract representations (see Table 1) by the cognitive system by accessing the morphosyntactic features of verbs.

To probe the use of abstract morphosyntactic feature representations, we introduced morphosyntactic violations in our auditory stimuli, similar to other ERP studies on subject-verb agreement in reading (for a review, see Molinaro et al., 2011). We chose to manipulate the type of feature (i.e., person feature or number feature in single violation) and the number of features (i.e., single violation involving one feature or double violation involving two features). We thus had four grammatical conditions (see Table 2): congruent condition (e.g., '*Tu montreras* – you$_{singular/2person}$ watch$_{singular/2person}$'), number violation (e.g., '*Vous montreras* – you$_{plural/2person}$ watch$_{singular/2person}$'), number and person violation (e.g., *'Nous montreras'* – we$_{plural/1person}$ watch$_{singular/2person}$'), and person violation (e.g., '*Je montreras* – I$_{singular/1person}$ watch$_{singular/2person}$'). As a result of accessing abstract morphosyntactic feature representations, we expected to observe ERP amplitude differences during the LAN and P600 time windows between the type of features (i.e., person vs. number violation) or the number of features (i.e., single vs. double violation), since morphosyntactic features seem to be processed as distinct components of the subject-verb agreement computation. If there is flexibility in accessing abstract morphosyntactic feature representations, we expect to observe a larger amplitude in sensitivity to morphosyntactic violations and a higher impact of the type or number of features introducing morphosyntactic violations over the LAN and P600 components in the grammatical categorization task than in the LDT.

Moreover, the access to associative representations was studied by contrasting pronouns that either had a high co-occurrence frequency (high associative frequency, e.g., *'nous'* and *'vous'*) or a low co-occurrence frequency (low associative frequency, e.g., *'je'* and *'tu'*) with a verbal inflection according to the large language corpora of film subtitles (New, Brysbaert, Veronis, & Pallier, 2007). As described in previous studies (Brunellière, 2011; Brunellière & Frauenfelder, 2014), the French language offers an interesting case of strong predictive context between subject and expected morpheme, as certain pronouns are always followed by the same verbal inflections (i.e., *'nous-ons'*; *'vous-ez'*). As associative frequency is related to the statistical properties of language, we expected to observe variations in N100 amplitude since this component seems to be related to statistical properties of auditory stimuli (Daikoku et al., 2017; Furl et al., 2011) and reflects top-down processing in spoken language (Getz & Toscano, 2019; Noe & Fischer-Baum, 2020). N100 is a negative ERP component occurring around 100 ms after stimuli onset. It is sensitive to top-down processing, so that associative representations accessed after perceiving the pronoun may have a top-down influence on the initial processing of verbs. N400 amplitude may also be larger for low associative frequency than for high associative frequency, as we mentioned earlier that N400 is a component related to lexical information (Brown & Hagoort, 1993; Chwilla, Brown, & Hagoort, 1995; Gomes, Ritter, Tartter, Vaughan, & Rosen, 1997; Thornhill & Van Petten, 2012). As a result of flexibility, we expected these associative frequency amplitude differences to be more significant in the LDT, which probes the use of lexical information, than in the grammatical categorization task (see Table 1 for summary of our predictions based on the nature of the task).

< Insert Table 1 here >

Alternatively, if the flexibility in accessing abstract morphosyntactic features and associative representations depends on the strategy to complete the task, we would expect the opposite pattern of flexibility depending on the nature of the task. The grammatical categorization task would amplify the access to associative representations more than the LDT by showing a stronger difference in amplitude over the N100 and N400 components. Moreover, the sensitivity of abstract morphosyntactic features would be enhanced by the LDT rather than the grammatical categorization task over the LAN and P600 components. This is due to a checking strategy by which the system needs to verify if the target shares some linguistic properties with the prime in the LDT (Becker, 1980; Kinoshita, Taft, & Taplin, 1985; McNamara, 2005; Perea, Rosa, & Gómez, 2005; Yap, Balota, & Tan, 2013). In the grammatical categorization task, participants would use the properties of primes to predict the grammatical category of targets because all nouns were preceded by articles, while all primes were subject pronouns before verbs. However, if there is no flexibility in accessing abstract morphosyntactic features and associative representations, there should be no difference between the two tasks in associative frequency or sensitivity to morphosyntactic violations over the ERP components previously described.

< Insert Table 2 here >

2. Experiment 1: Lexical decision task

2.1 Methods

2.1.1 Participants

Twenty-three French native speakers (18 females) participated and their age ranged between 18 and 30 years old (mean=21.6, SD=3.03). To ensure that all of them were right-handed, they were asked to fill in the Edinburgh Handedness Inventory (Oldfield, 1971). Furthermore, all of them had normal or corrected to normal vision and no hearing, language or neurological impairments. Each of them read and signed an informed consent form prior to the experiment and received a 15€ remuneration or credit for their participation. This experiment was approved by the ethics committee of *Université de Lille*. Data were collected on the Digital and Interactive Visual Environments (IrDIVE) research platform.

2.1.2 Materials

The stimuli consisted of 990 pairs of primes and targets, which were selected from the French database *Lexique* (New et al., 2007). They were structured as follows: 264 were used as critical stimuli (33 pairs in each experimental condition), while the rest were fillers (726) used for the need for performing experimental tasks (i.e., lexical decision task and grammatical categorization task). Filler targets thus consisted of pseudowords and nouns, on which participants made motor responses to perform the task. Motor responses are known to generate artifacts on EEG signals. The task is thus designed in such a way that participants only need to make a response on these filler targets and not on the critical stimuli to avoid artifacts on EEG signals time-locked to the verb targets presented within pairs of critical stimuli. Moreover, other filler targets were verbs in order to have 20% of all presented stimuli with a subject-verb violation in the whole of the design. The rationale is to have a low ratio of morphosyntactic violations in the whole of the design to avoid an adaptation of processes involved in the computation of subject-verb agreement, leading to an absence of sensitivity to morphosyntactic violations.

In the critical stimuli, primes were pronominal subjects such as *'je', 'tu', 'nous'*, and *'vous'*, and verb targets were in the future tense and consisted of either two or three syllables (e.g., '*battras*

– will break', '*montreras* – will show'). Critical verbs ended with an (/a/) or (/ɔ̃/) inflection, so that the verb inflection varied by adding only one phoneme after the word stem. Two factors were manipulated in the critical stimuli: grammaticality and associative frequency. Regarding the grammaticality factor, there were one congruent condition and three incongruent conditions (i.e., number violation condition, number and person violation condition, and person violation condition), as seen in Table 2. As mentioned earlier, the critical verbs ended either with an (/a/) or (/ɔ̃/) inflection; both congruent and incongruent conditions were thus related to the recognition of a verbal inflection with the same length and morphological complexity. In the congruent condition, the subject and the verb shared the same syntactic features, making the subject-verb relation syntactically correct. The number violation was introduced by pairing the verb with a subject pronoun that did not agree on the number feature. The person violation was introduced by pairing a verb with a subject that did not agree on the person feature. The number and person violation was introduced by pairing a verb with a subject that did not agree on both number and person features. Each selected verb stem was only used once to guarantee that there was no repetition of the same verbal forms ending with the (/a/) and (/ɔ̃/) inflections. The psycholinguistic properties (i.e., lexical frequency, lemma frequency, number of phonemes, phonological neighbors, and phonological uniqueness) of the verbal forms were matched between the verbal forms ending in (/a/) and those ending in (/ɔ̃/).

Associative frequency is the co-occurrence frequency between a subject and its inflection taken from the large language corpora of film subtitles (New et al., 2007) accessible on the *Lexique* website (www.lexique.org). To create high and low associative frequency conditions, we used the pointwise mutual information (PMI) formula (see Van Petten, 2014, and Brunellière, Perre, Tran, & Bonnotte, 2017, for other studies using the same method in semantic priming) as follows:

$$log_2\left(\frac{ct * corpus\ size}{c * t * span}\right)$$

c indicates the frequency of the subject pronoun, while *t* indicates the frequency of the inflection; *ct* thus indicates the co-occurrence count at which the subject pronoun and the inflection co-occur. Span is the distance between the pronoun (e.g., '*nous*') and the inflection (e.g., '-*ons*'). Corpus size was taken from the large language corpora of film subtitles (New et al., 2007). The pointwise mutual information (PMI) is a common method used to evaluate word associations (Church & Hanks, 1990). Contrary to latent semantic analysis (LSA) (Landauer & Dumais, 1997) informing about the semantic distance between two words in a corpus based on the distribution of lexical co-occurrence, the PMI simply refers to the number of co-occurrences of two words divided by the product of their individual frequencies. We adapted the latter by taking into account the number of co-occurrences of a word and a morpheme (here, an inflection such as '-*ons*'). The PMI is therefore very reliable for measuring associative frequency between a pronominal subject (e.g., '*nous*') and its inflection (e.g., '-*ons*'). When measuring the associative frequency between the pronominal subjects in the critical stimuli (*'nous', 'vous', 'je'*, and *'tu')* with their respective inflections, we found that subject pronouns, such as *'nous'* and *'vous'*, had high associative frequency with their inflections (respectively, 7.8 and 5.6) when compared with *'je'* and *'tu'* and their inflections (less than 3). This result is due to the fact that '*je*' and '*tu*' pronouns have more variance in their agreement inflections (e.g., '*je-e'*, '*je-ai*', '*je-is'*; '*tu-as*', '*tu-es*', '*tu-ais*') than '*nous*' and '*vous*' pronouns, which are followed by a regular inflection across tenses (e.g., '*nous-ons*', '*vous-ez*'). High associative frequency in our study means that the pronoun has a high co-occurrence frequency with one verbal inflection in French (e.g., the *'vous'* pronoun and the –/e/ verbal inflection), even though the pronoun was not necessarily followed by this particular verbal inflection in all conditions within the experimental design (i.e., in incongruent conditions).

