Neurodynamics of lexical access in sign language differ by age of acquisition: event-related potentials evidence from LSF

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Abstract. Sign languages are constituted of gestural lexical signs linked to a specific meaning. To date, there is little evidence that lexical access in a sign language occurs the same way as in spoken language, and particularly if the age of sign language acquisition influences lexical processing. The present study aims to provide first ERP data in French Sign Language (LSF) on semantic processing collected with an on-line sentence comprehension task in order to compare the time-course of lexical access in LSF. We used sentences with semantic anomalies to two groups of signers: Native and Late signers. We found an increased N400 amplitude in the incongruent conditions, suggesting that deaf signers were sensitive to the semantic incongruity. We observe a qualitative difference in semantic processing between Native and Late signers. Results are discussed in terms of similarity vs. specificity of language processing in sign language, and role of sign language Age of Acquisition.

Keywords. Sign Language, age of language acquisition, deaf signers, lexical access, Event-related potentials, Semantic violation, N400, P600.

Highlights

- First ERP data on semantic processing in LSF.

- Semantic processing is amodal: deaf signers of LSF (French Sign Language) exhibit biphasic waves (N400 and P600).

- Native and Late signers do not process semantic incongruity in the same way: early acquisition results in a larger N400 effect in adulthood.

1. Introduction

Studying signed languages permits important insights into our understanding of the neurobiology of language. Sign languages—being composed of gestural elements—present interesting (albeit sometimes complicating) properties which allow us to probe language processing through the visuo-gestural modality. As with spoken languages, sign languages can be analyzed in terms of their phonological, lexical, morphosyntactic and semantic characteristics (Emmorey, 2002; Sandler & Lillo-Martin, 2006). Sign languages are obviously different from spoken languages because the articulators involved in the composition of meaning are at once manual, bodily and facial, taking place in the signing space – a topological space - that becomes linguistically functional. This gestural characteristic has many consequences for production and perception/comprehension, which require great care in linguistic and psycholinguistic analyses.

Sign language processing relies on a different perceptual system than those used by spoken languages (Boutla et al., 2004; Brentari, 2002). Boutla et al. (2004) observed differences in serial recall in CODA participants (Child of Deaf Adults) according to the languages in which stimuli were recalled. They adapted a spoken Working Memory Task into a signed one by replacing spoken digits by signed letters and observed that serial recall was reduced in American Sign Language compared to spoken English. These results were discussed in terms of type of sensorial information processed: if the auditory system seems proficient to process sequential information, visual system does not seem to be quite so. Consequently, these sensory-motor properties must be considered in analysis of language abilities, in either behavioral or neural investigations.

1.1. Language acquisition in deaf people

Another particularity of sign languages is the way most deaf people acquire sign language. Native exposure to sign language is far from the most common situation: 95% of deaf children are born to hearing parents that are not able to use a sign language with their child at birth and in the early stage of life (Mitchell & Karchmer, 2004), others are born to deaf parents whose sign language is incomplete or non-proficient (Ferjan-Ramirez et al., 2013; Lu et al., 2016; Mayberry, 2007; Singleton & Newport, 2004). This late exposure to any sign language has major consequences on language development (Ferjan-Ramirez et al., 2013; Cheng and Mayberry, 2019; Bogliotti et al., 2020), and can also be observed in neural activation patterns with atypical localization patterns during isolated sign recognition (Ferjan Ramirez et al., 2016; Mayberry et al., 2018). If the gestural properties of sign language have no impact on the language network, it seems that early language deprivation shapes brain connectivity and the language network in an atypical way (Cheng et al., 2019).

Language deprivation causes significant cognitive and language delays (Courtin, 2000; Morgan et al., 2007). Several authors have shown that deaf children with late exposure to a sign language do not master some phonological aspects (Morford, 2000; Bogliotti et al., 2020) lexical processing (Mayberry et Eichen, 1991; Lieberman et al., 2015; Bogliotti et al., 2020), lexical storage (Ferjan-Ramirez et al., 2014), or morphosyntactic structures (Berk, 2003; Morford & Mayberry, 2000; Newport, 1990), and tend to behave like L2 learners (Mayberry & Eichen, 1991; Mayberry & Lock, 2003; Newman et al., 2002).

Several researchers report that early exposure to sign language provides benefits, even for second language (L2) literacy (Newman et al., 2002; Mayberry and Lock, 2003). Early/native exposure must be distinguished from sign language experience: even with 15 to 20 years of practice, non-native adults cannot behave like adults who are native signers (Mayberry, 2007). In addition, while native signers—either deaf or hearing—with deaf parents grow up and acquire language in a sign language-rich environment, non-native signers usually first encounter the gestural modality or sign language at school. Consequently, the linguistic environment has strong impacts on language acquisition and the linguistic skills observed in adulthood (Boudreault & Mayberry, 2006; Mayberry & Lock, 2003 ; Newman et al., 2002 ; Ferjan-Ramirez et al., 2013).

1.2. Lexical access in sign language

Sign language's linguistic units are gestural, and the lexicon is mostly expressed by manual articulators (arms, hands, and fingers) spread in the signation space, all these units being perceived by the visual system (Jepsen et al., 2015). During the last 25 years, there have been several experiments about lexical access in sign language reporting that lexical access takes place in the same way as in spoken languages. First, these studies reported a lexicality effect: signers recognized linguistic signs faster and more accurately in comparison to non-signs (Carreiras et al., 2008; Dye et al., 2016; Emmorey & Corina, 1993; Guttierez et Carreiras, 2009). As in spoken languages (see Segui, 2015, for a review), frequency effects have been observed in sign language. Several studies reported a familiarity effect: familiar signs are recognized faster and more accurately than unfamiliar signs (Carreiras et al., 2008; Ferjan Ramirez et al., 2016; Mayberry and Witcher, 2005). For most sign languages, these experiments are not easily replicable because the sign frequency is unknown: except for American Sign Language (ASL), Spanish Sign Language (LSE) and British Sign Language (BSL), which have available subjective frequency (lexical familiarity), rated by deaf signers (Caselli et al., 2017 for ASL; Guttierez-Sigut et al., 2016 for LSE; Fenlon et al., 2014 for BSL; Johnston et al., 2012 for a review on frequency in sign language), other sign languages do not have this information readily available.

