

Electrophysiological correlates of cross-linguistic semantic integration in hearing signers: N400 and LPC



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ABSTRACT

We explored semantic integration mechanisms in native and non-native hearing users of sign language and non-signing controls. Event-related brain potentials (ERPs) were recorded while participants performed a semantic decision task for priming lexeme pairs. Pairs were presented either within speech or across speech and sign language. Target-related ERP responses were subjected to principal component analyses (PCA), and neurocognitive basis of semantic integration processes were assessed by analyzing the N400 and the late positive complex (LPC) components in response to spoken (auditory) and signed (visual) antonymic and unrelated targets. Semantically-related effects triggered across modalities would indicate a similar tight interconnection between the signers' two languages like that described for spoken language bilinguals. Remarkable structural similarity of the N400 and LPC components with varying group differences between the spoken and signed targets were found. The LPC was the dominant response. The controls' LPC differed from the LPC of the two signing groups. It was reduced to the auditory unrelated targets and was less frontal for all the visual targets. The visual LPC was more broadly distributed in native than non-native signers and was left-lateralized for the unrelated targets in the native hearing signers only. Semantic priming effects were found for the auditory N400 in all groups, but only native hearing signers revealed a clear N400 effect to the visual targets. Surprisingly, the non-native signers revealed no semantically-related processing effect to the visual targets reflected in the N400 or the LPC; instead they appeared to rely more on visual post-lexical analyzing stages than native signers. We conclude that native and non-native signers employed different processing strategies to integrate signed and spoken semantic content. It appeared that the signers' semantic processing system was affected by group-specific factors like language background and/or usage.

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1. Introduction

Speech and sign language are two physically different manifestations of human communication. However, sign language is, like speech, a full-fledged linguistic system and is therefore likely to be processed in a way that is functionally similar to speech.

Previous investigators have explored the neurocognitive overlap of both systems. These concordantly have reasoned that similarities in representation and processing of speech and signing reflect core functions of human language. In contrast, they consider any differences in representation and processing to result from differences in sensory modalities of transmission (for a review see MacSweeney, Capek, Campbell, & Woll, 2008). The investigation of *cross-modal bilingualism* (i.e. knowledge of at least one spoken and one signed language, sometimes also referred to as bimodal bilingualism) and of the intra-subjective interplay between sign language and speech is still in its infancy. Sign language is not only used by deaf individuals (who often have visually acquired knowledge of speech). It is also used by several hearing populations, including relatives of deaf individuals, sign language interpreters, speech and language therapists, and some speech-impaired patient

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groups. It is thus common that sign language and speech co-exist. Yet little is known about the points of convergence in the underlying neural processes. Understanding these processes in cross-modal bilingualism is essential in order to effectively support groups that use both languages to communicate.

The present study examines how closely signed and spoken language semantic processing systems converge. This is done by analyzing the neurocognitive basis of cross-linguistically primed effects in two groups of hearing users of sign language that have different backgrounds in language acquisition and usage. The first group comprises native signers who naturally acquired signing as their first language (L1) during early childhood. The second group is of non-native signers who were taught sign language as a foreign language (L2) during adulthood. Signers in both groups were asked to judge the semantic relationship of intra-modal (speech – speech) and cross-modal (speech – sign language) lexeme pairs. As very little is known about the electrophysiological basis of sign language processing, a third hearing non-signing group was included in order to provide important information about how physical visual stimulus features without semantic meaning are processed. This group thus serves as a critical reference for linguistic processing of the same stimuli in the two signing groups.

Investigation of the cognitive basis of sign language representation and processing in *codas*, that is, *children of deaf adults*, has increased in recent years (e.g., Emmorey, Borinstein, Thompson, & Gollan, 2008; Emmorey & McCullough, 2009). The commonly used term *coda* (Brother, 1983) refers to the hearing children of at least one hearing-impaired parent and is used in reference to that person throughout his or her life. *Codas* often grow up cross-modally bilingual from an early age. They acquire sign language from their parents and the signing community and acquire speech from hearing family members or in interaction with others outside the family. Due to the challenging circumstances of language acquisition, there will always be some variation in the degree of acquired skill within signing-speaking populations. But as sign language and speech are mostly acquired naturally during early childhood, *codas* probably typify cross-modal bilingualism in its purest form among the signing groups. Profiling *codas'* linguistic characteristics is invaluable for gaining deeper insight into the cognitive foundation of cross-modal bilingualism. Comparing the early acquired cross-modal bilingualism of *codas* with that of the late learned cross-modal bilingualism of hearing users provides valuable insights into the impacts of group-specific factors like learning context and language usage on the semantic processing system.

In line with studies that suggest that speech and sign language rely on a shared mental lexicon (e.g., Klann, Kastrau, Kémeny, and Huber, 2002; MacSweeney et al., 2006), we aimed to uncover this suggested overlap in hearing cross-modal bilinguals by presenting a cross-linguistic semantic priming task to the participants. The task consisted of lexeme pairs for which an active semantic decision was required. *Semantic priming* refers to the improved speed or accuracy of response to a stimulus (*target*) following a preceding stimulus (*prime*) when the pair of stimuli are semantically related compared with when they are unrelated (Meyer & Schvaneveldt, 1971; see also McNamara, 2005). Semantic priming is thought to relate to the principle of *spreading activation* (Collins & Loftus, 1975). This means that semantic content is organized in the form of neural networks in which internal representations of concepts are linked to each other. An activated representation (such as a presented prime) spreads a certain level of activation to its proximal and more distal neighbors, decreasing with increasing distance from the prime. Thus, directly neighboring concepts are closely associated with each other, meaning that the target will be activated more strongly and rapidly compared with non-neighboring

concepts. There is an indirect semantic relationship between concepts within a wider neighborhood. For example, *countryside* is strongly associated with both *city* (antonym) and *forest* (associative: is mostly found in the countryside). *Countryside* thus links the latter two concepts indirectly with each other. Based on the spreading activation principle, any semantically primed effect in the cross-linguistic context would provide evidence that both mental lexica are interconnected and thus represented in one large semantic network.

Semantic priming effects in sign language have been shown behaviorally (Bosworth & Emmorey, 2010). In addition, detailed analysis of the behavioral outcome of this study (Zachau et al., 2012) provided clear evidence for an interconnected semantic network with spoken languages. But different performance profiles also indicated differences in processing strategies between hearing non-signers, early bilinguals, and late learned signers. While this requires further investigation, omnibus measures like response accuracy or reaction times cannot reveal the processes underlying the behavioral effects. For this reason, the present study examined participants' *event-related brain potentials (ERPs)* time-locked to the lexemes. These ERPs were simultaneously recorded with the previously published behavioral data (Zachau et al., 2012). ERPs provide neurocognitive measures that allow task-related processes to be followed on a millisecond time scale as they unfold. The N400 and the late positive complex (LPC) responses are reported for primed auditory and visual, semantically related and unrelated targets.

Speech-evoked effects of priming are reflected in the N400 ERP component. This component is a neural measure to potentially meaningful stimuli (e.g., Federmeier & Laszlo, 2009, Kutas & Federmeier, 2000) and is often reported in the context of language processing. It is a monophasic negative component generally peaking centro-parietally between 200 and 600 ms after stimulus onset. However, amplitude and topography may vary significantly depending on stimulus- and task-related parameters (see Kutas & Federmeier, 2009). This makes the determination of the N400 dependent on patterns of sensitivity to experimental variables rather than just on its morphology (Kutas & Federmeier, 2011). The N400 is not only generated in the auditory and the visual modality. It is modality-independent to the degree that N400 effects can be generated even across modalities as long as there is a semantic relationship between prime and target (for a review see Federmeier & Laszlo, 2009). The exact functional significance of the N400 is an issue of controversial debate, but it is thought to indicate “something fundamental about the processing of meaning” (Kutas & Federmeier, 2011, p. 624); this is neither fully automatic nor entirely controlled. Only a small number of studies have investigated the electrophysiological basis of sign language semantic processing so far. After the seminal study by Kutas, Neville, and Holcomb (1987) of the N400 using American Sign Language in deaf persons, a small but growing number of recent studies reported the N400 in relation to semantic processing of sign language (Capek et al., 2009; Grosvald, Gutierrez, Hafer, & Corina, 2012; Gutierrez, Williams, Grosvald, & Corina, 2012; Gutierrez, Müller, Baus, & Carreiras, 2012; Neville et al., 1997).