The fillers consisted of 726 pairs of primes and targets (see Table 3 for examples of fillers). The filler primes consisted of subject pronouns (i.e., '*je', 'nous', 'tu', 'vous',' il/s', and 'elle/s'*) and articles (i.e., '*le', 'la', 'les'*); the targets were verbs from present and past tenses (132), nouns (297), pseudoverbs (148) or pseudonouns (149). There were no morphosyntactic violations in the fillers. The number of noun targets was similar to that of pseudoword targets, leading to the number of targets to be detected being identical in both tasks (i.e., lexical decision task and grammatical categorization task). Moreover, the verb targets were derived from tenses (i.e., present and past tense) other than the future tense, and the verb stems were different from those used in the critical stimuli. In other words, there was no repetition of verb stems. The noun targets were feminine and masculine and the pseudoword targets were either pseudoverbs or pseudonouns. They were generated by the Wuggy software (Keuleers & Brysbaert, 2010). Pseudoverbs and verbs were preceded by pronominal subjects, while pseudonouns and nouns were preceded by articles. A French native speaker checked these pseudowords to make sure that they followed French phonological rules.

<Insert Table 3 here>

2.1.3 Stimuli recording

A French female native speaker pronounced all the stimuli several times in a soundproofed room. The auditory recordings were sampled digitally at 48 kHz with 16 bits. They were selected based on the best pronunciation, natural intonation and speaking rate. Praat (Boersma & Weenink, 2011) was used to extract the mean intensity, the mean fundamental frequency and the duration of target verbs in the critical stimuli. The verbal forms ending with –/a/ and –/ɔ̃/ inflections had a similar mean intensity (the average for all verb targets ending with –/a/ was 70.5 dB, while –/ɔ̃/

was 71.5 dB), mean fundamental frequency (the average for all verb targets ending with –/a/ was 172 Hz, while –/ɔ̃/ was 174 Hz), and duration (the average for all verb targets ending with –/a/ was 692 ms, while –/ɔ̃/ was 714 ms).

2.1.4 Experimental procedure

Before the main experiment, participants did a practice block to become familiar with the task. Experiment 1 was a lexical decision task (LDT) where participants were asked to respond when they heard a nonword target. This practice block consisted of 33 pairs of stimuli which were not presented in the main experiment, although the ratio between critical stimuli and fillers was the same. In the main experiment, there were three experimental blocks. The duration of each block was around 20 minutes. Participants could take a short break after completing each one. In total, the experiment lasted about one hour. There were 330 stimuli in each block, of which 88 were critical stimuli. Presentation order of the stimuli was randomized in each block. Moreover, we had four experimental lists, so that the four grammatical conditions (congruent condition, number violation, number and person violation and person violation) had the same verbal targets across all participants. Each critical verb was presented only once in each list. Fillers remained the same in all four experimental lists. Participants were randomly assigned to one of the four experimental lists. Each trial began with a 300-ms white fixation cross presented at the center of a black screen. The fixation cross was followed by an auditory prime, either a pronoun or an article, then by a 50-ms interstimulus interval (ISI). An auditory target followed, which was either a verb, a noun or a pseudoword. During the auditory presentation of the stimuli, the white fixation cross remained on the screen to keep the participants’ gaze and reduce eye movements. It then remained on the screen until 1500 ms after target offset to further reduce eye movements. After a 1000-ms intertrial interval (ITI), the next trial began.

2.1.5 EEG data acquisition

The BioSemi ActiveTwo AD-Box system with a 128-channel EEG cap was used to record the EEG data at a sampling rate of 1024 Hz. Two additional electrodes were also placed over the mastoids and two others on the face around the eye area to measure ocular movements. During the recording, the offset values (i.e., the voltage difference between each electrode and the CMS-DRL reference) of all electrodes were kept lower than 20 mV.

2.1.5.1 EEG data pre-processing

The Cartool software (Brunet, Murray, & Michel, 2011) was used for pre-processing procedure except for the independent component analysis (ICA). The ICA was performed using the BESA software to remove components related to eye movements. The pre-processing procedure performed by Cartool included filtering, threshold set-up for artifact rejection, data re-referencing to mastoids and channel interpolation. The low pass filter was set at 30 Hz and the high pass filter at 0.01 Hz. To remove remaining artifacts and noise, threshold amplitude was set at 100 mV, so that if any electrical brain activity exceeded that value at any time frame, the EEG epoch was rejected. Epoch for each experimental condition started 50 ms pre-stimulus onset and 1200 ms post-stimulus onset. No baseline correction was applied, since we found significant differences related to associative frequency during the grammatical categorization task in Experiment 2. EEG epochs were averaged per experimental condition for each participant. The data from each participant were then re-referenced to the left and right mastoids. Finally, channel interpolation was performed by using the 3D spline method, using the real position of channels; the average number of interpolated channels was three per participant.

The average number of acceptance trials for each experimental condition was matched between all experimental conditions. The average number of acceptance trials for low associative frequency was: 30.6 for the congruent condition, 30.8 for number and person violation, 30.7 for number violation, and 30.8 for person violation. For high associative frequency, it was as follows: 30.3 for the congruent condition, 30.5 for number and person violation, 30.3 for number violation and 30.7 for person violation.

2.1.5.2 ERP Analysis

Since prior research used many different time windows to explore subject-verb agreement, we followed recommendations given by Keil et al. (2014, p.7) by creating *"an average across all all participants and conditions and to use this information to identify the time range and topographical distribution of a given component*". Based on this approach, we selected three time windows where we observed peak amplitudes: 100-160 ms (N100), 300-600 ms (LAN/N400) and 920-1120 ms (P600). We refer to LAN and N400 components during the second time window as these two ERP components are known to occur between 300 and 600 ms (Brown & Hagoort, 1993; Chwilla, Brown, & Hagoort, 1995; Gomes, Ritter, Tartter, Vaughan, & Rosen, 1997; Molinaro, Barber, & Carreiras, 2011; Thornhill & Van Petten, 2012). For statistical analysis, we extracted the mean amplitude of the ERP data over these time windows from seven regions of interest (ROIs), which are the ROIs to describe the four components. For each representative site, we selected nine electrodes as follows: left anterior (D3-D5, D10-D12, D19-D21), right anterior (B22-B24, B29-B31, C3-C5), frontal (C12-C14, Afz-Fz, C25-C27), central (Cz-CPz, B1, B2, C1, D1, D15, D16), left mid-parietal (A6-A8, D17, D26-D30), left mid-parietal (A6-A8, D17, D26-D30) and posterior (A5, A17-Poz, A30-A32). A three-way repeated analysis of variance (ANOVA) was conducted on the mean amplitude over each time window with three independent variables: associative frequency (low and high), grammaticality (congruent condition, person violation, number and person violation, and number violation) and ROIs (left and right anterior, central, frontal, left and right mid-parietal and posterior sites). Based on our hypotheses, only main effects of grammaticality or associative frequency, or significant interactions between grammaticality and associative frequency (including the ROIs or not) were reported. To adjust for violations of sphericity, a Greenhouse-Geisser (Greenhouse & Geisser, 1959) correction was performed when there was more than one degree of freedom in the numerator. In the results section, we report only the corrected *p*-values. Effect size was reported as partial eta-squared (η^2_p). If a significant effect or interaction was found, post-hoc Tukey tests were performed to interpret the significance of those effects.

2.2. Results

2.2.1 Behavioral results

Participants paid attention to the auditory targets as the mean accuracy of correct response was 89% (range: 74-98%; median: 94%). The mean hit rate was 0.93 and the mean false alarm rate was 0.13. The average reaction time was 1249 ms after the onset of pseudoword targets.

2.2.2 ERP results

As seen in Figure 1, the ERP waveforms showed that N100 was observed over the central site. Its amplitude seemed to increase for low associative frequency. In the LAN/N400 time window (300-600 ms), we observed negativity that seemed to be enhanced by the double violation condition. In the P600 time window (920-1120 ms), positive amplitudes were observed over the posterior site and incongruent conditions involving number violation and number and person violation seemed to increase this positivity in comparison with the congruent condition. The statistical analysis of each time window is shown in Table 4.

< Insert Figure 1 and Table 4 here >

2.2.2.1 N100: Time window between 100 and 160 ms

In this first time window, we observed a significant interaction between associative frequency and ROIs ($F(6,132) = 2.80$, $p < .05$, $\eta^2_p = .11$). We then performed a post-hoc Tukey test which revealed no significant differences when the same ROIs were compared between the two associative frequency conditions. However, when we compared ROIs within the same associative frequency condition, we found that the spatial distribution of N100 significantly differed as a function of associative frequency. We reported the significant comparisons between each site within the same associative frequency condition below. In the low associative frequency condition, N100 was larger over the central and frontal sites compared with the left anterior, right, left mid-parietal and posterior sites (p<.001). Moreover, the central site also presented more negative values than the right anterior site (p<.001), while the right anterior site showed more negative values than the left mid parietal site (p<.05). As for high associative frequency, we found that left anterior, central, and frontal sites presented more negative values than the right mid-parietal site (p<.001). In addition, the central site had more negative values than the left anterior (p<.05), right anterior, left mid-parietal and posterior sites (p<.001). The frontal site showed more negative values than the posterior sites (p<.01). The left anterior site also presented more negative values than the right mid-parietal (p<.01) and posterior sites (p<.001). Altogether, this suggests that the spatial distribution of N100 significantly differed as a function of associative frequency, with a more negative predominance for high associative frequency over the left anterior site (see Figure 2).

< Insert Figure 2 here >

2.2.2.2 LAN/N400: Time window between 300 and 600 ms

In this second time window, we observed a main effect of grammaticality (F(3,66) =5.06, p<.01, η^2_p=.18), as depicted in Figure 3a. The post-hoc Tukey test showed that incongruent conditions involving double violations with number and person features elicited larger negativity in comparison with the congruent condition (p<.01) and the person violation condition (p<.05).