Although the same trends are observed in the lexical access process in sign language as in spoken language, the gestural modality influences the timing of access. Because of the simultaneity of sublexical features and the minimal sequentiality, a sign is recognized faster than a spoken word: signs are recognized when around 35% of the sign has been produced, while words are recognized when around 80% of the word has presented (Emmorey and Corina, 1990; Gutiérrez- Sigut and Baus, 2021). These results are supported by the simulations generated by Caselli and Cohen-Goldberg's (2014) computational model. Caselli and Cohen-Goldberg observed that model simulations matched the experimental data: the location parameter was activated earliest and seemed to be the most robust parameter due to its high sublexical frequency (the inventory of locations is smaller than those of handshapes or movements) and high perceptual saliency (location is the first parameter placed in the signing space), and due to its articulatory characteristics (i.e., more global motoric articulation), holds a large part of signing space. Consequently, this perceptual saliency led to a stronger memory encoding/trace (Gutiérrez-Sigut and Baus, 2021). One question that remains is which word/sign recognition characteristics are universal (language-general) in spoken and sign languages in models, and which are specific to each language modality (language-specific).

1.3. Electrophysiological evidence of semantic processing in sign languages

Since the Kutas and Hillyard princeps study (1980), numerous studies in several spoken languages have reported that semantic integration activates a negative component around 400 milliseconds after the stimulus onset (N400; for a review see Federmeier & Kutas, 2011; Friederici, 2011; Isel & Kail, 2018). These studies observed a larger N400 amplitude when a word is unexpected and could not easily be integrated in the sentence context. In contrast to spoken languages, few ERP studies have focused on the time course of semantic or syntactic processing in sign language (for ASL: Neville et al., 1997; Capek et al., 2009, Gutierrez et al., 2012; Grosvald et al., 2012; Malaia et al., 2020. For German sign language (DGS): Skotara et al., 2012; Hosemann et al., 2013; Hänel-Faulhaber et al., 2014. For Spanish Sign Language (LSE): Guttierez et al., 2012. For preliminary results in Finnish Sign Language (FinSL): Hernández et al., 2022). These studies all reported an elicitation of an N400 component for violation of selectional restriction in the sign language investigated, suggesting that semantic processing is modality independent. Although these studies underlined that signed and spoken languages share similar underlying neurodynamic language processes, some authors mentioned sign processing specificities as a later elicitation for the N400 than in spoken languages, or a more anterior distribution compared to those observed in spoken language and reading studies (Capek et al., 2009; Grosvald et al., 2012; Hanel-Faulhaber et al. 2014; Neville et al., 1997). These results could be the consequence of signs' characteristics as the variability in the recognition point or lengthier transition times between signs. These latter explanations highlight the technical challenges to resolve in implementing EEG experiments in sign languages.

In addition, as Boutla et al. (2004) suggested, sign languages are gestural languages and perceived by the visual system that has its own perceptual specificities (Brentari, 2002). It is unclear whether previous studies have taken perception modality differences into account. For example, is visual perception of a written language like visual perception of a signed language? As sign language is spread in signation space and with simultaneous linguistic cues, the question about the visual process is legitimate.

Language deprivation is another factor to consider in the investigation of language skills in deaf signers. Few ERP studies have investigated the role of AOA and / or language experience on semantic processing. Neville et al. (1997) observed processing differences between native signers (deaf or hearing) and late signers, especially for the processing of closed-class stimuli (specific sign language units). Results of Neville's study should be interpreted with caution due to their choice of stimuli. In the same way, Skotara et al., (2012) in a violation paradigm experiment in which deaf native signers, deaf non-native signers and hearing native German speakers were submitted to process German written sentences with semantic or syntactic violations. While they observed that syntactic processing was affected by language deprivation, semantic processing was not. This result suggests that syntactic processing may be more cognitively demanding than semantic processing, especially in less-experienced signers.

So, the several studies on neurophysiological processing in sign language are consistent with previous findings from spoken language studies, and that semantic processing is largely modality independent. To the best of our knowledge, no ERP studies attempted to investigate the neurochronometric correlates of semantic processes in LSF. The goal of this study is to provide the first ERP results in LSF using a violation paradigm and an acceptability judgment task to examine age of sign language acquisition effects.

2. The present study

The present study aimed to investigate the neurophysiological processing of LSF, with a focus on the semantic level. In particular, we aimed to investigate how ERP markers associated with semantic processing in spoken languages and other sign languages are quantitatively and qualitatively similar or different in LSF. For this purpose, we used a violation paradigm with an offline acceptability judgment task in two groups of deaf adults: Native signers and Late signers.

2.1. Predictions

According to previous studies, we aimed to replicate the electrophysiological correlates of semantic processing. We predicted the emergence of an N400 component in response to the processing of sentences with a semantic violation (semantic incongruity). This N400 may be followed by a posterior P600 reflecting reanalysis of semantic integration (DeLong et al., 2011). We predict that the different ERP markers observed in this task should be modulated in both amplitude and latency as a function of AOA: Native signers should show a greater effect of semantic incongruity in comparison to Late signers. Absence of N400 in Late signers should be considered a neurophysiological marker of language delay or reduced proficiency as a consequence of the language deprivation in childhood. Correlation analyses should enable to precise the interplay between age of LSF acquisition and early detection of semantic anomalies. A negative correlation should be expected between age of LSF acquisition and the amplitude of the N400: the later the age of LSF acquisition, the lower the amplitude of the N400. The reverse prediction is made for the latency of the N400: the sooner the age of LSF acquisition, the greater the latency of the N400. Later cognitive processes like syntactic reanalysis should be less influenced by the age of LSF acquisition. This should be reflected by relatively comparable amplitude and latency of posterior P600 between Native and Late language learners of LSF. These markers should differ quantitatively between Native signers and Late signers: Native LSF learners should present a larger N400/P600 biphasic ERP complex with shorter latency than the second language/ late learners of LSF.

2.2. Methodology

2.2.1. Participants. Twenty-five deaf signers (14 female) participated in the experiment (mean age: 29.7 years-old, SD = 9.7 years; 18-51 y.o.). They presented various Ages of Acquisition of LSF and varied in experience in LSF in terms of length of daily exposure or quality of LSF input (See Table 1 in Supplementary Material for the biographical characteristics of the participants). Consequently, we considered 14 deaf adults as Native signers who grew up in deaf families and had daily exposure to LSF from birth (Mean Age = 27.2 years, SD = 6.9 years), and we considered 11 deaf as Late signers, who grew up in hearing families, with a first exposure to LSF after 6 years-old (Chronological Age: Mean Age =32.9 years-old, SD= 12.14 ; Age of Acquisition: Mean Age = 13 years-old, SD = 5.1 years-old (range 6-22)). There is no significant difference of Chronological Age between the two groups ($t(23) = -1.45$; $p = 0.15$). We measured language experience with a self-evaluation and a questionnaire with several questions about LSF exposure in daily life (family, friends, work) and quality of signed language skills of other deaf or hearing signers. All deaf signers had no known history of neurological disease and had normal vision. Participants were informed about the experiment before giving their written consent and received monetary compensation. The data collected were anonymized by applying the European Data FAIR principle in collaboration with HumaNum for the management of the experimental data (Wilkinson et al., 2016). The study was approved by the local ethics committee of Paris Nanterre University and was performed in accordance with the principles of the Declaration of Helsinki.