The use of cross-linguistic priming for studying semantic organization in bilinguals is not new (for a review, see Altarriba & Basnight-Brown, 2009, pp. 80–84). To the best of our knowledge, only Zachau et al. (2012) reported data obtained from cross-modal bilinguals, but without being able to clearly separate the (automatic) effects of priming from other (higher-order) processing strategies. More fine-grained information on semantically primed cross-linguistic effects in hearing signers could be gained by examining the N400 and the LPC components. These components have been proven valuable tools in the study of language switching (also referred to as *code-switching*) in (speech–speech) bilinguals. Moreno, Federmeier, and Kutas (2002) compared written

within-language lexical switches (English–English) with code switches (English–Spanish) in English–Spanish bilinguals. They reported large posterior positivity (LPC, 450–850 ms) elicited by code switches but not by lexically unexpected within-language switches, while both types of switches elicited enhanced effects in the N400 time window (250–450 ms) with different topographic distribution. The authors suggested that ERP patterns relating to code switches seemed qualitatively different from those to within-language switches, but this did not mean that there were very large lexical-semantic processing costs. Code switches seemed to be processed more like physically unexpected events. In a similar study, Proverbio, Leoni, and Zani (2004) studied the electrophysiological basis of code-switching in highly proficient, simultaneous, native Italian interpreters and found, unlike Moreno et al. (2002), an enhanced N400 (300–500 ms) to code switches. Proverbio et al. suggested that this effect reflected differences in functional organization or access systems caused by the later acquisition of language. No late positive complex (LPC) ERP component was reported in response to unexpected words. Proverbio et al. explained the inconsistency between their N400 finding and that of the Moreno et al. study with differences in stimulation (context-violating targets vs. associative partners of the expected words). Another difference between the two studies that received no attention was between the examined target groups. Moreno et al. studied bilinguals, who presumably learned both their languages naturally, while Proverbio et al. examined very proficient, professional interpreters who acquired late L2 (English) in highly structured surroundings during adolescence and later. Van Der Meij, Cuetos, Carreiras, and Barber (2011) examined code-switching in Spanish L2 learners of English and compared the two sub-groups of high and low proficient L2 users. They found that both N400 (300–450 ms) and LPC (450–850 ms) effects to code-switched written words (L2→L1 direction) were more prominent in high over low proficient L2 learners. The authors suggested that the N400 reflected that L2 has more autonomy from L1 in high proficient late learners than in low proficient learners. This is in accordance with models of second language acquisition like the *Revised Hierarchical Model (RHM, Kroll & Stewart, 1994)*, in which it is proposed that low proficient L2 learners rely more strongly on L1 connections to the conceptual level and highly proficient learners are thought to make increasing use of direct connections from L2 words to concepts. An enhanced N400 might thus reflect enhanced lexical processing costs of switching. Higher proficiency in Van Der Meij et al.'s study further entailed differences in the topography of the N400 and LPC responses with more extended left anterior negativity for the N400 and enhancement at posterior sites for the LPC.

We explored the neurocognitive basis of cross-linguistic priming in hearing signers and non-signers by studying ERPs connected to lexeme pairs including occasional language switches (spoken prime – signed target). Lexeme pairs of varying semantic relationships had to be judged and followed by a behavioral decision response. The electrophysiological responses to auditory and visual, antonymic and unrelated targets were measured. First, we asked whether or not speech and sign language are interconnected to the extent that semantic context presented by speech can influence the processing of semantic targets presented by sign language. Second, we examined the potential diversity in target processing between a group of natively acquired L1 signers and a group of late learned L2 signers. Finally, highlighting the relevance of the electrophysiological measures for the actual behavior, we examined the correlation between ERP outcome and behavioral task performance (the latter as published in Zachau et al., 2012).

We made several predictions: (a) ERP studies of word recognition memory (see, e.g., Rugg & Curran, 2006) often suggest that the N400 is linked to highly automatic processes of recognition

and familiarity while the LPC reflects more controlled recollection processes. Task execution requires the knowledge of the stimuli on the one hand and decisions making about them on the other hand. We therefore expect both the N400 and LPC components to be evoked by our task. (b) All participants were native Finnish speakers but differed in their knowledge of Finnish Sign Language (FinSL). We therefore did not expect lexical effects in response to the signed targets in the non-signing group, but we did expect semantically primed effects to be reflected in the brain responses of the two groups of signers. (c) We expected qualitative processing differences between native and late learned signers to occur.

2. Materials and methods

2.1. Participants

The volunteers were recruited by word-of-mouth and tested at Oulu University Hospital, Finland, where they received detailed information about the general test procedure and gave written consent. A total of 43 adult hearing participants were included in the final analyses: 15 non-signing individuals (hereafter *controls*), 15 natively bilingual signers (hereafter *codas*), and 13 sign language interpreters with late acquisition of Finnish Sign Language (FinSL; hereafter *interpreters*; for an overview see Table 1). None of the interpreters were coda, and only two of the codas were professional sign language interpreters. All interpreters actively used sign language on a nearly daily basis. A self-rating language assessment scale served to differentially characterize the two target groups' language behavior. Codas used their sign language knowledge predominantly in private situations while interpreters used it more often in official situations (Table 1). Codas rated their language balance significantly more towards sign language and also reported using more sign language in communication with other hearing sign language users (i.e., with other bilinguals, Table 1) than interpreters. No significant differences were found in independent-samples *t*-tests for the language generally used to communicate with friends, for the preferred language, for the reported general importance of the hand in communication, or for the amount of deliberate and unintended code-switches in communication ($ps > .05$). Normal hearing was verified based on audiogram screening at the beginning of the test session. All participants had normal or corrected-to-normal vision, no diagnosed neurological diseases, and had not taken any interfering medication prior to the examination.

2.2. Experimental setup

Because cross-modal bilinguals rarely code-switch but use both languages simultaneously in an intermixed way (*code-blending*, Emmorey, Borinstein, & Thompson, 2005), a word pair design rather than semantic anomalies in sentences was chosen. A two-forced-choice (2-AFC) semantic decision task was designed, in which within- and cross-linguistic lexeme pairs of varying semantic relationship were presented. The prime was always presented in the auditory modality. The target was either another Finnish word (*context-coherent*) or the corresponding lexeme translated into FinSL (*context-incoherent*). The paired lexemes were presented one after another and had to be semantically judged by the participants. Verbal explanations of the investigators accompanied by a visual computer demonstration ensured the participants' task comprehension prior to its actual execution. The participants' electroencephalogram (EEG) was recorded along with their behavioral decision responses.

2.2.1. Stimuli

Antonymic word pairs were selected because the basis of antonymic relations is common knowledge-intensive. Correct contextualization, though, is essential for antonyms to be perceived as such. The study participants were hence asked for their explicit semantic decision on the antonymic relationship ('was the second lexeme the opposite of the first one?').

To ensure antonymic accuracy, gradable, complementary, and reciprocal antonymic pairs of nouns (see, e.g., Jones, 2002) were included. These linguistic sub-categories were not task-relevant, though, and all the antonymic pairs were treated as one entity of antonymic stimuli throughout the analyses. The relationship between the lexemes was either antonymic (*Antonymy*, e.g. *kaupunki* [Engl. *city*] – *maaseutu* [Engl. *countryside*]), semantically indirectly related (*Indirectness*, e.g. *metsä* [Engl. *forest*] replacing its associative partner *maaseutu* [Engl. *countryside*]), or semantically unrelated (*Unrelatedness*, e.g. *kaupunki* [Engl. *city*] – *vauva* [Engl. *baby*]). On the semantic level, antonyms were strongly related. An associative partner of the antonym, instead of the antonym itself, was presented in the indirectness condition, which related the two lexical items to some extent (though less strongly) to each other. Unrelated lexemes were not systematically related at all. For a full list of the experimental stimuli see Appendix A.

Table 1
Study participants.