< Insert Figure 3 here >

2.2.2.3 P600: Time window between 920 and 1120 ms

A significant interaction was observed between grammaticality and ROIs ($F(18,396) = 2.52$, $p<.05$, $\eta^2_p=.10$). When the post-hoc Tukey test compared the same ROIs between the grammaticality conditions, significant differences were observed over the posterior site (Figure 3b), where incongruent conditions for number violation ($p<.05$) and number and person violation ($p<.001$) increased the amplitude of positivity in comparison with the congruent condition. The number and person violation elicited larger positive amplitudes than the congruent condition over the right mid-parietal site ($p<.001$).

2.3. Discussion

By manipulating the two factors of interest, i.e. grammaticality and associative frequency, we expected to reveal the underlying representations that are used during subject-verb agreement processing in a lexical decision task (LDT). The results from this experiment showed that accessing associative representations influences the initial processing of verbs, as highlighted in the N100 time window. Indeed, N100 amplitude was increased over certain sites depending on the associative frequency between the pronoun subject and its verbal inflection. Interestingly, this finding suggests a top-down processing of the verb inflection by accessing the associative representations after the cognitive system perceives the subject pronoun input. This is in line with previous findings in spoken word recognition, wherein lexical top-down processing can affect phonological processing (Getz & Toscano, 2019; Noe & Fischer-Baum, 2020) and supports the hypothesis that the brain actively generates the possible upcoming input (Bar, 2007; Clark, 2013; Friston, 2005). As initially predicted in the lexical decision task, lexical co-occurrence frequency between the subject and its verbal inflection affected the early processing of the verb at phonological level owing to the prediction of the upcoming verbal inflection from the subject prime. However, although N400 is a component related to lexical information (Brown & Hagoort, 1993; Chwilla, Brown, & Hagoort, 1995; Gomes, Ritter, Tartter, Vaughan, & Rosen, 1997; Thornhill & Van Petten, 2012), lexical co-occurrence frequency between the subject and the verbal inflection did not influence the amplitude of the negativity occurring from 300 ms.

Regarding sensitivity to morphosyntactic violations, our results revealed that incongruent conditions involving a double violation in comparison to the congruent condition first increased the amplitude of negativity occurring from 300 ms, and then that of late positivity over the posterior sites. These results are in line with the findings of previous ERP studies in agreement processing research (Isel & Kail, 2018; Mancini et al., 2011b; Shen, Staub, & Sanders, 2013; Silva-Pereyra & Carreiras, 2007; Zawiszewski et al., 2016) by replicating negative and positive modulations elicited by morphosyntactic violations. Unlike some previous ERP studies manipulating the various types of morphosyntactic features separately (Mancini et al., 2011a; Nevins et al., 2007), differences between morphosyntactic violations involving either number feature or person feature were not found. Moreover, we observed differences between violations involving double and single features, like Silva-Pereyra & Carreiras (2007) and Zawiszewski et al. (2016). As well, we found that double violations elicited larger amplitude than single violations involving the person feature. Higher negativity for a double violation compared with a single person violation might reflect the fact that a double feature violation is easier to recognize than a single feature violation. The French behavioral study by Lambert & Kail (2001) supported this idea by showing that the response time for detecting double feature violations was faster than for single feature violations. Surprisingly, double violations increased the amplitude of negativity from 300 ms in comparison with single violations involving the person feature. Studies by Silva-Pereyra & Carreiras (2007) and Zawiszewski et al. (2016) had observed this effect in the P600 time window. This discrepancy in temporality might be due to the language difference and to the way the stimuli were presented. Indeed, the study by Silva-Pereyra & Carreiras (2007) was in Spanish and the one by Zawiszewski et al. (2016) was in Basque. Both of them used visual stimuli while we used French auditory stimuli in our study. Altogether, the difference between the processing of a double violation and that of a single violation of person feature suggests that person and number features are processed as distinct abstract morphosyntactic features used in the subject-verb agreement computation.

In short, the findings of Experiment 1 showed that both abstract morphosyntactic features and associative representations are accessed during subject-verb agreement processing. This study confirms the importance of statistical language information as it is not only used in agreement production (Haskell & MacDonald, 2005; Haskell et al., 2010; Thornton & MacDonald, 2003) but also in comprehension during agreement processing. Importantly, the fact that associative representations derived from the subject constrain early phonological verb processing supports the idea of prediction in language processing (DeLong, Urbach, & Kutas, 2005; Fleur, Flecken, Rommers, & Nieuwland, 2020; Ito, Corley, Pickering, Martin, & Nieuwland, 2016; Van Berkum, Brown, Zwitserlood, Kooijman, & Hagoort, 2005) wherein higher level representations constrain the processing of lower level representations (Kuperberg & Jaeger, 2016). In the following part, we present the methods and results of Experiment 2, in which participants were asked to perform a grammatical categorization task on the target. In Experiment 2, we expected the cognitive system to be more sensitive to the use of abstract morphosyntactic feature representations if the nature of the task affected the access to morphosyntactic features and associative representations, or the reverse pattern, if the access to morphosyntactic features and associative representations was affected by the cognitive strategy to solve the task (i.e., with more use of associative representations in the grammatical categorization task and less use of morphosyntactic features). If there is no flexibility in accessing abstract morphosyntactic features and associative representations, the same pattern of findings as that of Experiment 1 should be observed in Experiment 2.

3. Experiment 2: Grammatical categorization task

3.1 Methods

3.1.1 Participants

Twenty-four French native speakers (17 females) participated in this experiment, and their ages ranged between 19 and 25 years old (mean=21.6, SD=1.41). As in Experiment 1, all of them were right-handed. They had normal or corrected to normal vision and no hearing, language or neurological impairments. Each of them read and signed an informed consent form before the experiment and they received a 15€ remuneration for their participation. This experiment was also approved by the ethics committee of *Université de Lille*. As in Experiment 1, data were collected on the IrDIVE research platform.

3.1.2 Materials

The stimuli materials were identical to those in Experiment 1.

3.1.3 Stimuli recording

The stimuli recording was identical to that in Experiment 1.

3.1.4 Experimental procedure

The experimental procedure was identical to that in Experiment 1, except that in this experiment, the task was a grammatical categorization task. Participants were asked to respond when they heard a noun target.

3.1.5 EEG data acquisition

The EEG data acquisition was identical to that in Experiment 1.

3.1.5.1 EEG data pre-processing

The EEG data pre-processing was identical to that in Experiment 1, except that we did not perform ICA because of few ocular artifacts. As in Experiment 1, the number of acceptance trials was also matched between all experimental conditions. Therefore, the total number of accepted epochs was equal across all experimental conditions. For low associative frequency, the number was 28.8 for the congruent condition, 29.2 for the number and person violation condition, 29.2 for the number violation condition and 29.2 for the person violation condition. For high associative frequency, the number of accepted epochs was 29.4 for the congruent condition, 28.9 for the number and person violation condition, 29.3 for the number violation condition and 28.5 for the person violation condition.

3.1.5.2 ERP analysis

The ERP analysis was identical to that in Experiment 1.

3.2 Results

3.2.1 Behavioral results

In Experiment 2, the mean accuracy of correct responses was 96% (range: 84%-99%, median: 97%). The mean hit rate was 0.95, while the mean false alarm rate was 0.037. The average response time was 1135 ms after the onset of the noun target. These results suggest that participants paid attention to the targets.

3.2.2 ERP results

As seen in Figure 4, low associative frequency enhanced the amplitude of N100. In the following time window, from 300 to 600 ms, we observed another negativity peak (LAN/N400), followed by positivity (P600) from 920 to 1120 ms over the posterior site. Although associative frequency seemed to increase N100 amplitude and the second negativity peak, the sensitivity to detect morphosyntactic violations was weak. The summary of the statistical results from the three time windows is presented in Table 5.

< Insert Figure 4 and Table 5 here >

3.2.2.1 N100: Time window between 100 and 160 ms

In this first time window, we observed main effects of associative frequency ($F(1,23)=10.50$, $p<.01$, $\eta^2_p=.31$). Concerning the main effect of associative frequency, it seems that low associative frequency elicited a larger N100 amplitude than high associative frequency (see Figure 5a). A significant interaction between associative frequency and ROIs also was observed (Figure 5b), ($F(6,138)$, 3.03, $p<.05$, $\eta^2_p=.12$). Post-hoc Tukey *t*-tests showed that low associative frequency increased N100 amplitude when compared with high associative frequency over all sites ($p<.001$), except for the right mid-parietal sites (see Figure 5b).

< Insert Figure 5 here >

3.2.2.2 LAN/N400: Time window between 300 and 600 ms

The topography observed over this time window is similar to that of the traditional N400 component. We thus refer to N400 hereafter. In this time window, a main effect of associative frequency ($F(1,23)=17.31$, $p<.001$, $\eta^2_p=.43$) was found. As in the first time window, low associative frequency enhanced N400 amplitude more than high associative frequency. We also observed two significant interactions involving the grammaticality factor. First, we found a significant interaction between associative frequency and grammaticality ($F(3,69)=5.20$, $p<.01$, $\eta^2_p=.18$). The post-hoc Tukey test showed that the amplitude of N400 was larger for low associative frequency than for high associative frequency, in the congruent condition ($p<.01$) and the person violation condition ($p<.05$) only. Moreover, for low associative frequency, we observed that the amplitude of N400 was increased significantly by the number and person violation condition than by the number violation condition ($p<.05$).