2.2.2. Material. 120 signed sentences were created with two Native deaf signers and sign language linguists. Sentences were targeted to deaf adults, focusing on Deaf culture with social and daily life themes. Sentences were compounded of 5 to 14 signs length (median: 10 signs) and were produced at a natural speed. The set of stimuli was divided in two conditions: 1) *Control condition:* 60 sentences were semantically correct; 2) *Semantic Incongruent Condition*: 60 sentences were semantically incorrect, with a violation of lexical restriction (Figure 1). All sentences were videotaped.

Insert Figure 1 here

Figure 1. One trial presented in the two conditions: Control Condition, in which all stimuli are semantically congruent; Semantic Incongruent Condition, in which one sign is unexpected in the presented sentence (here PHOTO).

Every 6-8 trials, participants were submitted to a behavioral task to keep their attention throughout the experiment. This task asked participants whether an isolated sign (Figure 2, scenario b) was produced in the previous sentence. The participants had to press a button corresponding to the GREEN SMILEY if the isolated sign was present in the sentence, and another corresponding to the RED SMILEY if not. The participants checked 16 isolated signs.

2.2.3. Procedure. Before the experiment started, instructions were presented in LSF, by the deaf Native signer who recorded the stimuli. The participant could repeat the instructions if needed. The participant would then do four practice trials to familiarize them with the task. Once the experimenter ensured that the participant understood the instructions, the experiment started. Each trial started with a centered fixation cross for 1000ms. Then, the sentence was presented as a continuous video. For the 16 trials with a verification question (the attentional task), 10 seconds were allocated after the end of the stimulus presentation for the response. After each sentence, a black screen appeared for 1000ms before the next fixation cross.

The ordering of the sentences was pseudo-randomized for each participant, such that the same condition could not appear more than three times in a row within a given block. Participants were seated comfortably in front of the computer screen, which was positioned 50 cm from the participant at eye level. They had a keyboard to answer to the attentional judgement task: a red and a green sticker were placed on the F and J keys (alternatively GREEN or RED button; counterbalanced for each participant). The experimental stimuli were presented using PsychToolbox (Kleiner et al., 2007) in Matlab (The Mathworks, Inc.). The total duration of the experiment was 60 minutes, not including the electrode cap installation time (30 minutes) and removing the electrode cap (10 minutes).

Insert Figure 2 here

Figure 2. Experimental procedure. Participants saw the LSF sentence, and (a) either the next stimulus appeared or (b) either participant were submitted to the attentional task.

2.2.4. Trigger in sign language. As mentioned earlier, several technical and linguistic challenges must be resolved in order to create an EEG experiment using sign language videos as stimuli. For example, while setting a trigger to the onset of the spoken word is easy because coarticulation and transition are clear-cut, the manual sign onset is more complex to define.

These technical and linguistic issues are strongly interdependent must be addressed in order to be able to correctly analyze lexical integration. Firstly, given that i) sign articulation is known to be slower, ii) places of articulation between two signs are more or less distant (e.g., location of one first sign to the second one can be from the neutral space going to forehead, or nose to chest, or hear to eye, etc.) and consequently transitions between manual signs are more or less shorter, iii) according to the length of transitions, coarticulation timing and manual articulator preparation can be more or less brief. Secondly, Emmorey (2012) reported that lexical access is very quick due to the production of simultaneous manual cues. So, what point is the appropriate chrono-location to consider as the onset of the sign? Is the sign onset when all manual parameters (correct handshape, correct location, and correct movement) are well-formed? If we consider this as the onset sign, we could lose some processing information: for manual sign preparation and during sign-to-sign transition, signers produce some phonological cues that could give semantic information perceived by signers, meaning that the lexical access process could already be in progress. In our experiment, we defined sign onset (and corresponding trigger point for the EEG) as the first detectable handshape change of the sign that will be signed. More precisely, the handshape was not necessarily completely well-formed in terms of location, or movement, but there were enough phonetic cues to activate lexical candidates.

2.2.5. Electrophysiological recording. Scalp EEG was recorded using a BioSemi ActiveTwo system from sixty-four active electrodes fixed on the participant's scalp by means of an elastic cap (Neurospec AG Switzerland). Electrodes were positioned according to the 10-20 international system. Horizontal eye movements (HEOG) were registered by electrodes at the outer canthus of each eye and vertical eye movements (VEOG) were recorded by electrodes fixed above and below the left eye. DRL and CMS electrodes (on either side of the POz electrode) were used as the online reference. EEG was re-referenced offline to the average of the two mastoids. The EEG signal was recorded with a sampling rate of 512 Hz, and online band-pass filtered between 0.5 and 100Hz.

2.2.6. ERP Data analysis. Matlab (The Mathworks, Inc.), EEGlab (Delorme & Makeig, 2004) and Fieltrip (Oostenveld et al., 2011; http://fieldtriptoolbox.org/) software were used to analyze the EEG data. Data were re-referenced to the averaged mastoids and band-pass filtered between 0.5 to 40. Segments containing large artifacts due to participant movement were removed by manual inspection. ICA decomposition was performed using the default runica algorithm, and components corresponding to ocular artifacts were removed. Data were then separated into 1100 ms epochs (-100 to 1000 ms about sign onset) and were averaged by condition for each participant. Electrodes were grouped into 7 regions of interest: 3 on the left hemisphere (frontal, temporal, posterior), 3 on the right hemisphere (frontal, temporal, posterior), and one on the median line. We further selected two temporal regions of interest corresponding to our expected components: 350-550ms for the N400, and 600-800ms for the P600.

3. Results

Visual inspection of the data showed differences in amplitude and scalp distribution at the different time windows studied (350-550 ms and 600-800 ms). Scalp maps show the differences between the Baseline and Semantic Condition at the 350-550ms (Figure 3) and 600-800ms (Figure 5) time windows.

3.1. Statistical analysis. We ran two repeated-measures ANOVAs, a first one to investigate lexical-semantic integration (N400, time window 350-550 ms), and a second one to investigate the reanalysis mechanism (P600, time window 600-800 ms). ANOVAs were run with Groups (2 levels: Native *vs* Late signers) as between-subject factors, and Condition (2 levels: Control condition *vs* Semantic condition) as within-subject factor.