Group	n	♂	Age ^a	Language(s)		Self-rated language assessment ^b			
				Finnish	Finnish Sign Language	Language balance ^c	Communication with other bilinguals ^d	Sign language private ^e	Sign language official ^f
Controls	15	5	42 (SD=10.08)	Native	Non-signing	n/a	n/a	n/a	n/a
Codas	15	5	45 (SD=12.91)	Native	Natural acquisition during early childhood (predominantly from birth on)	3.80 (SD=2.10)	3.19 (SD=3.77)	5.04 (SD=2.91)	3.07 (SD=3.00)
Interpreters	13	1	31 (SD=7.31)	Native	Systematic acquisition during adulthood at a mean age of 22 years (SD=6.04) at a mean 10 years (SD=4.52) before the examination	1.18 (SD=1.06)	1.79 (SD=1.62)	2.56 (SD=2.64)	6.01 (SD=3.37)

^a In years at examination.

^b Visual Analog Scales (VAS).

^c Between Finnish (=0) and Finnish Sign Language (=10).

^d "How do you communicate with other bilingual (signing-speaking) persons?" spoken=0, signed=10.

^e "How often do you use sign language in private situations?" never=0, always=10.

^f "How often do you use sign language in official situations?" never=0, always=10.

*** Independent samples *t*-test between codas and interpreters significant at the <.001 level (alpha level.05).

** Independent samples *t*-test between codas and interpreters significant at the <.01 level (alpha level.05).

* Independent samples *t*-test between codas and interpreters significant at the <.05 level (alpha level.05).

Antonymy and semantic unrelatedness stand for opposing decisions ('yes' and 'no'). We therefore assumed that they produce the clearest interpretable results in the context of our experimental design and the research questions of this article. Indirectly related targets were included in the setup, but the results of these will be reported elsewhere.

A total of 144 words (mean length 864 ms, *SD*=175.95), spoken by a female native Finnish speaker, was digitally recorded in a sound-shielded recording studio. The 98 signs corresponded to direct translates of antonymic and indirectly related second lexemes and, in two cases, included two different signs for the identical spoken lexeme presented in two different conditions (mean length 2824 ms, *SD*=526.20). They were signed by a female native Finnish speaker and professional sign language interpreter, and were digitally videotaped. The signer stood in front of a dark background. She started and ended each sign in the very same resting position (see Figs. 5 and 6, lower pictures), which served as smooth changeover between the individually cut signs. On- and offset were defined as the points, when the signer's hands began to move and returned to the resting position.

Mean lengths of neither auditory antonymic (874 ms, *SD*=159.52) versus indirectly related (834 ms, *SD*=175.59), nor visual antonymic (2806 ms, *SD*=498.66) versus indirectly related (2791 ms, *SD*=566.22) targets differed significantly from each other in independent-samples *t*-tests.

2.2.2. Experimental design

The experimental setup contained six stimulus conditions: (1) context-coherent antonymy, (2) context-coherent indirectness, (3) context-coherent unrelatedness, (4) context-incoherent antonymy, (5) context-incoherent indirectness, and (6) context-incoherent unrelatedness.

Three blocks of stimuli containing stimulus pairs of all six conditions but only one kind of antonymic relationship (gradable, complementary, or reciprocal) in each, were presented to the study participants. Samples from the set of indirectly related items were also presented as unrelated second lexemes of word pairs within the same block, and on rare occasions (a total of 19) lexemes were repeated in different conditions (e. g., *night* as associative partner for the target of the pair *brightness-darkness* and as prime for *day*, see Appendix A). This ensured that differences in outcome between two conditions are truly task-related. Each of the six conditions was presented at a total of 55 trial cycles (19, 18 and 18 trial cycles/block, respectively) in a randomized order, which was identical for all subjects. The three blocks were presented in pseudorandom order to different participants, and a break was held between them.

To keep both the signers' languages at an activated level, we instructed the participants to look at the screen continuously. A still image of the signers' resting position was presented on the screen throughout the entire test session, and was only interjected by the dynamic signs. The participants were informed of the intra- and cross-linguistic nature of the stimuli and were asked to judge or guess spontaneously whether two presented lexemes were 'opposites of each other' (antonymic) or not by pressing buttons on the computer mouse ('yes, opposite' or 'no, not opposite') after an acoustic go-signal (sine tone at 500 Hz and 200 ms of duration). They were uninformed about the indirectness condition.

The interstimulus interval (ISI) between the two lexemes was 400 ms, the ISI between the second lexeme and the go-signal was 700 ms, and the inter-trial interval (ITI) between the behavioral response and the presentation of the first word of the subsequent lexeme pair (new trial cycle) was 1500 ms.

2.2.3. Behavioral outcome

The responses of all three groups of participants were correct for more than 95% of the auditory antonymic targets (Zachau et al., 2012). This suggests that antonymy was recognized very well within the given task, and the stimuli therefore provided a sound basis for studying strong semantic relationship. But the responses to visual targets were significantly less accurate. Controls detected visual antonym in 61.29%, codas in 89.32%, and interpreters in 95.52% of cases. Bias-corrected *d*'-prime (*d*') scores (the difference between signal and signal-plus-noise or, in other words, between the *z*-score of hit rate and the *z*-score of false alarm rate: $d' = z(H) - z(F)$) revealed higher levels of decision sensitivity in all three groups in response to the auditory than to the visual conditions. Interpreters showed the highest *d*' scores to targets from both modalities. Controls and codas were equally sensitive to auditory targets, but codas had larger *d*' scores in response to the visual targets than controls. Only the coda group's decision sensitivity (*d*') scores were positively correlated between modalities. When correlations were based on untransformed response frequencies, no correlations between the responses to the auditory and visual targets were found in controls, the indirectly related and unrelated target responses were highly correlated between modalities in codas, and the responses to the antonymic and indirectly related targets were cross-modally correlated in interpreters.

2.3. EEG data

2.3.1. Data acquisition

Electrophysiological measures were recorded in an electrically shielded room. The participants were seated on a bench and held a computer mouse in their preferred hand. They were equipped with an electrode cap (see below) and insert earphones. The stimuli were presented by ErpStim software (unpublished and noncommercial version by K. Suominen). The auditory stimuli were presented at 74 dB SPL. Visual stimulation was digitally projected onto a screen at a distance of approximately 270 cm from the bench (sign-containing frame: approx. 86 cm height × 93.5 cm width, corresponding to a vertical visual angle of ~18° and a horizontal visual angle of ~20°).

The EEG was digitally recorded (Neuroscan SynAmps amplifier, Neuroscan Acquire software, AC recording, sampling rate of 1000 Hz, data accuracy of .168 μV, online band-pass filter .05 Hz–70 Hz) from 30 Ag/AgCl surface electrodes (Fz, Cz, Pz, POz, Oz, Iz, Fp1/Fp2, F3/F4, C3/C4, P3/P4, O1/O2, F7/F8, FT9/FT10, T7/T8, CP5/CP6, TP9/TP10, P7/P8, PO9/PO10) plus Afz as ground electrode, FCz as online-reference and a bipolar electro-oculogram (EOG) recorded from above the right and below the left eye. The electrodes were applied using an electrode cap with equidistant electrode positions (10-10-system, EasyCap, Falk Minow Services). Electrode impedances were regularly checked and kept below 5 kΩ.

2.3.2. Offline post-processing

The acquired data were offline post-processed with Brain Vision Analyzer (Brain Products GmbH) software version 1.05. The data were re-referenced to the average reference (thereafter FCz was used for data analysis among the other electrodes), a notch filter (50 Hz, +/- 2.5 Hz at 24 db/oct) and an offline band-pass filter of .5 Hz–25 Hz were applied (at 12 db/oct), the EEG was segmented into epochs of 970 ms (-100 ms to 870 ms in relation to stimulus onset), and electro-ocular artifacts were corrected (Gratton & Coles algorithm; Gratton, Coles, &

Donchin, 1983). Segments exceeding an absolute amplitude of $\pm 150 \mu\text{V}$, a voltage difference of $50 \mu\text{V}$ between two sampling points or a voltage difference of $200 \mu\text{V}$ within the segment and segments not reaching a voltage difference of $50 \mu\text{V}$ within 100 ms intervals were rejected from further analysis. Segments were baseline corrected to -100 ms . Separately averaged segments for responses to the auditory prime, the three auditory targets and the three visual targets, regardless of the correctness of the related behavioral decision, were used to construct the stimulus-locked ERPs.