The second interaction involved associative frequency, grammaticality and ROIs ($F(18,414)=2.64$, $p<.05$, $\eta^2_p=.10$). Post-hoc Tukey *t*-tests for high associative frequency showed that the number violation condition increased N400 amplitude more than the congruent condition over the right anterior, central, frontal ($p<.001$) and left anterior sites ($p<.01$). The person violation condition enhanced negative amplitudes more than the number violation condition over the left anterior and frontal sites ($p<.05$). The double number and person violation condition elicited higher negativity than the congruent condition over the right and left anterior, frontal ($p<.01$) and central sites ($p<.001$). This double violation also elicited more negative values than the person violation condition over the left anterior site ($p<.05$). Comparison between the grammaticality conditions within the low associative frequency condition showed that the congruent condition elicited larger N400 amplitude than the number violation condition over the right and left anterior, central, frontal ($p<.001$) and left mid-parietal sites ($p<.01$). Grammaticality conditions involving a double violation, such as number and person features, elicited more negative values than the number violation condition over all ROIs ($p<.001$), except the posterior sites ($p<.01$). The double violation also elicited more negativity than the person violation condition over the frontal site ($p<.05$). To sum-up, as in Experiment 1, it was found that the double violation elicited a larger negativity than the person violation independently of associative frequency but only over specific sites in Experiment 2 (see Figure 6). All incongruent conditions enhanced the N400 amplitude with respect to the congruent condition over left anterior and frontal sites when the associative frequency was high (see Figure 6). In contrast, when the associative frequency was low, double violation and congruent condition increased the N400 amplitude with respect to the number violation over the right and left anterior, central, frontal and left mid-parietal sites.

< Insert Figure 6 here >

3.2.2.3 P600: Time window between 920 and 1120 ms

In this last time window, we did not observe any effect related to associative frequency or grammaticality.

3.3 Discussion

In Experiment 2, we used the same stimuli as in Experiment 1 and the only difference was the task (LDT versus a grammatical categorization task). As in Experiment 1, the results showed that N100 was modulated by associative frequency, which confirmed top-down processing related to associative representations during the early stage of verb processing. Regarding abstract morphosyntactic feature representations, a main effect of grammaticality was not observed in the LAN time window or in the P600 time window, contrary to our initial predictions. Although morphosyntactic violations did not enhance N400 or P600 amplitude, our results show that the accessing of morphosyntactic feature representations was influenced by associative frequency, as observed in the N400 time window. As in Experiment 1, double violations increased the amplitude of negativity arising from 300 ms in comparison with a single violation involving the person feature but only over particular sites in Experiment 2 (over the frontal site for low associative frequency and over the left anterior site for high associative frequency). Another pattern which differed in associative frequency was the brain reaction to number violation. Although the N400 amplitude was larger for the number violation than for the congruent condition when the associative frequency was high, this pattern was inverted when the associative frequency was low. Importantly, as in many other languages, the grammatical category of nouns in French expresses the feature of number and gender but not that of person. We posit that when the task required participants to determine as quickly as possible whether the target was a noun, it caused their attention to shift to the relevant properties of the grammatical category, such as the number feature in this study. As a result, when a verbal inflection was strongly expected from the subject (i.e., high associative frequency), the number violation was detected as a morphosyntactic anomaly, reflected by a negative shift elicited by that violation. However, when there was no strong prediction of verbal inflection (i.e., low associative frequency), the number violation was not treated as a morphosyntactic anomaly and may have acted as a cue to judge whether the target was part of other grammatical categories such as nouns. Our results are therefore in line with previous findings showing that the processing of subject-verb violations is highly dependent on task demands and requires a higher level of attention during the computation of the subject-verb agreement (Batterink et al., 2010; Gunter & Friederici, 1999).

The results of Experiment 1 and Experiment 2 seem to indicate that there is task-related flexibility in using both associative and abstract morphosyntactic feature representations. This flexibility thus seems to rely on the cognitive strategy to solve the task. The lexical decision task elicited access to more morphosyntactic features, while the grammatical categorization task elicited the use of more associative representations activated by the subject. To confirm these patterns, we performed *t*-tests comparisons between the two experiments to examine the effect of experimental tasks in the N100, N400 and P600 time windows. Only the significant results are reported below.

4. Comparing ERP results from Experiment 1 and Experiment 2

As our aim was to probe the flexibility in the representations used in subject-verb agreement according to task demands, we thus conducted statistical comparisons on the factors of interest (i.e., associative frequency and grammaticality, including or not ROI) between the two experiments. We limited our statistical comparisons to a few factors in the statistical analysis by using independent *t*-tests, in order to reduce false positive effects. When significant effects were found, the Cohen *d* effect size was also reported.

4.1 Results of the comparison in the three time windows

4.1.1 N100: Time window between 100 and 160 ms

In the N100 time window, we found a significant interaction between associative frequency and ROIs in both experiments. We thus investigated the experimental task effect on the size of the associative frequency effect according to ROIs by performing *t*-tests comparing the subtraction between high and low associative frequency in Experiment 1 and in Experiment 2 over each ROI. We only found a significant difference in the associative frequency effect between the two experiments over the left anterior site ($t(45)=2.23$, $p<.05$, $d=.65$), for which the effect of associative frequency was stronger in Experiment 2 than in Experiment 1 (see Figure 7a).

< Insert Figure 7 here >

4.1.2 LAN/N400: Time window between 300 and 600 ms

Since we found that double violations with number and person features elicited stronger negativity than the congruent condition and the person violation condition in Experiment 1, we conducted a *t*-test comparing the subtraction of number and person violation minus congruent condition in Experiments 1 and 2, and another *t*-test comparing the subtraction of number and person violation minus person violation in Experiments 1 and 2. The *t*-tests showed a significant effect of experimental task for the subtraction of number and person violation minus congruent condition, $t(45)=2.47$, $p<.05$, $d=.72$) and there was a trend effect of experimental task for the subtraction of number and person violation minus person violation. The negative shift for double violation compared to the congruent condition was stronger in Experiment 1 than in Experiment 2 (see Figure 7b).

4.1.3 P600: Time window between 920 and 1120 ms

In this last time window, both the number violation and the number and person violation increased the amplitude of positivity in comparison with the congruent condition over the posterior site. We thus performed a *t*-test over the posterior site, comparing the subtraction of grammaticality conditions as follows: 1) number and person violation minus congruent condition, 2) number violation minus congruent condition. The *t*-tests only showed a significant effect of experimental task over the posterior site between number and person violation and congruent condition ($t(45)=2.20$, $p<.05$, $d=.64$). As seen in Figure 7c, the positive shift for double violation compared to the congruent condition was larger in Experiment 1 than in Experiment 2. This was due the fact that the positive shift for double violation was found only in Experiment 1.

4.2 Discussion

The purpose of the present study was to investigate flexibility in accessing the abstract and associative representations during subject-verb agreement processing. We found an experimental task effect modulating these three ERP components: N100, N400 and P600. Our findings are in line with our alternative hypothesis that flexibility is affected by the cognitive strategy to solve the task. The lexical decision task in Experiment 1 would thus rely more on morphosyntactic information while the grammatical categorization task in Experiment 2 would rely more on associative representations. We posit that this is due to the lexical decision task requiring a verification strategy between prime and target to check whether the target was a word or a nonword (Becker, 1980; McNamara, 2005; Yap et al., 2013). Since the cognitive system checked whether the target word was part of the word set that shared some properties with the prime, it was more sensitive to morphosyntactic violations during the lexical decision task. In the grammatical categorization task, the cognitive system did not need to do this kind of verification between prime and target since all nouns were preceded by articles, while all primes were subject pronouns before verbs. The grammatical categorization task emphasized the use of properties of primes, such as associative representations, and paid less attention to the subject-verb relationship. Although using the properties of primes was a useful strategy, performing the grammatical categorization task still forced participants to focus on the target, as an article prime was followed by either a noun or a pseudonoun. According to our findings, the flexibility in accessing the representations during the processing of subject-verb agreement depended on task strategies. In the following part, we discuss the findings for each ERP component related to flexibility in accessing the representations involved in subject-verb agreement.

4.2.1 N100: an early stage of verb processing

In our experiments, N100 findings suggest that the accessing of associative representations after perceiving the subject pronoun constrains the phonological verb processing. These findings are in line with previous studies that found that N100 is related to statistical properties (Daikoku, Yatomi, & Yumoto, 2017; Furl et al., 2011) and provides evidence of a lexical top-down effect during phonological processing (Getz & Toscano, 2019; Noe & Fischer-Baum, 2020). The information from the preceding input, acting as a prime, could affect the phonological processing of the target input (Bien & Zwitserlood, 2013). Furthermore, N100 results show that associative representations are guided by the cognitive strategy to solve the task, suggesting flexibility in accessing these representations. Higher use of associative representations related to lexical co-occurrence frequency between the subject and its verbal inflection was found over the left anterior site in the grammatical categorization task than in the lexical decision task. Beyond the flexible use of associative representations depending on the cognitive strategy to solve the task, their access seems to have an automatic component. The access to associative representations modulated the N100 component in terms of amplitude in the grammatical categorization task, or in terms of topographical variations in the lexical decision task. This finding is not surprising since these representations encode statistical language properties and previous studies have suggested that this process occurs implicitly (Aslin & Newport, 2012; Conway, Bauernschmidt, Huang, & Pisoni, 2010; Kidd, 2012; Kittleson, Aguilar, Tokerud, Plante, & Asbøjrnsen, 2010).