3.1.1. Semantic integration analysis (N400). For the time window 350-550 ms, the ANOVA showed a main effect of Condition on the set of electrodes Pz-P2-P4 ($F(1,23)=4.05$; $p<.05$) suggesting that Semantic condition induces a greater negativity than the Control condition (Figure 3). We do not observe a Group effect, or Group x Condition interaction (both $F<1$). We observe differences between Native signer's scalp map and Late signer's scalp map: a central-posterior negativity, more right-lateralized, is observable in Native signers while Late signers show a very low negativity. In addition, ERP traces show a larger peak in Native signers in comparison to Late signers (Figure 4). Given the visual difference and lack of Group effect, we ran an independent t-test on the selected set of electrodes Pz-P2-P4 in order to check processing differences between the two conditions for both groups. For Native signers, the t-test is significant ($t(26)=2.13$; $p<.05$) suggesting that semantic integration process differs in the two conditions. This is not the case for Late signers group ($t(20)=1.01$; $p=0.33$) suggesting there is effectively no N400 in the Late signers group.

Insert Figure 3

Figure 3. Scalp map for Native and Late signers in the time window 350-550 ms

Insert Figure 4

Figure 4. Mean ERPs semantic condition. Mean ERPs in the semantic condition for deaf Native signers for cluster Pz-P2-P4 (N400). The blue lines denote the ERP in the semantic condition (semantic violation), the red lines denote the ERP in the correct condition (baseline). The analyzed time epoch is marked with a grey box.

3.1.2. Syntactic Reanalysis (P600). For the time window 600-800 ms, the ANOVA show a main effect of Condition on the set of electrodes AFz-F1-F3 ($F(1,23) = 5.46$; $p < .03$) suggesting a reanalysis mechanism in the Semantic condition (Figure 5). We do not observe a Group effect or Group x Condition interaction (both $F < 1$). Descriptively, we observe differences between the groups in the distribution of the effect on the scalp. Our results show a more anterior P600 effect, however, whereas previous studies have shown a more posterior effect. In our study, Native signers exhibit a central-frontal positivity, while Late signers exhibit a more broadly distributed positivity. In addition, ERP traces show a larger peak in Late signers in comparison to Native signers in the 600-800 ms time-window (Figure 6). Given the visual difference and lack of Group effect, we ran an independent t-test on the selected set of electrodes AFz-F1-F3 in order to check processing differences between the two conditions for both groups. There is no difference for either Native or Late signers (respectively ($t(26)=1.16$; $p=0.26$ and $t(20)=-1.62$; $p=0.12$) suggesting that both groups performed equally in Control and Semantic conditions.

Insert Figure 5 here

Figure 5. Scalp map for Native and Late signers in the time window 600-800 ms.

Insert Figure 6 here

Figure 6. Mean ERPs semantic condition. Mean ERPs in the semantic condition for deaf Native signers AFz-F1-F3 (P600). The blue lines denote the ERP in the semantic condition (semantic violation), the red lines denote the ERP in the correct condition (baseline). The analyzed time epoch is marked with a grey box.

4. Discussion

The present study aimed to investigate for the first time the processing of selectional restriction violations in LSF using ERPs. Based on the ERP data in different spoken languages, neurochronometric models of sentence processing have been developed to account for the neurodynamics of the linguistic semantic processes (for reviews, see Federmeier et Kutas, 2011; Friederici, 2011; Isel et al., 2007; Isel & Kail, 2018). Undoubtedly, neurodynamic studies in sign languages will lead researchers to reconceptualize language processing in the gestural modality and consequently allow for more research into general functioning, processing, and acquisition of language in the gestural modality.

In contrast to spoken languages, relatively few ERP studies have focused on semantic processing in sign language, either in deaf or hearing speakers (in ASL: Neville et al., 1997; Capek et al., 2009, Gutierrez et al., 2012; Malaia et al., 2020; in German Sign Language (DGS): Hänel-Faulhaber et al., 2014; German written sentences in deaf signers: Skotara et al., 2012; for preliminary results in Finnish Sign Language (FinSL): Hernandez et al., 2022). These studies reported an elicitation of a biphasic N400 and P600 brainwaves, respectively a marker of the violation of the selective restriction and the syntactic reanalysis mechanism, suggesting that sign language and spoken language qualitatively share similar underlying linguistic processes.

Our results in LSF are consistent with previous results: we were able to observe the impact of semantic violation on semantic processing, particularly in Native signers. Unfortunately, we did not observe any differences between Native and Late signers, suggesting Age of Acquisition did not significantly impact semantic processing. This result can be explained by the heterogeneity of the deaf population and the weakness of the Native / Late distinction. It would be more interesting to consider the frequency of exposure: while Late signers learnt LSF later in life (late childhood, teenager), most of them use LSF in their daily life. Consequently, in addition to length of exposure -the age of acquisition-, we must provide an efficient way to measure the frequency of exposure. As proposed in Puissant-Schontz (2020), language ability of deaf signers could be conditioned by several factors: age of acquisition, frequency of exposition, quality of exposition in daily life (school, friends, family). In her work, she proposes an index of language proficiency (called *Language Functioning Index)* and analyzed language skills of deaf signers' children from this score: the lower the IFL, the more deficient morphosyntactic abilities in LSF (Puissant-Schontz, 2020). For further studies, it will be necessary to collect most exhaustive metadata to complete an Index of Potential Language Abilities (IPLA). For now, it is impossible to analyze our data with this IPLA because we do not collect enough metadata to compute it.

However, when we compared each group differences for the two conditions, Native signers show interference when they processed incongruent sentences (N400), Late signers do not. These results suggest that level of sign language proficiency impacts semantic processing. Contrary to several results, the N400 effect in this study was not time-delayed as we observed it in the expected 350-550 ms time-window. In Holcomb & Neville (1991), the authors reported a difference in the temporality of the N400 as a function of the stimulus presentation modality: visual incongruent stimuli had a later N400 than auditory incongruent stimuli. In contrast, Hernández et al. (2022) observe a very early N400 (200-400 ms) in visual modality with FinSL sentences.

The P600 results in Native and Late groups show very different pattern of processing. Native signers exhibited a frontal positivity and Late signers a centroparietal positivity. Regarding the P600 in Late signers, we could evoke the previous study of Kolk et al. (2003) who observed a centroparietal P600 occurring after processing of semantic anomalies, rather than biphasic brainwaves frequently observed (N400 and posterior P600). They suggested that P600 could be observed after the processing of an unexpected element without an N400 effect (semantic integration). In addition, this P600 could be show a difficulty of processing complex sentences. In the present study, we can suppose that sentences, whether they were congruent or incongruent, were complex to process for Late signers and were more memory-demanding relative to Native signers.

Regarding Native signers, we observed a frontal P600. This frontal P600 is frequently observed and considered as the syntactic (or semantic integration) reanalysis (Friederici, 2002; DeLong et al., 2011). Kaan & Swaab (2003) reported frontal P600 for ambiguity resolution, which could be what occurred with Native signers, given that semantic anomalies impact their processing.