The number of averaged segments was counted for grouped auditory and visual segments separately. Participants with low trial numbers after artifact rejection in any one of the four auditory conditions (prime and three targets) or three visual target conditions were entirely excluded from further analysis of the respective stimulus group. Consequently, four participants (two controls, one coda, and one interpreter) were excluded from all auditory conditions, whereas none were excluded from the visual conditions. Further analyses of electrophysiological data are hence based on the remaining 13 controls, 14 codas, and 12 interpreters for auditory conditions, whereas all the 15 controls, 15 codas, and 13 interpreters were included in visual conditions. Across groups, out of a maximum of 55 EEG-epochs for each target type, an individual average of 54 responses to auditory antonyms ($SD=1.98$), 54 responses to auditory distantly related targets ($SD=1.08$), 54 responses to auditory unrelated targets ($SD=1.14$), 54 responses to visual antonyms ($SD=1.71$), 55 responses to visual distantly related targets ($SD=1.14$), and 54 responses to visual unrelated targets ($SD=1.29$) were included in the analyses.

2.4. Data analyses

2.4.1. Temporal principal component analysis (tPCA)

Factor-analytical tPCA was chosen as the data-driven analysis method because it provides an objective approach to separating ERP components that represent specific brain processes, even if they are latent and may overlap each other (e.g., Kayser & Tenke, 2005). Initial visual inspection of the data revealed several ERP components at early latencies and others with wide distribution and without clear peaks at later latencies. Temporal PCA was able to capture the variance related to these ERP responses. Factor scores for each subject, condition, and electrode included in the data matrix represent the contribution (weight) of each respective data point to the overall result, which is signified in factor loadings.

Temporal PCA was run with SPSS software using a covariance matrix. Two methods of rotation, Varimax and Promax, were applied. We favored the Varimax rotation (Kayser & Tenke, 2003, cf. Dien, Beal, and Berg, 2005) with Kaiser's (1958) normalization because it separated individual components of our data more reliably. Components cumulatively explaining 99% of the variance within the dataset were rotated (Kayser & Tenke, 2003). Two separate tPCAs were carried out, one for individual averages of the responses to the auditory targets and one for individual averages of the responses to the visual targets. Note that the responses to the associative targets, although not further analyzed, were included in the PCA model to increase the signal-to-noise ratio and to sustain direct comparability to the data of interest in this article. The matrix for responses to auditory targets was based on 39 individuals (from 3 groups), 3 stimulus types (antonyms, distantly related and unrelated targets), 31 EEG channels (EOG excluded), and every fourth recorded data point between -100 ms and 870 ms (250 Hz sampling rate). This resulted in a matrix of 3627 cases by 243 data points for auditory targets. The matrix for responses to the visual targets was identically organized but with all 43 individuals included, which resulted in a matrix of 3999 cases by 243 variables. The computed temporal principal components were assigned to ERP components of interest by visually comparing curve progression and spatial distribution of both (tPC and ERP) datasets, and by considering temporospatial characteristics usually reported for the components occurring in the respective time windows. The tPCs were named using their component number and latency in ms. Four tPCs in the time range commonly comprising components associated with effects of processing semantic anomalies were selected for further analyses. Temporal PC factor scores were used as dependent variables for all statistics.

2.4.2. Statistics

Temporal PC factor scores of grouped electrodes (Fig. 1) were subjected to repeated-measures Analyses of Variance (rmANOVAs) including 4 within-subjects factors (condition (antonymic/unrelated target), hemisphere (left/right), medial [F3/F4, C3/C4, CP5/CP6/P3/P4, O1/O2] and lateral [F7/F8, T7/T8, TP9/TP10, P7/P8, PO9/PO10]), and anterior–posterior (5 levels: frontal [F3/F4, F7/F8], central [C3/C4, T7/T8], centro-parietal [CP5/CP6, TP9/TP10], parietal [P3/P4, P7/P8], and occipital [O1/O2, PO9/PO10])) and group as between-subject factor (controls, codas and interpreters). Where applicable, data were corrected for violations of sphericity by Greenhouse–Geisser correction (Greenhouse & Geisser, 1959). Statistically significant group-related interactions were followed up by group-wise paired comparisons and within-group rmANOVAs using the same model as above. Paired-samples *t*-tests (on mean values for cross-level effects) were employed to further uncover significant interactions and main effects. Only the responses to the antonymic and unrelated stimuli were subjected to statistical analyses. The responses to the auditory and visual targets were analyzed separately. When correlation analyses were conducted, normal distribution of the data was assured

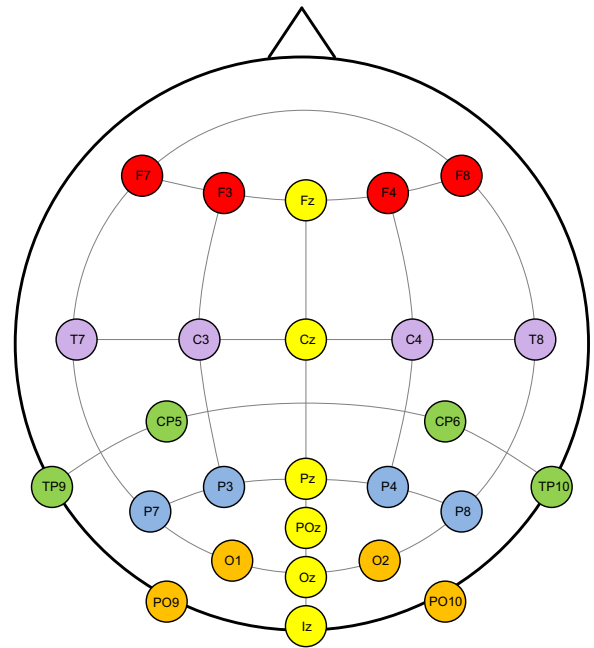


Fig. 1. Electrode groupings for statistical analyses. Frontal (red), central (purple), centro-parietal (green), parietal (blue), and occipital (orange) electrodes were further divided into 2 medial levels (medial: F3/F4, C3/C4, CP5/CP6/P3/P4, O1/O2 and lateral: F7/F8, T7/T8, TP9/TP10, P7/P8, PO9/PO10). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

by one-sampled Kolmogorov–Smirnov tests (two-tailed). An alpha level of .05 was used for all analyses.

3. Results

3.1. ERP waveforms

Auditory (Fig. 2) and visual lexemes (Fig. 3) produced clear response patterns to the targets: the auditory target responses changed their morphology across electrodes, displaying a negativity peaking at around 150 ms , a positivity peaking after 200 ms and practically disappearing at parietal sites. This was followed by a long-lasting late (after 300 ms) response with a shift from initial frontal positivity into negativity with an opposite polarity pattern at the parietal areas displaying a negative peak at about 400 ms and positivity starting around $500\text{--}600 \text{ ms}$. The overall morphology of responses to visual targets was rather similar across electrodes, peaking roughly at $100\text{--}200 \text{ ms}$ with negative voltage and thereafter shifting to positive voltage with two positive peaks at about 250 ms and $350\text{--}400 \text{ ms}$ and a long-lasting positive shift after approximately 300 ms . While responses to the auditory unrelated targets were more negative than to the auditory antonyms in the posterior electrodes in the later course of time (after 300 ms), visual antonym responses were more negative than unrelated target responses for the two signing groups around the same time.

3.2. Principal component analysis

PC factor loadings for the auditory and the visual components (Fig. 4, upper and lower pictures respectively), illustrate that auditory and visual targets evoked non-identical electrophysiological responses, which only partly resembled each other. Auditory tPC3-512, auditory tPC1-772, visual tPC7-520, and visual tPC1-752 were selected for further analysis. Repeated-measures ANOVA results for the responses to the auditory targets are displayed in