4.2.2 Anterior negativity, N400 and P600: ERP components sensitive to morphosyntactic violations

Anterior negativity, N400 and P600 components are known to be sensitive to morphosyntactic violations (for a review, Molinaro et al., 2011) and to be affected by task demands (Chwilla et al., 1995; Gunter & Friederici, 1999; Hahne & Friederici, 2002; Schacht et al., 2014). In line with these previous studies, we found that the sensitivity to morphosyntactic violations over a large negativity and P600 was more significant in a task leading to do a verification strategy between prime and target, such as during the lexical decision task. In contrast, performing the grammatical categorization task showed an N400-like pattern over the central site. It even revealed no sensitivity to morphosyntactic violations over the P600 time window. This is in line with the proposal that N400 is also sensitive to syntactic processing (e.g., Gunter & Friederici, 1999; Schacht, Sommer, Shmuilovich, Martíenz, & Martín-Loeches, 2014; Zawiszewski, Santesteban, & Laka, 2016) and that P600 is associated with more controlled processes (Gunter & Friederici, 1999; Hahne & Friederici, 1999, 2002; Hasting & Kotz, 2008). Moreover, owing to the absence of sensitivity to morphosyntactic violations over the P600 time window in grammatical categorization task, we posit that the processing of morphosyntactic features is more controlled than that of the associative representations. The latter might also act as constraints to affect the processing of morphosyntactic features during the detection of morphosyntactic violations, as shown by the interaction between the two types of representations involved in the subject-verb agreement processing in the grammatical categorization task.

This is the first study to explore the flexibility of various representations involved in subject-verb agreement. Importantly, there are fewer studies on subject-verb agreement processing conducted in spoken language than in written language. Further research is needed to identify the flexibility of representations in a wider variety of tasks, with various strategies and in various languages. As proposed by Ackema & Neeleman (2019), additional studies on subject-verb agreement should be conducted to obtain more information about the use of morphosyntactic features according to the processing of pronominal subjects and subjects with content words. Moreover, since the accessing of associative representations related to the prediction of the upcoming verbal inflection from the subject could influence the use of morphosyntactic features, the hierarchical organization of associative representations and morphosyntactic features should be explored.

5. Conclusion

The present study sheds new light on the flexible use of representations that are involved in agreement processing, particularly in subject-verb agreement. The accessing of abstract representations was more affected by task demands than the use of associative representations. Interestingly, the importance of statistical language information in grammatical agreement is not only found in language production but also in language comprehension. The accessing of associative representations related to the prediction of the upcoming verbal inflection from the subject could influence the use of morphosyntactic features.

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Tables

Table 1

Summary of predicted findings if flexibility depends on the nature of the task

		Experimental task			
		LDT		**Grammatical categorization**	
		Associative frequency	**Grammaticality**	**Associative frequency**	**Grammaticality**
ERP components & ROI	**N100** ROI: frontal, central	✓✓		✓	
	LAN ROI: Anterior, frontal, central		✓		✓✓
	N400 ROI: central	✓✓		✓	
	P600 ROI: posterior		✓		✓✓

Note. ✓ indicates that we expect a significant effect related to associative frequency or grammaticality during the time window that is specified on the first column (i.e., N100, LAN, N400, P600). The number of ticks indicates the magnitude of the effects. An associative frequency effect means a difference of processing between high and low associative frequency conditions. The grammaticality factor was composed of one congruent condition and three incongruent conditions (i.e., congruent, number violation, person violation, number & person violation) to probe the access to abstract morphosyntactic features. Four ERP components are predicted based on prior literature and the regions of interests (ROIs) were those where the amplitude of ERP components was described as being the strongest. As a result of flexibility in accessing abstract morphosyntactic features and associative frequency, we expected over each ERP component a significant interaction between experimental task and one of the two following factors: associative frequency and grammaticality (including ROIs or not). We would expect the opposite pattern as that shown in this table if flexibility depends on the cognitive strategy to complete the task and no significant interactions between experimental task and associative frequency/grammaticality (including or not ROI), if no flexibility exists. For N100, the strongest negative values are known to occur over the frontal and central sites. In a relatively similar time window, the strongest negative values are usually found over the anterior and frontal sites for the LAN and over the centroparietal site for N400. Lastly, the strongest positive values are usually observed over the posterior sites for the P600 component. In case of significant interactions between experimental task and associative frequency/grammaticality including ROIs, we expected that the regions of interests (ROIs) of each ERP component would be those for which significant effects would appear.

Table 2

Examples of stimuli in each experimental condition, depending on grammaticality and associative frequency

Grammaticality	Phrase stimuli	Associative frequency
Congruent	***Tu***$_{\text{2nd person-singular}}$ *montrer**as***$_{\text{2nd person-singular}}$- You will show	Low
	Nous$_{\text{1st person-plural}}$ *rester**ons***$_{\text{1st person-plural}}$ - We will stay	High
Person violation	***Je***$_{\text{1st person-singular}}$ *montrer**as***$_{\text{2nd person-singular}}$ - I will show	Low
	Vous$_{\text{2nd person-plural}}$ *rester**ons***$_{\text{1st person-plural}}$ - You will stay	High
Number and person violation	***Nous***$_{\text{1st person-plural}}$ *montrer**as***$_{\text{2nd person-singular}}$ - We will show	High
	Tu$_{\text{2nd person-singular}}$ *rester**ons***$_{\text{1st person-plural}}$ - You will stay	Low
Number violation	***Vous***$_{\text{2nd person-plural}}$ *montrer**as***$_{\text{2nd person-singular}}$ - You will show	High
	Je$_{\text{1st person-singular}}$ *rester**ons***$_{\text{1st person-plural}}$ - I will stay	Low

Table 3.

Example of filler stimuli

Pronoun-verb pairs		**Article-noun pairs**		**Pairs with pseudoword target**	
Prime	**Target**	**Prime**	**Target**	**Prime**	**Target**
Je I	*vocalise* vocalize	*La* The$_{\text{feminine}}$	*fondation* foundation	*Je* I	*clairfoue*
Nous We	*stoppions* have stopped	*Le* The$_{\text{masculine}}$	*doyen* dean	*Nous* We	*larons*
Tu You$_{\text{singural}}$	*ratrappes* catch up	*Les* The$_{\text{plural}}$	*saphirs* sapphires	*Tu* You$_{\text{singural}}$	*mitais*
Vous You$_{\text{plural}}$	*changiez* have changed			*Vous* You$_{\text{plural}}$	*padripiez*
Il He	*pétarade* backfires			*Il* He$_{\text{l}}$	*sablissent*
Elle She	*discernait* has discerned			*Elle* She	*sulmite*
				La The$_{\text{feminine}}$	*pournais*
				Le The$_{\text{masculine}}$	*vajel*
				Les The$_{\text{plural}}$	*choufions*

Note. The pseudoword targets are not translated into English because they are not real words.

Table 4

Statistical results for lexical decision task

	Time window between 100 and 160 ms	**Time window between 300 and 600 ms**	**Time window between 920 and 1120 ms**
Associative frequency	$F(1,22)=0.003$, $p>.2$	$F(1,22)=1.42$, $p>.2$	$F(1,22)=2.35$, $p=.14$
Grammaticality	$F(3,66)=0.05$, $p>.2$	$F(3,66)=5.06$, $p<.01$	$F(3,66)=0.44$, $p>.2$
ROIs	$F(6,132)=6.83$, $p<.001$	$F(6,132)=2.41$, $p=.06$	$F(6,132)=25.26$, $p<.001$
Associative frequency x Grammaticality	$F(3,66) = 1.35$, $p>.2$	$F(3,66) = 0.83$, $p>.2$	$F(3,66) = 2.20$, $p=.11$
Associative frequency x ROIs	$F(6,132)=2.80$, $p<.05$	$F(6,132)=0.29$, $p>.2$	$F(6,132)=1.44$, $p>.2$
Grammaticality x ROIs	$F(18,396) = 1.33$, $p>.2$	$F(18,396) = 1.52$, $p=.17$	$F(18,396) = 2.52$, $p<.05$
Associative frequency x Grammaticality x ROIs	$F(18,396)=0.90$, $p>.2$	$F(18,396)=0.57$, $p>.2$	$F(18,396)=0.94$, $p>.2$

Table 5

Statistical results for grammatical categorization task

	Time window between 100-160 ms	**Time window between 300-600 ms**	**Time window between 920-1120 ms**
Associative frequency	$F(1,23)=10.50$, $p<.01$	$F(1,23)=17.31$, $p<.001$	$F(1,23)=1.51$, $p>.2$
Grammaticality	$F(3,69)=1.41$, $p>.2$	$F(3,69)=1.91$, $p=.15$	$F(3,69)=0.19$, $p>.2$
ROIs	$F(6,138)=5.15$, $p<.05$	$F(6,138)=4.25$, $p<.05$	$F(6,138)=29.60$, $p<.001$
Associative frequency x Grammaticality	$F(3,69) = 1.75$, $p=.17$	$F(3,69) = 4.25$, $p<.01$	$F(3,69) = 0.97$, $p>.2$
Associative frequency x ROIs	$F(6,138)=3.02$, $p<.05$	$F(6,138)=0.21$, $p>.2$	$F(6,138)=0.32$, $p>.2$
Grammaticality x ROIs	$F(18,414) = 1.13$, $p>.2$	$F(18,414) = 0.54$, $p>.2$	$F(18,414) = 0.93$, $p>.2$
Associative frequency x Grammaticality x ROIs	$F(18,414)=0.93$, $p>.2$	$F(18,414)=2.64$, $p<.05$	$F(18,414)=2.02$, $p=.07$

Figure captions

Figure 1.

ERP waveforms over seven ROIs from Experiment 1 in LDT

Note. X axis depicts timescale in milliseconds. Y axis depicts mean amplitude in microvolts (μV). Negative value is at the top. Black represents congruent condition, green represents number violation condition, red represents number and person violation condition and blue represents person violation condition. Vertical dashed line in middle of each plot is mean onset of inflection (482 ms). Shaded areas are time windows that we focused on. The first time window was from 100 to 160 ms; the second time window was from 300 to 600 ms; the third time window was from 920 to 1120 ms.

Figure 2.

Mean amplitude and standard error of the mean (SEM) bars related to associative frequency effect from Experiment 1 in LDT

Note. a.) topographical maps for each associative frequency condition wherein negative values are indicated with blue color while positive values are indicated with red color. b.) * $p<.05$, ** $p< .01$, *** $p< .001$. Negative value is at the top. Bar graph showed interaction between associative frequency and ROIs.