Testing a sign language requires solving methodological and scientific issues. First, the experimental paradigm adaptation to the gestural modality is rarely mentioned in sign language literature while it is a huge challenge. Constraints linked to the visuo-gestural modality (motoric production and perceptual specificities) could have consequences on language processing, requiring us to redesign the type of paradigm, procedure and analysis to be used. For example, while word onset seems quite clear, determining sign onset is more complex. By choosing to consider the sign onset as the first detectable handshape, we are certain to include the first phonological cue and semantic information on which a signer can rely to access the signed lexicon.

Regarding to the methodology of sign language investigation, it would be interesting to match ERP and eye-tracker methodologies to observe how signers retrieve language information in sign language. Given the simultaneity feature of sign language, we could suppose the gaze of the signer could be fixed at different points on the screen, i.e.: different language cues during isolated stimuli or sentence presentation, ensuring that participants do not miss the semantic violation influencing the incongruity effect. The eye-tracking could be a good way to better understand the process of sign language perception and what level(s) of linguistic units' deaf signers focus on during sentence perception.

Investigating Late signers' language ability offers a unique perspective to understand the impact of language deprivation or deficient exposure on language processing and neurobiology of language. Once again, investigating the impact of AOA on language acquisition is complicated. To date, researchers have focused on AOA, but it will be necessary to propose a more ecological distinction in the future.

This structural difference (visuo-gestural modality) and psycholinguistic context (typical and atypical acquisition) are of major interest for studying the neurobiology of language and understanding the specificity vs. similarity properties of language processing in sign languages.

Acknowledgments

We thank Jérôme Ponsignon for help us in sentence creation, Thomas Guiffard-Colombeau for stimuli video-capture and signal cutting, Sylvain Madec for EEG analysis, Aude Julien Da Cruz Lima for research data management support and Romane Kasprzak for recruitment of deaf signers. This study was funded by the IUF project *Clinical Linguistics and French Sign Language. A Model for Acquisition and Sign Language Disorders* (PI. Caroline Bogliotti).

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Supplementary Material

Table 1. Biographical characteristics of the participants.

Group	Gender	C.A	Sign Language Level	AOA	Frequency of Exposure
Native01	male	46	native	0	frequent
Native02	male	30	native	0	daily
Native03	male	17	native	0	daily
Native04	female	39	native	0	daily
Native05	male	24	native	0	daily
Native06	female	26	near-native	4	daily
Native07	male	27	native	0	daily
Native08	male	20	native	0	daily
Native09	female	39	native	0.5	daily
Native10	female	24	native	2	daily
Native11	male	35	native	3	daily
Native12	female	27	native	0	daily
Native13	male	18	native	0	daily
Native14	male	26	native	2	daily
Late01	female	41	late	9	frequent
Late02	female	49	late	18	unfrequent
Late03	female	51	late	16	daily
Late04	female	23	late	10	daily
Late05	male	50	late	10	daily
Late06	female	21	late	6	daily
Late07	female	27	late	15	daily
Late08	female	26	late	16	frequent
Late09	male	25	late	15	unfrequent
Late10	female	26	late	22	frequent
Late11	female	23	late	6	frequent

Table 1

Group	Gender	C.A	Sign Language Level	AOA	Frequency of Exposure
Native01	male	46	native	0	frequent
Native02	male	30	native	0	daily
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Native08	male	20	native	0	daily
Native09	female	39	native	0.5	daily
Native10	female	24	native	2	daily
Native11	male	35	native	3	daily
Native12	female	27	native	0	daily
Native13	male	18	native	0	daily
Native14	male	26	native	2	daily
Late01	female	41	late	9	frequent
Late02	female	49	late	18	unfrequent
Late03	female	51	late	16	daily
Late04	female	23	late	10	daily
Late05	male	50	late	10	daily
Late06	female	21	late	6	daily
Late07	female	27	late	15	daily
Late08	female	26	late	16	frequent
Late09	male	25	late	15	unfrequent
Late10	female	26	late	22	frequent
Late11	female	23	late	6	frequent

Figure 1

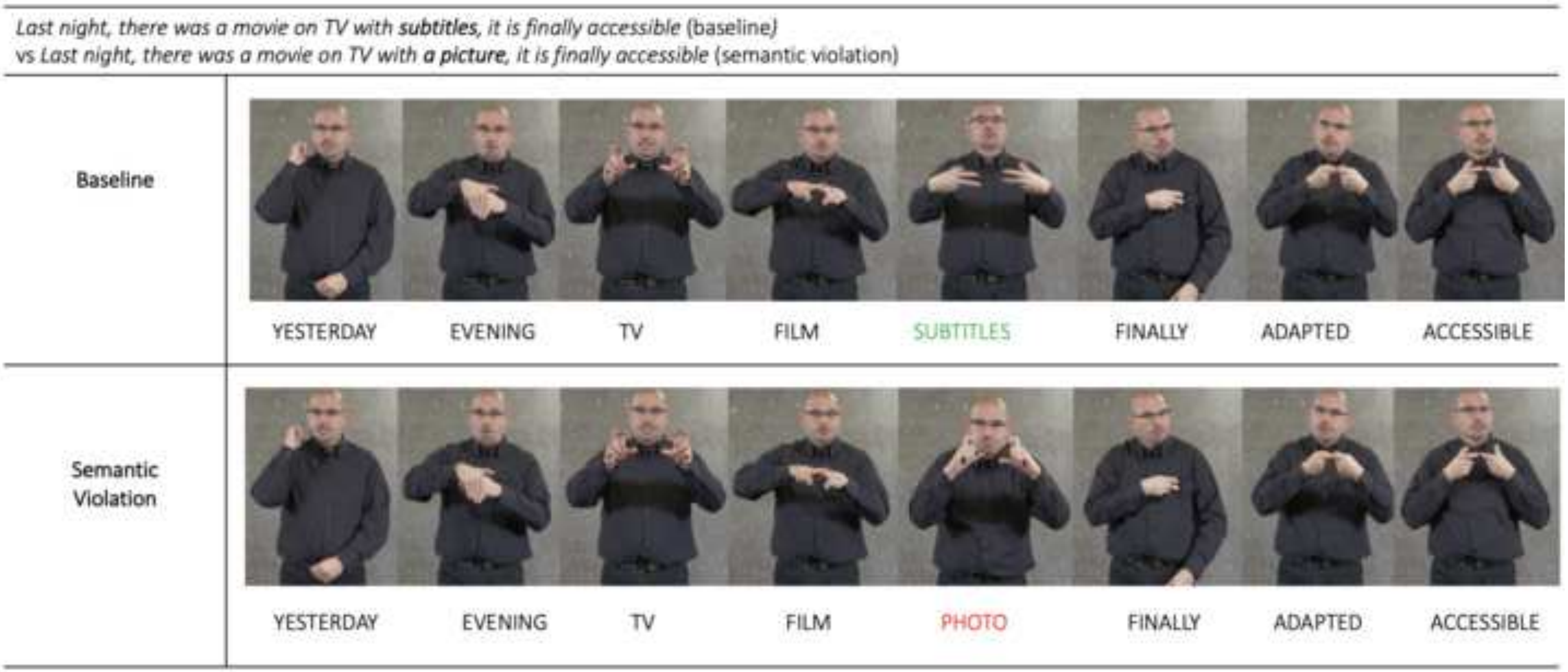
Last night, there was a movie on TV with ***subtitles****, it is finally accessible* (baseline)
vs *Last night, there was a movie on TV with* ***a picture****, it is finally accessible* (semantic violation)
Baseline
YESTERDAY
EVENING
TV
FILM
SUBTITLES
FINALLY
ADAPTED
ACCESSIBLE
Semantic Violation
YESTERDAY
EVENING
TV
FILM
PHOTO
FINALLY
ADAPTED
ACCESSIBLE