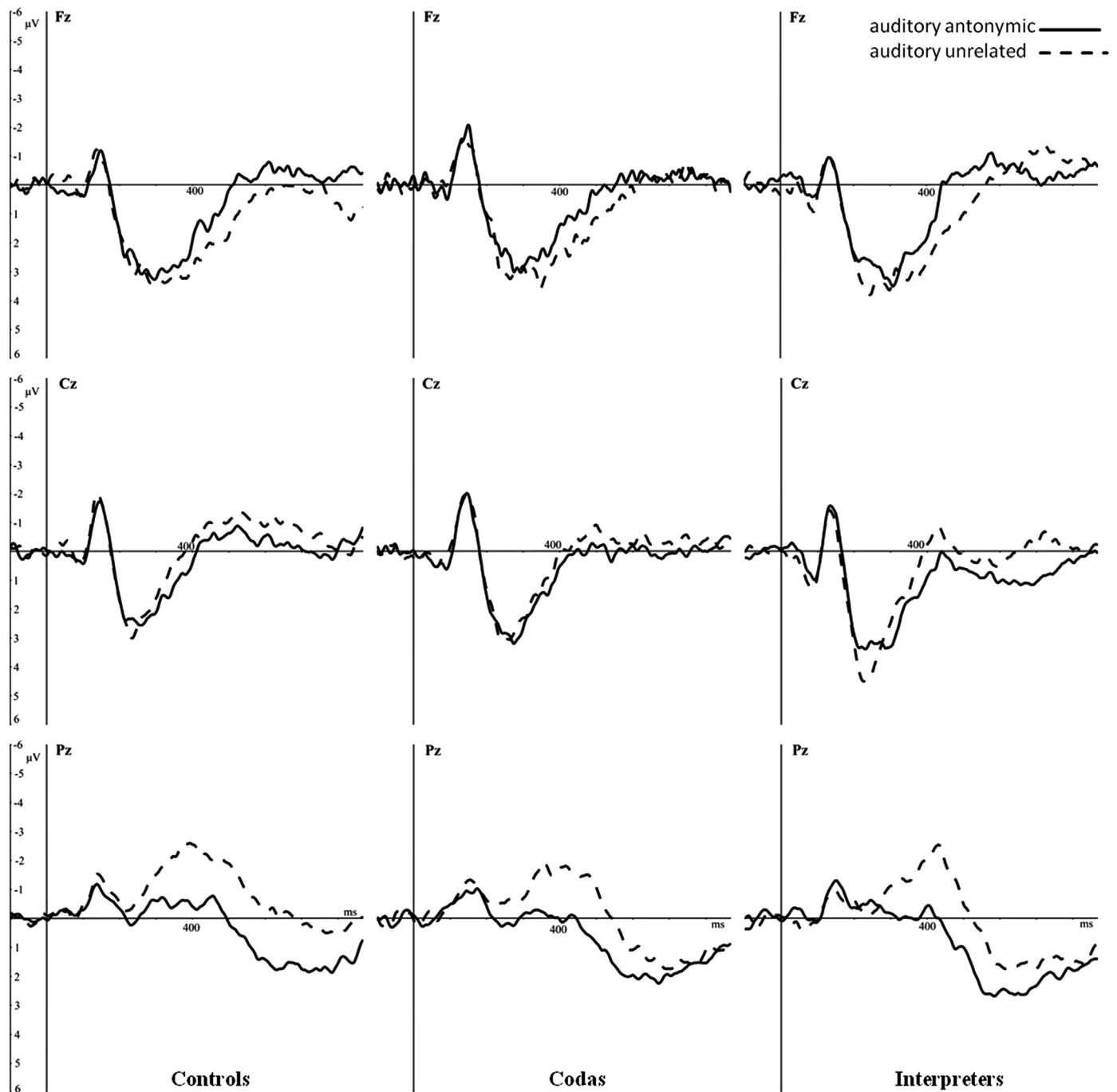


Fig. 2. Averaged EEG segments of responses to the auditory antonymic and unrelated targets of a semantic priming task across speech and sign language. Grand averages of the auditory targets for 13 controls (left column), 14 codas (middle column) and 12 interpreters (right column) are displayed for electrodes Fz (upper row), Cz (middle row) and Pz (lower row). Intervals are shown from -100 ms to 870 ms (x -axis) and from -6 to 6 μ V (y -axis, tick marks every 100 ms) at a sampling rate of 1000 Hz. Negativity is plotted upwards.

Table 2, and results for the responses to visual targets are displayed in Table 3.

3.2.1. Auditory tPC3-512 (N400)

Auditory tPC3-512 (Fig. 5, upper row) was a long-lasting component showing partially differential topography and amplitude for auditory antonymic targets and auditory unrelated targets (with larger frontal negativity and parietal positivity for the antonymic targets). It explained 6.46% of the variance within the dataset and corresponded to the N400 ERP component.

Repeated-measures (rm)ANOVA revealed a significant three-way interaction between medial levels, anterior–posterior levels and group (Table 2), which derived, according to the paired group comparisons, from interpreters processing these dimensions differently compared with controls ($F(2.3, 53.5)=3.36, p=.036$) and codas ($F(2.5, 60.6)=3.00, p=.045$). The latter two groups did not differ ($p > .05$). In the within-group analyses, interpreters did not show any main effects of or interactions by recording site, which indicated an overall large response at all recording sites. But controls and codas showed an interaction of medial and anterior–posterior factors (Table 2), indicating that the auditory response had a specific topographic pattern which did not, however, differ

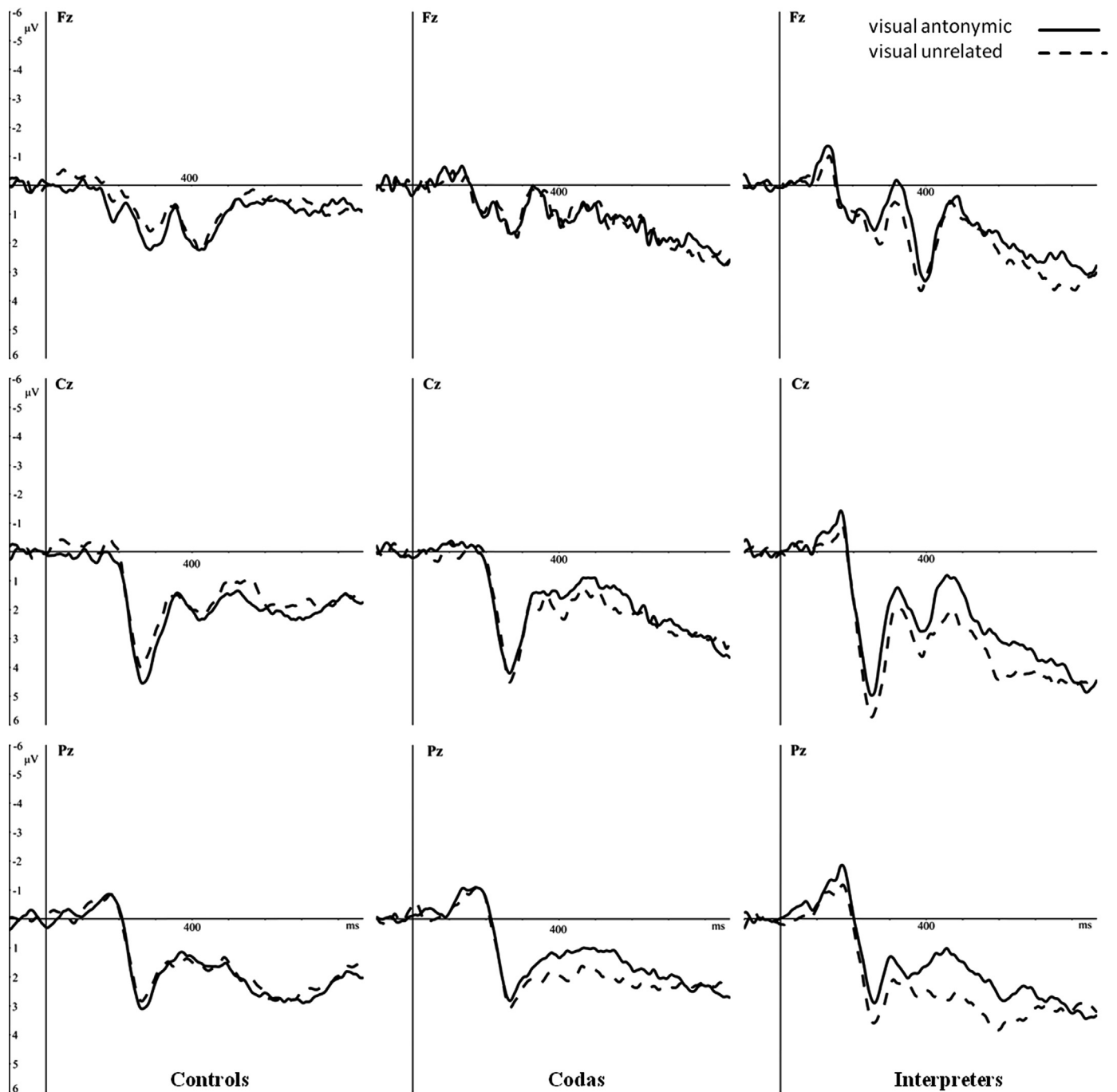


Fig. 3. Averaged EEG segments of responses to the visual antonymic and unrelated targets of a semantic priming task across speech and sign language. Grand averages of the visual targets for 15 controls (left column), 15 codas (middle column) and 13 interpreters (right column) are displayed for electrodes Fz (upper row), Cz (middle row), and Pz (lower row). Intervals are shown from -100 ms to 870 ms (x -axis) and from -6 to 6 μV (y -axis, tick marks every 100 ms) at a sampling rate of 1000 Hz. Negativity is plotted upwards.