Figure 3.

Mean amplitude and standard error of the mean (SEM) bars of grammaticality effect from Experiment 1 in LDT

Note. * p<.05, ** p< .01, *** p< .001. Negative value is at the top. Black represents congruent condition, green represents number violation condition, red represents number and person violation condition and blue represents person violation condition. a.) Mean amplitude over all sites in the time window of 300-600 ms; b.) mean amplitude over the posterior site in the time window of 920-1200 ms.

Figure 4.

ERP waveforms over seven ROIs from Experiment 2 in grammatical categorization task

Note. X axis depicts timescale in milliseconds. Y axis depicts mean amplitude in microvolts (μV). Negative value is at the top. Black represents congruent condition, green represents number violation condition, red represents number and person violation condition and blue represents person violation condition. Vertical dashed line in middle of each plot represents mean onset of inflection (482 ms). Shaded areas are time windows that we focused on. The first time window was from 100 to 160 ms; the second time window was from 300 to 600 ms; the third time window was from 920 to 1120 ms.

Figure 5.

Mean amplitude and SEM bars of associative frequency effect for Experiment 2 in grammatical categorization task

Note. ** p< .01, *** p< .001. On Y axis, negative value is at the top. a.) illustrates main effect of associative frequency and b.) depicts significant interaction between ROIs and associative frequency. Red represents high associative frequency and green represents low associative frequency.

Figure 6.

Mean amplitude and standard error of the mean (SEM) bars of interaction between associative frequency, grammaticality, and ROIs from Experiment 2 in grammatical categorization task

Note. * p<.05, **p< .01, ***p< .001. On the top is the bar graph depicting interaction between grammaticality conditions and ROIs in high associative frequency condition while the same interaction for low associative frequency condition is shown on the bottom.

Figure 7.

Mean amplitude and standard error of the mean (SEM) bars of the experimental effect.

Note. * p<.05. a.) Subtraction between high and low associative frequency in both experiments during the time window of 100 -160 ms over left anterior site; b.) Subtraction between number and person violation with congruent condition during the time of 300-600 ms over all sites; c.) Subtraction between number and person violation with congruent condition during the time window of 920-1120 ms over the posterior sites.

Figure 1

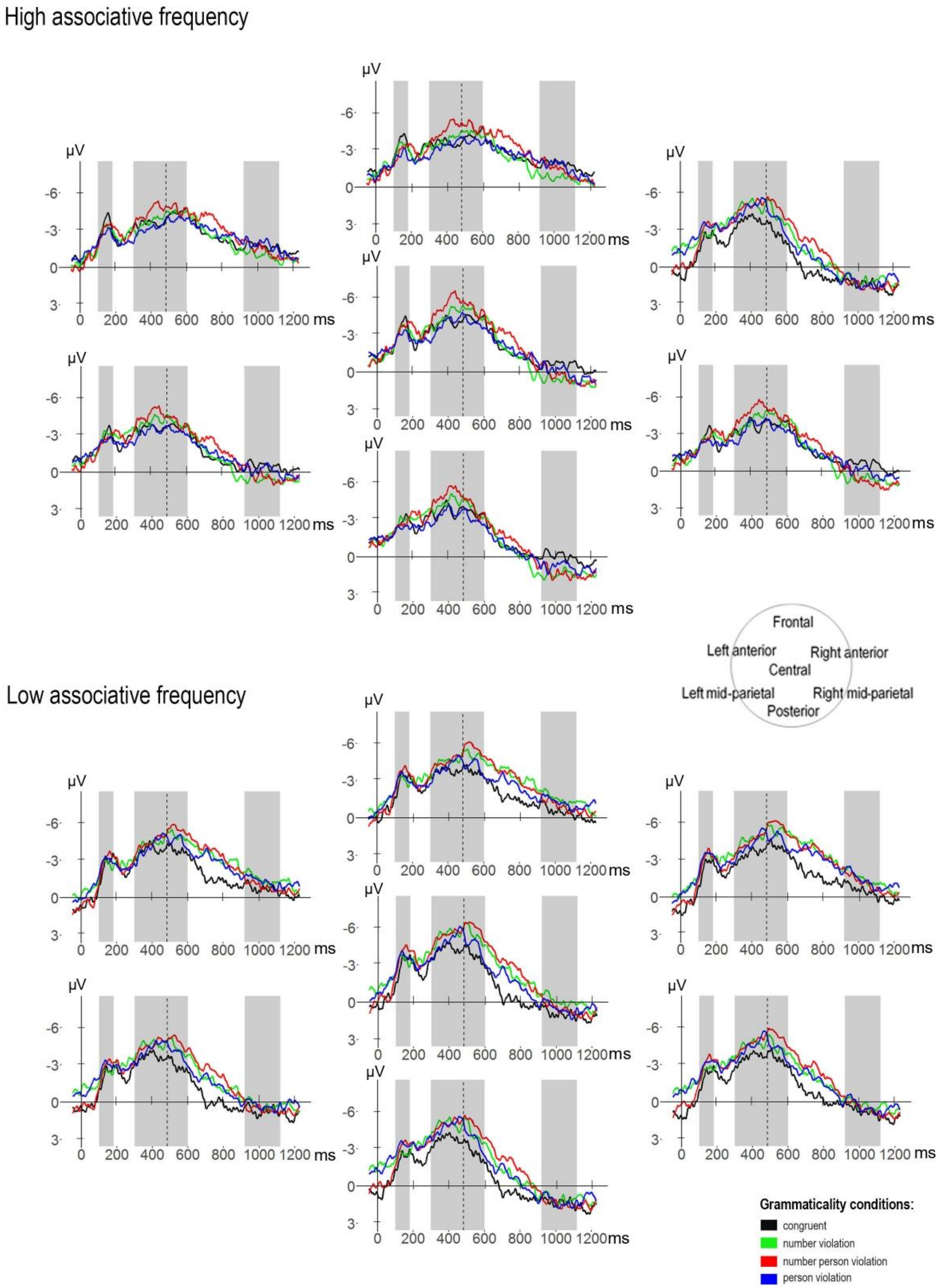

High associative frequency
Low associative frequency
Frontal
Left anterior
Right anterior
Central
Left mid-parietal
Right mid-parietal
Posterior
Grammaticality conditions:
congruent
number violation
number person violation
person violation

Figure 2

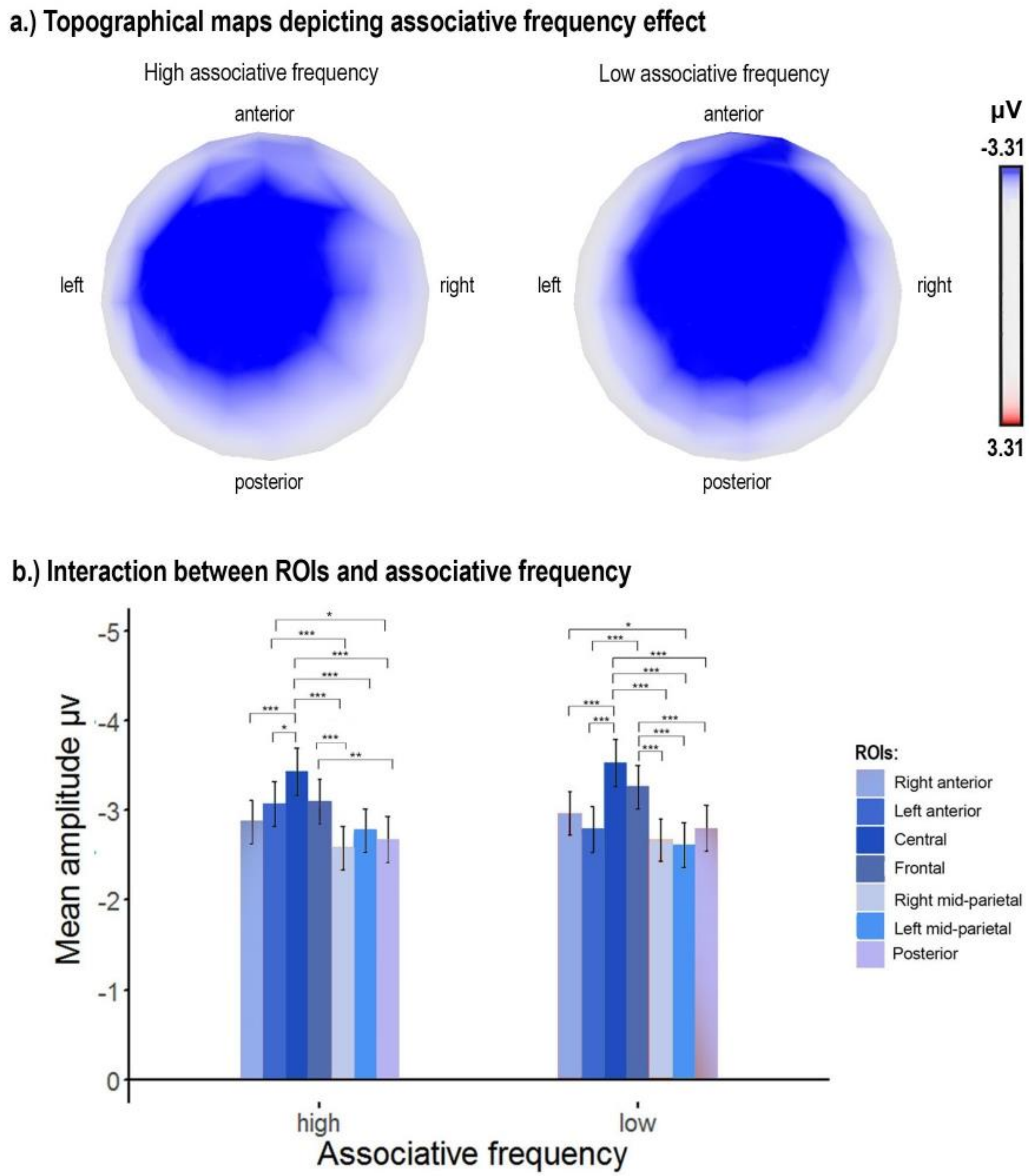

a.) Topographical maps depicting associative frequency effect
High associative frequency
Low associative frequency
anterior
left
right
posterior
μV
-3.31
3.31
b.) Interaction between ROIs and associative frequency
Mean amplitude μv
-5
-4
-3
-2
-1
0
high
low
Associative frequency
ROIs:
Right anterior
Left anterior
Central
Frontal
Right mid-parietal
Left mid-parietal
Posterior