Figure 2

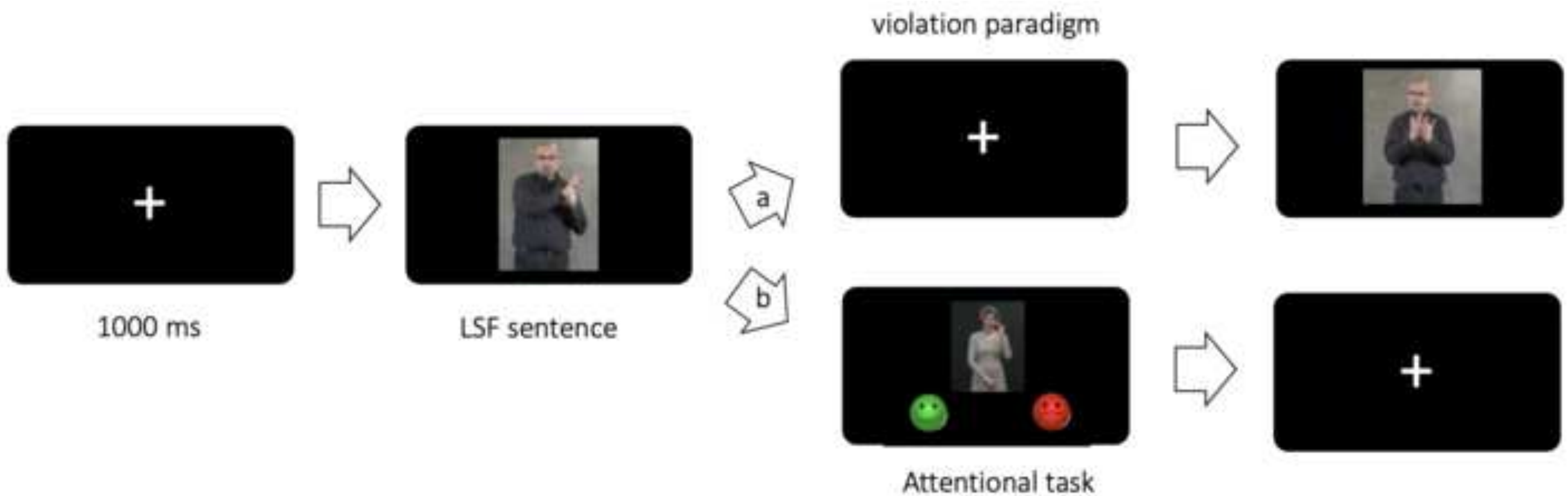
violation paradigm
a
b
1000 ms
LSF sentence
Attentional task