between the responses to different stimuli. Follow-up within-group rmANOVAs separately run for lateral and medial levels (across auditory stimuli and hemispheres) confirmed significant effects of anterior–posterior direction only in controls (medial sites: $F(1.2, 14.6)=9.89, p=.005$; lateral sites: $F(1.4, 17.3)=4.07, p=.047$) but not in codas (medial and lateral sites $p > .05$), reflecting that the fronto-central negativity (but not the parietal positivity) was centered at medial levels in controls and more extending to lateral sites in codas. In summary, these results indicated that the topography of the responses to the auditory stimuli were similar in controls and codas, while interpreters differed from both groups. Follow-up

analyses, however, showed that even though both groups' responses to the auditory targets were very similar, responses were less pronounced and less focused in codas than in controls (Fig. 5).

A significant interaction between stimulus, hemisphere and anterior–posterior factors and a significant interaction of stimulus, medial factors and anterior–posterior factors were also found (Table 2). These interactions did not differ between groups ($p > .05$).

Follow-up analyses (rmANOVAs) for responses to each stimulus separately and across all groups revealed significant interactions between hemisphere and anterior–posterior factors for the auditory antonyms only ($F(1.7, 64.8)=5.41, p=.010$; auditory unrelated

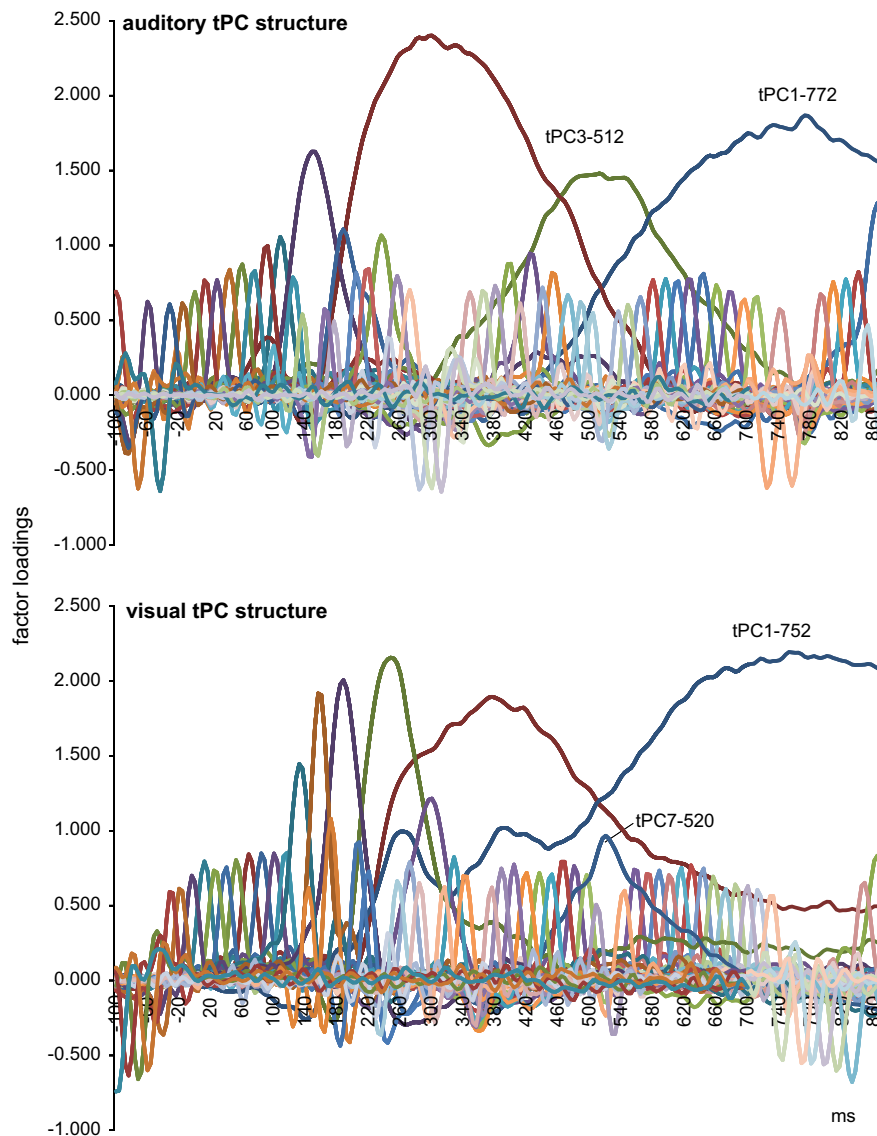


Fig. 4. Temporal principal component (tPC) factors of responses to the auditory and visual targets of a semantic priming task across speech and sign language. Two separate PCAs were conducted on auditory (upper picture) and visual (lower picture) targets. 69 (68) Varimax-rotated PCA factors explaining 99% of the variation for auditory (visual) antonyms, distantly related targets and unrelated targets across 13 (15) controls, 14 (15) codas and 12 (13) interpreters are plotted against the 970 ms (–100 ms to 870 ms) sampling epoch.

targets: $p > .05$), while there was a significant interaction for medial and anterior–posterior factors for the responses to both auditory antonymic ($F(2.6, 100.5) = 4.28, p = .009$) and unrelated targets ($F(2.7, 104.4) = 12.69, p = .000$). Following up the interactions between the medial and anterior–posterior factors, the rmANOVA analyses for the responses averaged across electrodes at both hemispheres and including all groups, revealed significant anterior–posterior effects at medial electrodes ($F(1.3, 49.9) = 15.20, p = .000$) and at lateral electrodes ($F(1.3, 48) = 15.43, p = .000$) for antonymic target responses, but only at medial electrodes ($F(1.3, 49.1) = 3.72, p = .049$) for unrelated target responses (lateral level $p > .05$). These results indicated that auditory antonyms generated a pronounced negative response at medial fronto-central and a positive response at parieto-occipital sites, while unrelated targets were processed with a significantly different topography focused on medial centro-parietal areas (Fig. 5).

Following the interactions between hemisphere and the anterior–posterior factors, rmANOVAs for the responses averaged across lateral-medial sites showed significant anterior–posterior main effects for the responses to the auditory antonyms at left (F

(1.2, 48.3) = 17.62, $p = .000$) and right ($F(1.3, 48.6) = 11.86, p = .000$) hemispheric sites across groups. Paired t -tests between the hemispheres showed that only the activity over parieto-occipital areas was significantly lateralized ($t = 2.57, p = .014$) with a left-hemispheric dominance (all other $ps > .05$). The widely distributed fronto-central negative response to auditory antonyms, therefore, was not lateralized, but the parieto-occipital positivity was significantly left-dominant (Fig. 5).

3.2.2. Auditory tPC1-772 (LPC)

Auditory tPC1-772 topography showed positive scores at parieto-occipital sites and negative scores at bilateral fronto-temporal sites (Fig. 6, upper row). It explained 40.27% of the variance and corresponded to the late positive complex (LPC) ERP component.

Analyses of variance revealed a significant three-way interaction between stimulus, anterior–posterior levels, and group (Table 2). The paired group rmANOVAs revealed that this effect derived from a difference between controls and interpreters

Table 2
Repeated-measures ANOVA results of auditory antonymic and unrelated targets.