Figure 3

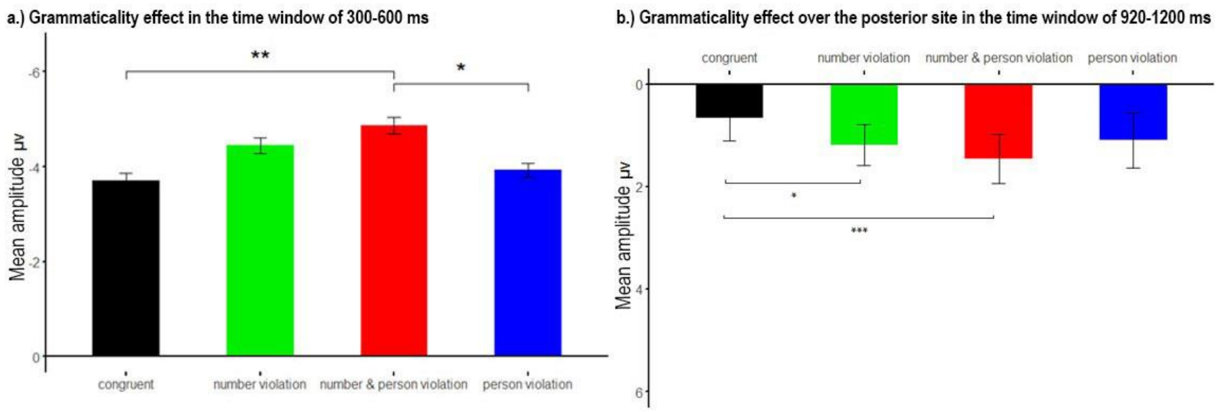
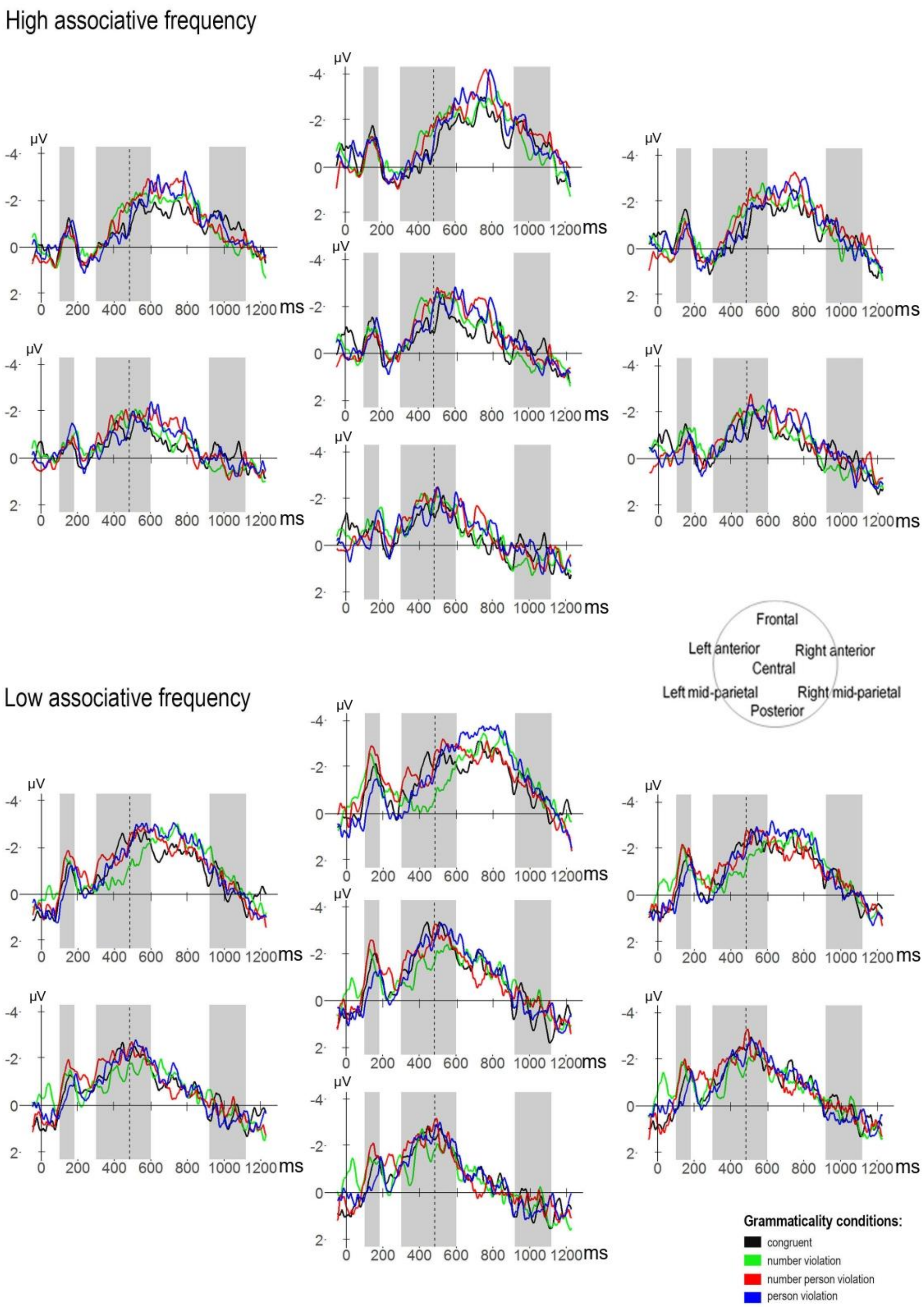

a.) Grammaticality effect in the time window of 300-600 ms
Mean amplitude μv
-6
-4
-2
0
**
*
congruent
number violation
number & person violation
person violation
b.) Grammaticality effect over the posterior site in the time window of 920-1200 ms
congruent
number violation
number & person violation
person violation
0
2
4
6
Mean amplitude μv
*
***

Figure 4



High associative frequency
Low associative frequency
Frontal
Left anterior
Right anterior
Central
Left mid-parietal
Right mid-parietal
Posterior
Grammaticality conditions:
congruent
number violation
number person violation
person violation

Figure 5

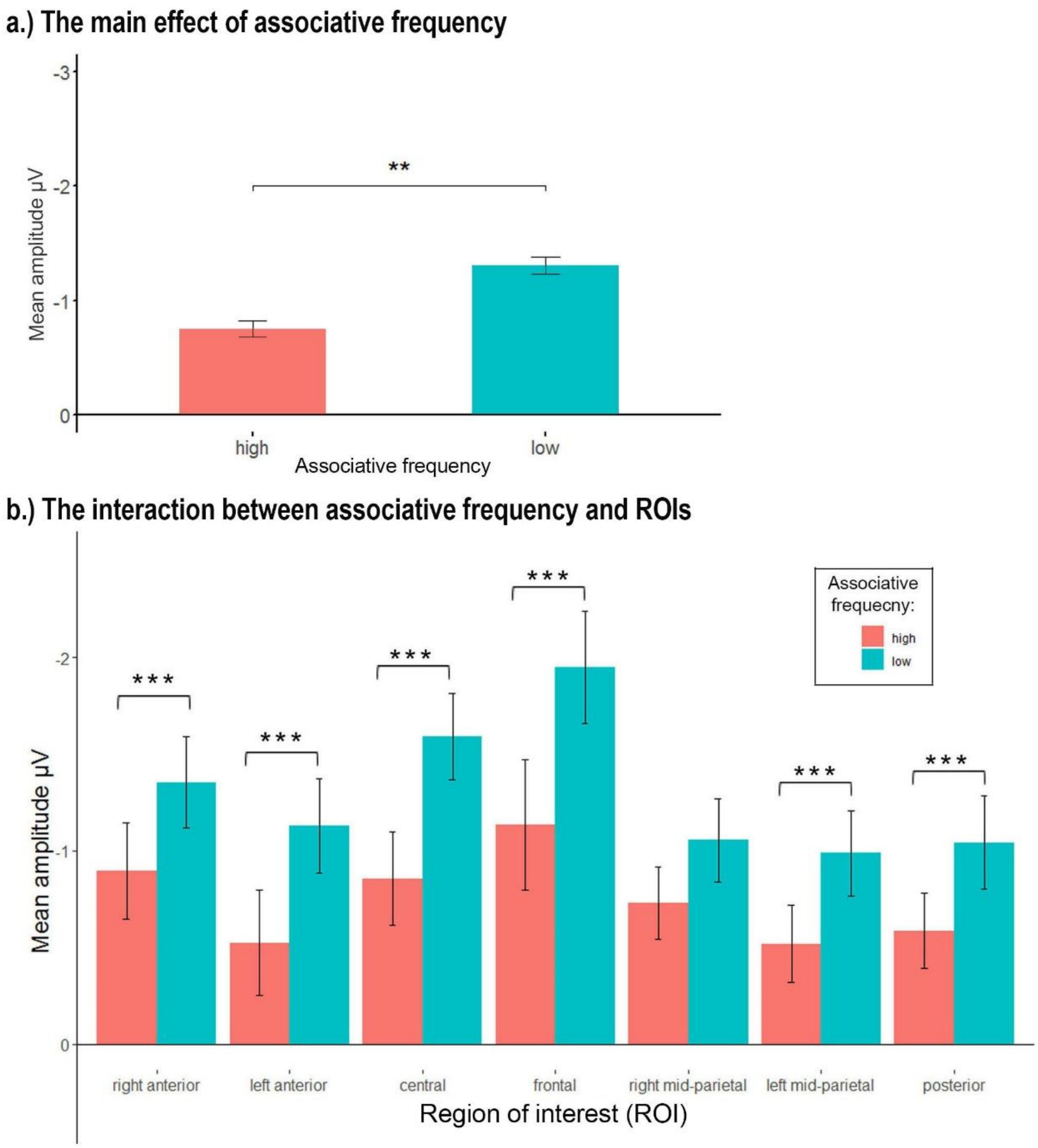

a.) The main effect of associative frequency
-3
-2
-1
0
Mean amplitude µV
**
high
low
Associative frequency
b.) The interaction between associative frequency and ROIs
-2
-1
0
Mean amplitude µV
***
Associative frequecny:
high
low
right anterior
left anterior
central
frontal
right mid-parietal
left mid-parietal
posterior
Region of interest (ROI)