Figure 3

Click here to access/download;Figure;Figure 3.png

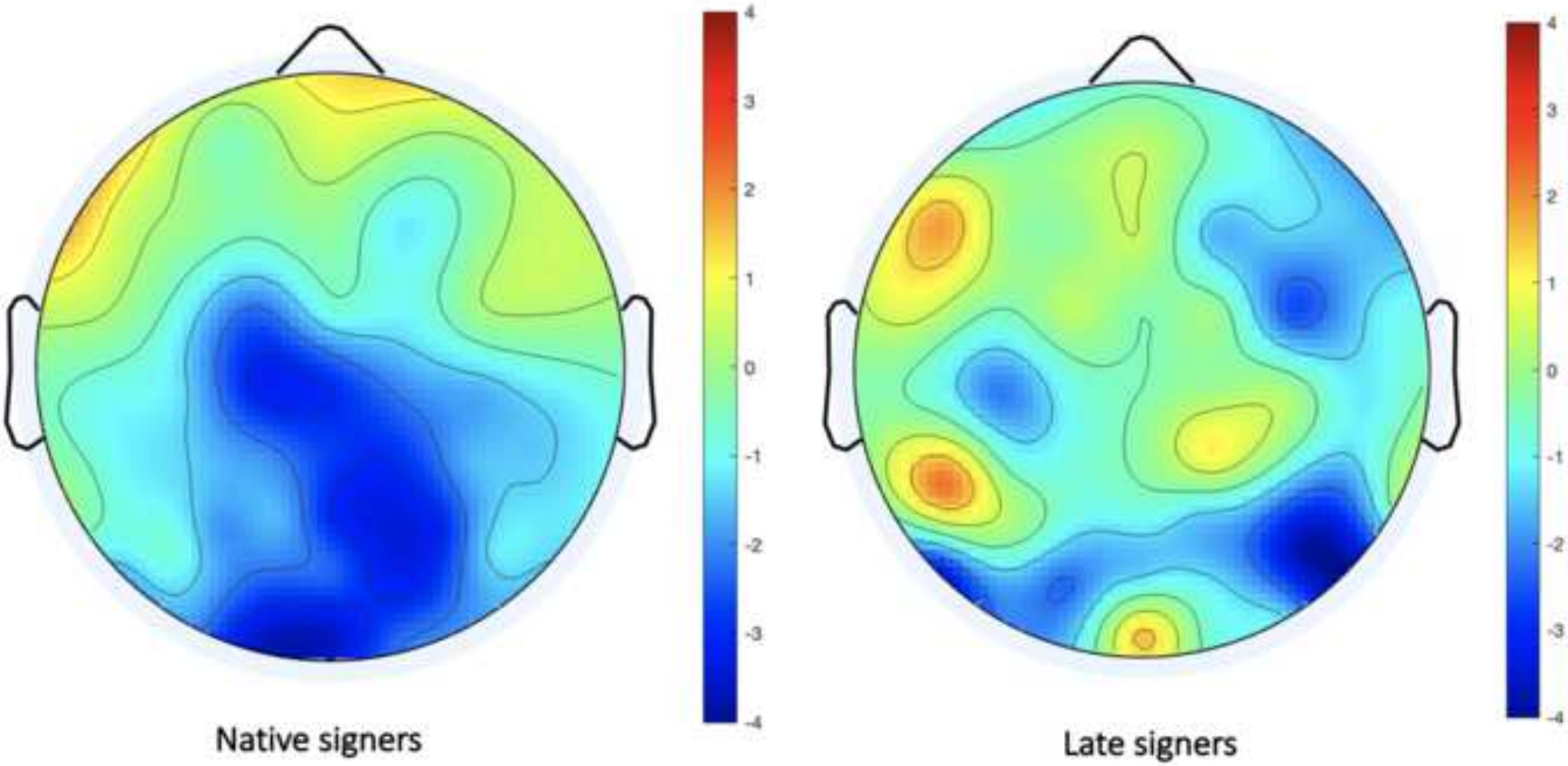

Figure 4

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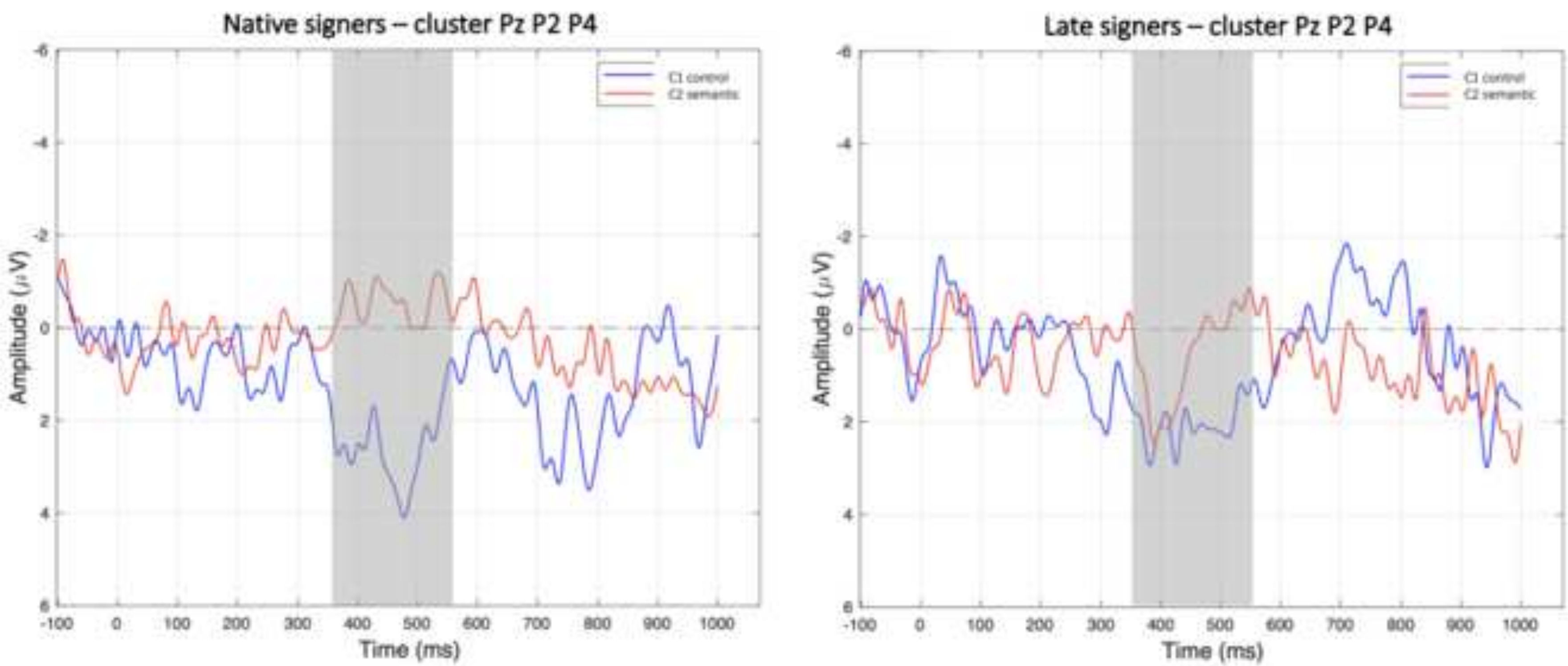