Source	Between subjects			Within subjects					
	Across groups ^a		Group comparisons ^b	Controls ^c		Codas ^c		Interpreters ^c	
	df	F		df	F	df	F	df	F
Auditory tPC3-512 (N400)									
Medial*ant_post*group	5.3, 94.9	2.53*	C=Co, C ≠ I*, Co ≠ I*	.	.	.	.	.	.
Medial*ant_post	.	.	.	2.3, 27.2	10.90***	2.6, 33.5	3.92*	2, 1, 23	2.24
Medial	.	.	.	1, 12	22.11**	1, 13	1.54	1, 11	.79
Ant_post	.	.	.	1.3, 15.3	7.10*	1.1, 14	.71	1.2, 13.3	3.11
Stimulus*hemisphere*ant_post	1.6, 57	12.39*****	.	.	.	.	.	.	.
Stimulus*medial*ant_post	2.5, 90.9	4.14*	.	.	.	.	.	.	.
Auditory tPC1-772 (LPC)									
Stimulus*ant_post*group	2.8, 51	3.32*	C=Co, C ≠ I**, Co=I	.	.	.	.	.	.
Stimulus*ant_post	.	.	.	1.5, 18.3	9.11**	1.2, 15.9	.27	1.4, 14.8	1.64
Stimulus	.	.	.	1, 12	5.26*	1, 13	.66	1, 11	5.18*
Ant_post	.	.	.	1.8, 21.7	8.95**	1.6, 20.3	13.82***	1.5, 16.3	15.74***

Note. Comparisons were based on 4 within-subject factors (*condition* (antonymic/unrelated), *hemisphere* (left/right), *medial* (medial [F3/F4, C3/C4, CP5/CP6/P3/P4, O1/O2] and lateral [F7/F8, T7/T8, TP9/TP10, P7/P8, PO9/PO10]), and *anterior-posterior* (=ant_post; 5 levels: frontal [F3/F4, F7/F8], central [C3/C4, T7/T8], centro-parietal [CP5/CP6, TP9/TP10], parietal [P3/P4, P7/P8], and occipital [O1/O2, PO9/PO10]) and group as between-subject factor.

A dash means that data cannot be computed, are not reported, or are not interpretable.

Data were Greenhouse–Geisser corrected where applicable.

^a Between-subjects effects including controls (C), codas (Co), and interpreters (I).

^b Based on three paired comparisons (CCo, CI, and CoI), for details see text.

^c Based on within-group comparisons (C and Co and I respectively).

* $p < .05$.

** $p < .01$.

*** $p < .001$.

Table 3
Repeated-measures ANOVA results of visual antonymic and unrelated targets.

Source	Between subjects			Within subjects					
	Across groups ^a		Group comparisons ^b	Controls ^c		Codas ^c		Interpreters ^c	
	df	F		df	F	df	F	df	F
Visual tPC7-520 (N400)									
Stimulus*hemisphere*ant_post*group	4.6, 91.7	2.40*	C ≠ Co*, C=I, Co ≠ I*	.	.	.	.	.	.
Stimulus*hemisphere*ant_post	.	.	.	1.7, 23.7	.38	4, 56	7.03***	2, 23.9	.23
Stimulus*hemisphere	.	.	.	1, 14	.93	1, 14	2.20	1, 12	.45
Stimulus*ant_post	.	.	.	1.7, 23.2	.15	2.1, 29.5	1.27	1.4, 17.1	2.72
Hemisphere*ant_post	.	.	.	1.9, 26.7	.63	2.3, 32.2	1.22	2.4, 28.4	5.48**
Stimulus	.	.	.	1, 14	.21	1, 14	.01	1, 12	3.40
Hemisphere	.	.	.	1, 14	.15	1, 14	1.36	1, 12	11.14**
Ant_post	.	.	.	1.4, 20.2	7.50**	1.9, 26.3	.60	1.5, 17.5	4.41*
Visual tPC1-752 (LPC)									
Medial*ant_post*group	8, 160	4.70***	C=Co, C ≠ I***, Co ≠ I**	.	.	.	.	.	.
Medial*ant_post	.	.	.	4, 56	13.08***	4, 56	21.67***	4, 48	34.17***
Medial	.	.	.	1, 14	32.08***	1, 14	55.74***	1.12	51.78***
Ant_post	.	.	.	2, 28.3	4.74*	1.6, 22	8.48**	1.5, 17.8	20.16***
Stimulus*hemisphere*group	2, 40	5.27**	C ≠ Co**, C ≠ I*, Co=I	.	.	.	.	.	.
Stimulus*hemisphere	.	.	.	1, 14	1.08	1, 14	11.55**	1, 12	4.10
Stimulus	.	.	.	1, 14	.77	1, 14	2.86	1, 12	.64
Hemisphere	.	.	.	1, 14	.09	1, 14	3.20	1, 12	.85

Note. Comparisons were based on 4 within-subject factors (*condition* (antonymic/unrelated), *hemisphere* (left/right), *medial* (medial [F3/F4, C3/C4, CP5/CP6/P3/P4, O1/O2] and lateral [F7/F8, T7/T8, TP9/TP10, P7/P8, PO9/PO10]), and *anterior-posterior* (=ant_post); 5 levels: frontal [F3/F4, F7/F8], central [C3/C4, T7/T8], centro-parietal [CP5/CP6, TP9/TP10], parietal [P3/P4, P7/P8], and occipital [O1/O2, PO9/PO10]) and group as between-subject factor.

A dash means that data cannot be computed, are not reported, or are not interpretable.

Data were Greenhouse–Geisser corrected where applicable.

^a Between-subjects effects including controls (C), codas (Co), and interpreters (I).

^b Based on three paired comparisons (CCo, CI, and CoI), for details see text.

^c Based on within-group comparisons (C and Co and I respectively).

* $p < .05$.

** $p < .01$.

*** $p < .001$.

($F(1.5, 33.7)=7.31, p=.005$), as this interaction was not significant between codas and either controls or interpreters ($ps > .05$). Within-subject follow-up rmANOVAs revealed that only controls

processed antonymic and unrelated stimuli differently in anterior–posterior dimensions (Table 2). This reflected the appearance of a frontal positivity, which was exclusive to controls processing the

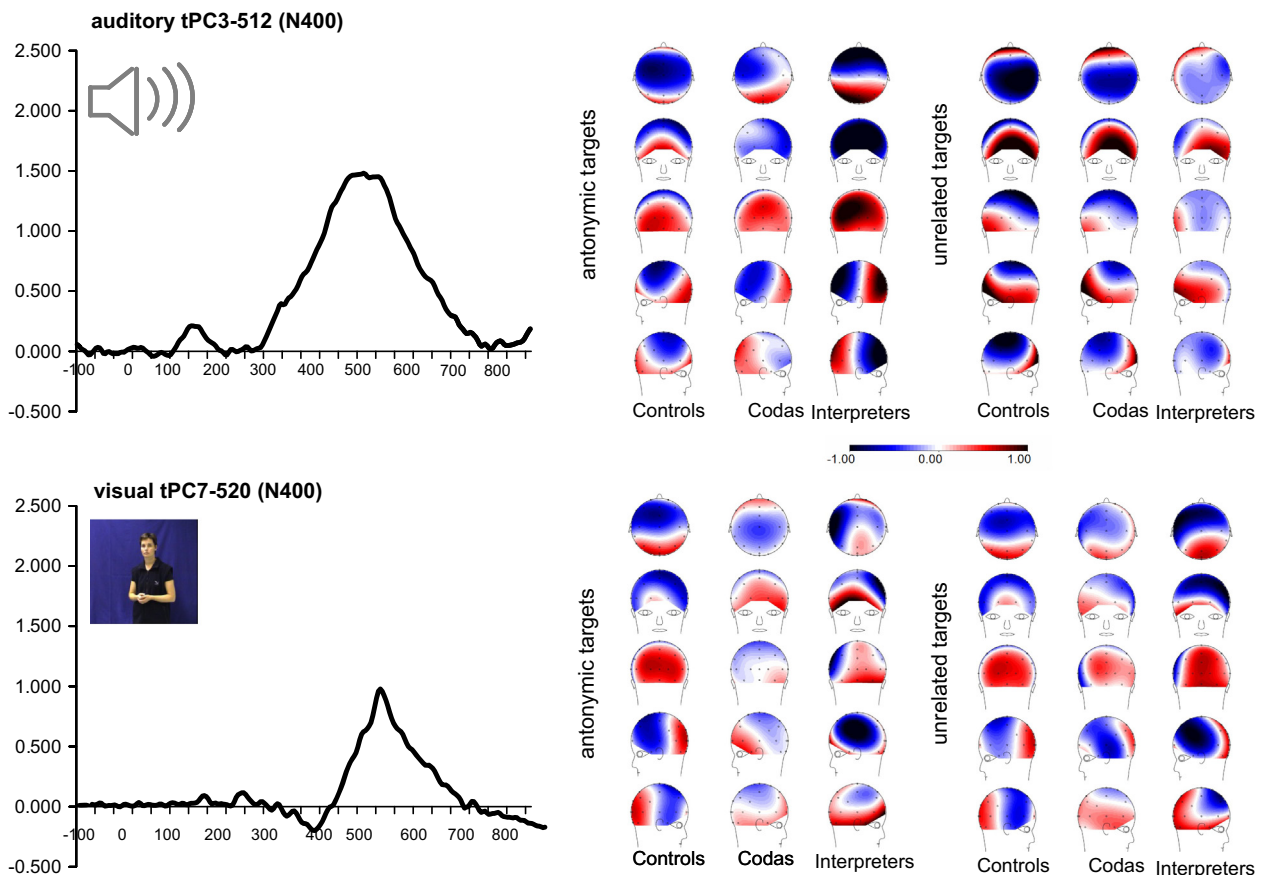


Fig. 5. Temporal principal components (tPCs) corresponding to auditory (top) and visual (bottom) N400 ERP components. Temporal PC factor loadings representing the N400 are displayed on the left. The column on the right shows factor score topographies of each group for the corresponding component within antonymic and unrelated targets.