Figure 6

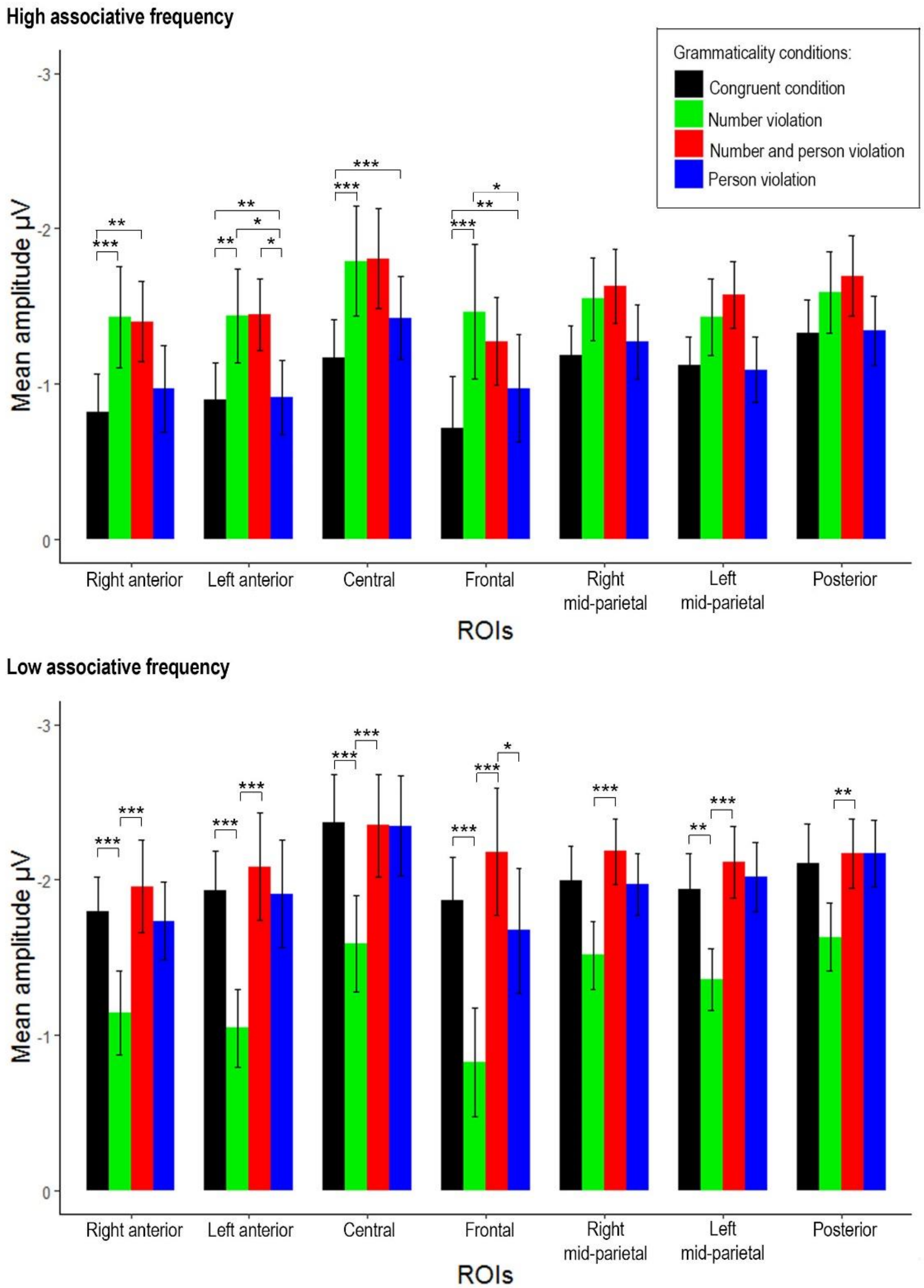
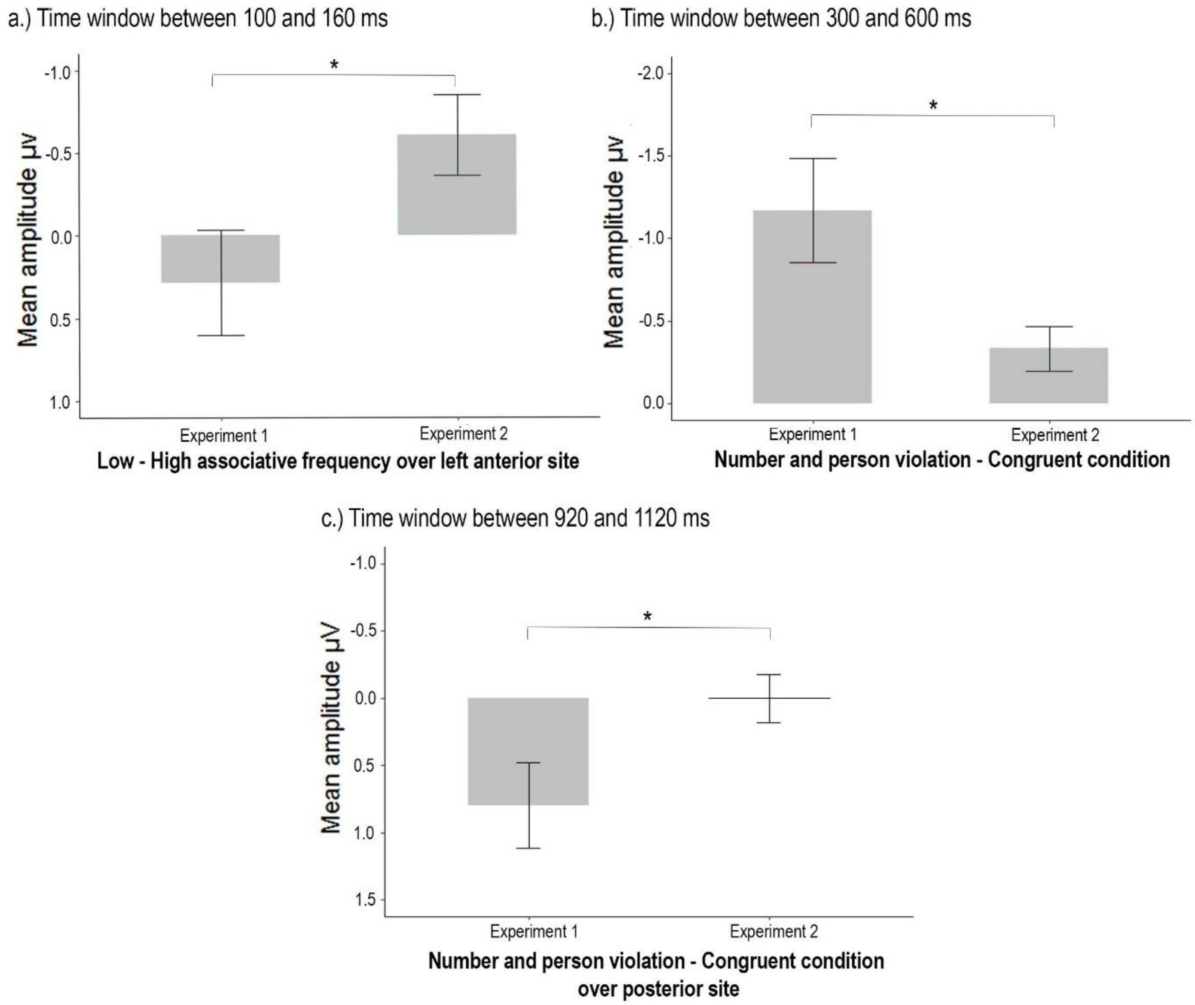

High associative frequency
Grammaticality conditions:
Congruent condition
Number violation
Number and person violation
Person violation
Mean amplitude µV
-3
-2
-1
0
Right anterior
Left anterior
Central
Frontal
Right mid-parietal
Left mid-parietal
Posterior
ROIs
Low associative frequency
Mean amplitude µV
ROIs

Figure 7



a.) Time window between 100 and 160 ms
Mean amplitude µV
-1.0
-0.5
0.0
0.5
1.0
*
Experiment 1
Experiment 2
Low - High associative frequency over left anterior site
b.) Time window between 300 and 600 ms
Mean amplitude µV
-2.0
-1.5
-1.0
-0.5
0.0
*
Experiment 1
Experiment 2
Number and person violation - Congruent condition
c.) Time window between 920 and 1120 ms
Mean amplitude µV
-1.0
-0.5
0.0
0.5
1.0
1.5
*
Experiment 1
Experiment 2
Number and person violation - Congruent condition over posterior site