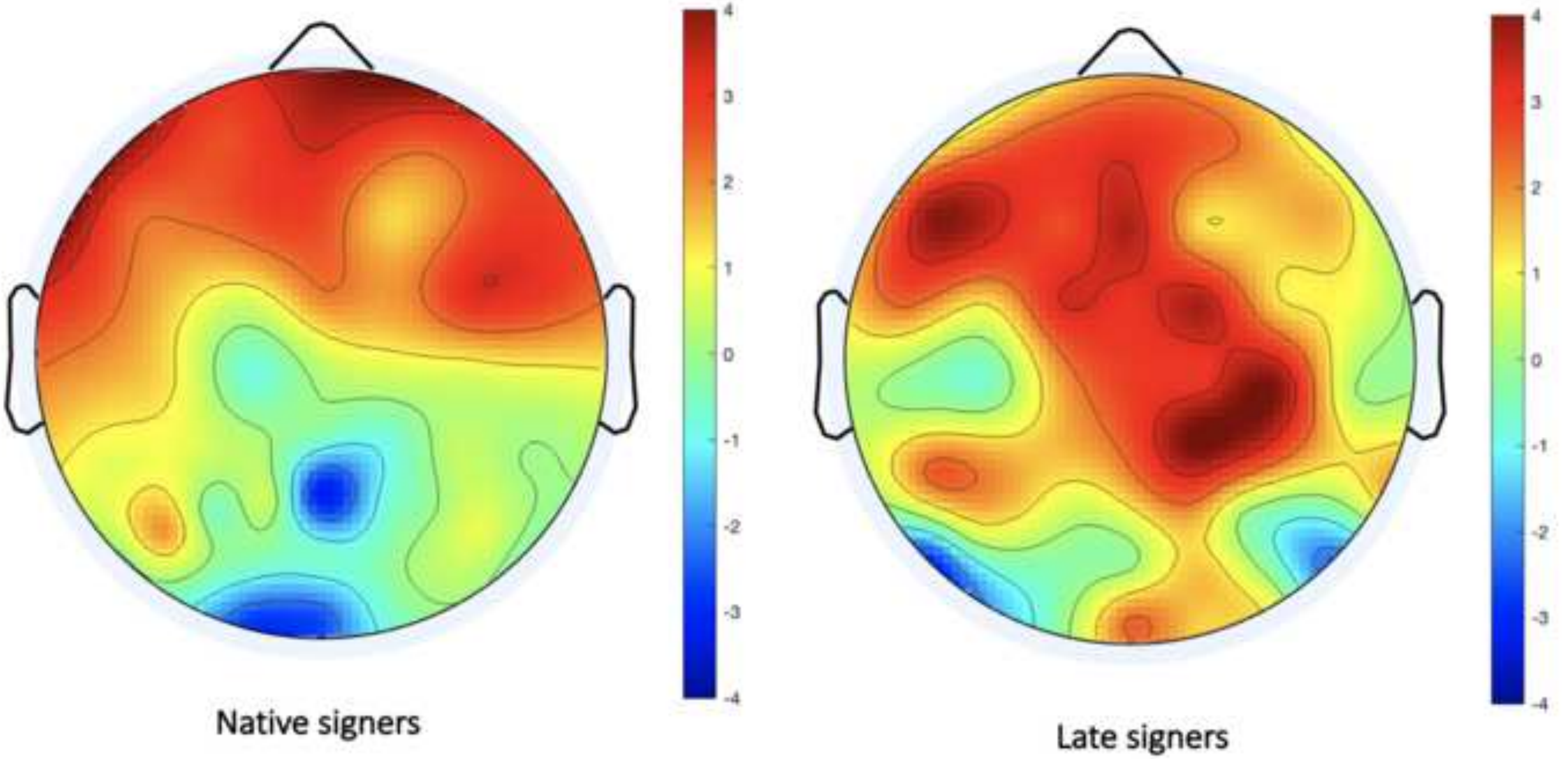
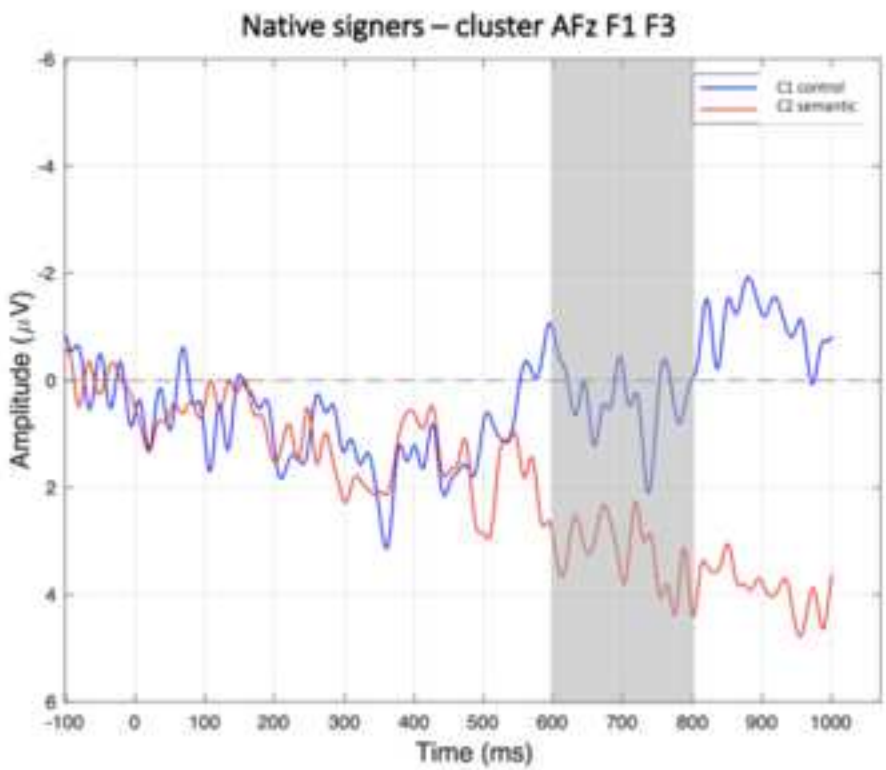
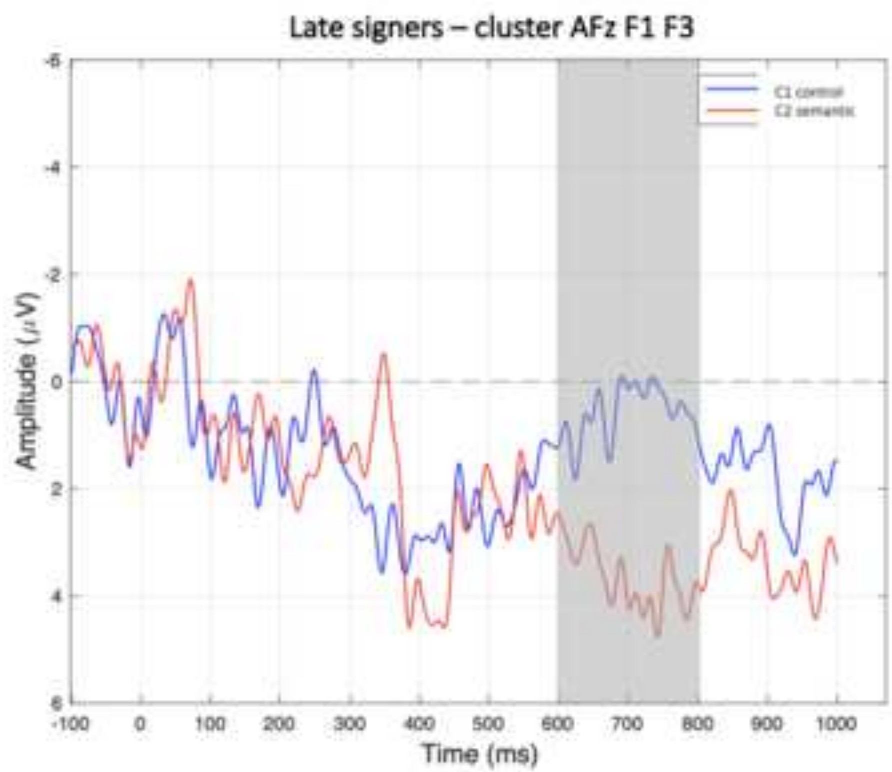

4
3
2
1
0
-1
-2
-3
-4
Native signers
4
3
2
1
0
-1
-2
-3
-4
Late signers

Figure 6


Native signers – cluster AFz F1 F3
C1 control
C2 semantic
Amplitude (μV)
Time (ms)
-6
-4
-2
0
2
4
6
-100
0
100
200
300
400
500
600
700
800
900
1000


Late signers – cluster AFz F1 F3
C1 control
C2 semantic
Amplitude (μV)
Time (ms)
-6
-4
-2
0
2
4
6
-100
0
100
200
300
400
500
600
700
800
900
1000