unrelated targets, and at the same time a significant reduction of the parieto-occipital positivity (Fig. 6). Controls thus displayed strikingly different LPC patterns in response to the auditory unrelated and antonymic targets. Interpreters (but not codas) showed a significant stimulus main effect (Table 2) over left-hemispheric centro-parietal and right-hemispheric fronto-central brain areas. In sum, controls engaged dissimilar LPC networks for processing the antonymic and the unrelated targets whereas signers displayed a rather similar response pattern to both targets. The intensity of interpreters' but not codas' responses was different between the targets predominantly at left centro-parietal and right fronto-central electrodes (Fig. 6). The parieto-occipital positivity most canonically reflecting the LPC was significantly reduced in controls' response to the unrelated targets but was relatively similar to both auditory target types in the two signing groups except for a slightly wider left parietal response in interpreters.

3.2.3. Visual tPC7-520 (N400)

Visual tPC7-520 scored negatively at frontal and central sites and positively at posterior regions (Fig. 5, lower row). Only codas' topography suggested a differential distribution for the antonymic and the unrelated target responses. Visual tPC7-520 explained 1.37% of the variance and corresponded to the N400 component.

Analyses of variance showed a significant interaction between stimulus, hemisphere, anterior–posterior levels and group (Table 3) with codas differing from controls ($F(2.2, 62.5)=4.02, p=.019$) and interpreters ($F(2.6, 68)=3.25, p=.033$), while controls and interpreters did not differ from each other ($p>.05$). The interaction of stimulus, hemisphere and anterior–posterior levels was significant

in codas only (Table 3). Separate rmANOVAs for each stimulus in codas revealed that hemisphere and anterior–posterior dimensions interacted significantly in response to the unrelated targets ($F(2.5, 34.3)=4.35, p=.015$) but not to the antonymic targets ($p>.05$). Codas, thus, displayed a left-hemispheric centro-parietal negativity in response to the visual unrelated (but not to the antonymic) targets, while both other groups showed more central negativities bilaterally, which did not differentiate between stimuli (Fig. 5).

3.2.4. Visual tPC1-752 (LPC)

Visual tPC1-752 had positive scores over central sites and negative scores over occipital and parietal sites bilaterally (Fig. 6, lower row). It explained 59.31% of the variance within the dataset and corresponded to the LPC ERP component.

Repeated-measures ANOVAs showed a significant interaction between medial levels, anterior–posterior levels and group (Table 3). Grouped comparisons (rmANOVAs) revealed that this result derived from interpreters processing medial by anterior–posterior dimensions differently from controls ($F(4, 104)=7.54, p=.000$) and codas ($F(4, 104)=4.54, p=.002$), while controls and codas did not differ from each other ($p>.05$). Within-group rmANOVAs showed significant interactions of medial and anterior–posterior levels in all three groups (Table 3). Averaged across stimuli and hemispheres, medial electrodes were more positive than lateral sites in all three groups ($t_s > 2.67, p_s < .021$). This mirrored the group-independent positive responses over fronto-central midline and medial regions and the negative responses over lateral and parieto-occipital areas (Fig. 6). The fronto-central medial positivity, though, was more frontally distributed in

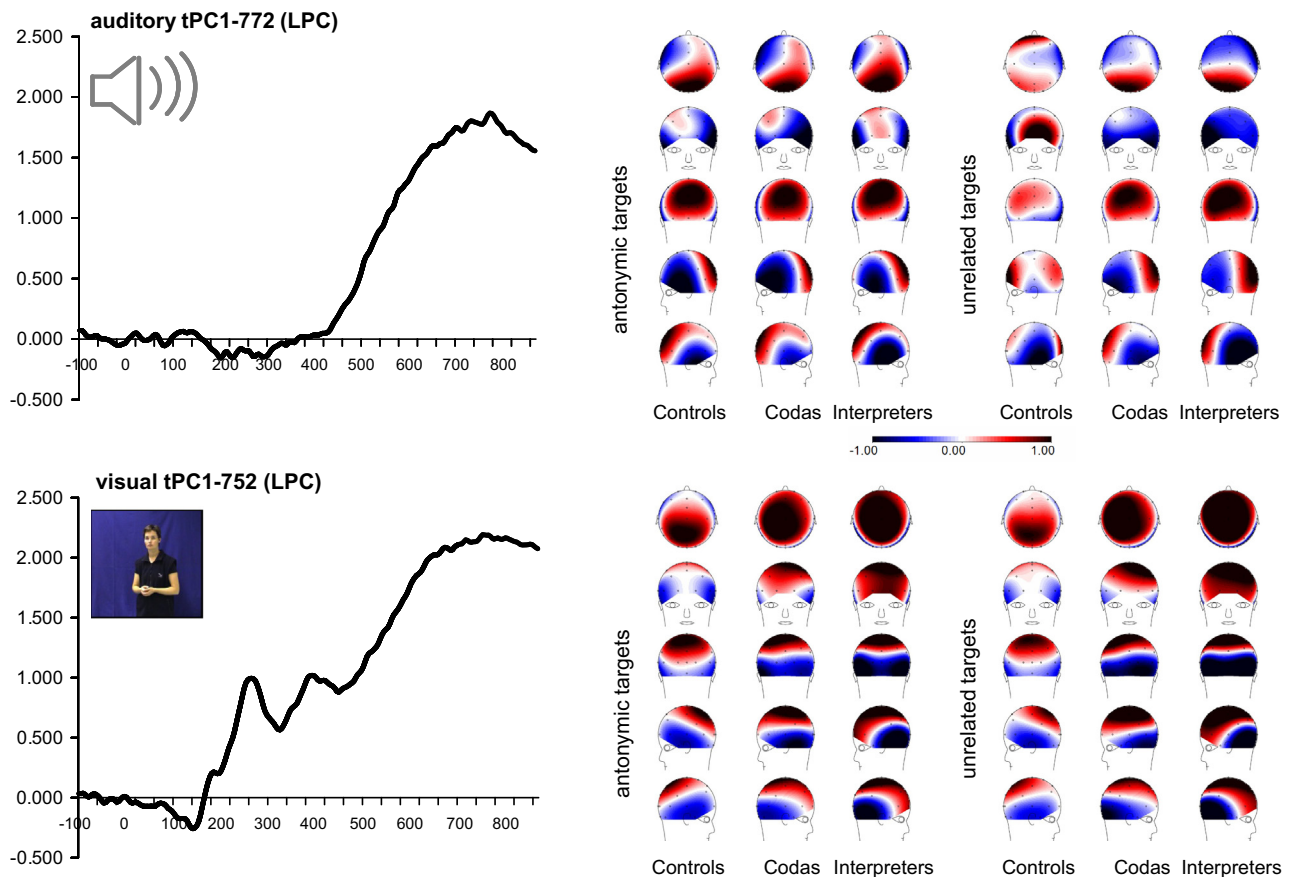


Fig. 6. Temporal principal components (tPCs) corresponding to auditory (top) and visual (bottom) late positive complex (LPC) ERP components. Temporal PC factor loadings representing the LPC are displayed on the left. The column on the right shows factor score topographies of each group for the corresponding component within antonymic and unrelated targets.

codas and interpreters (also expanding more laterally in them) than in controls (Fig. 6).

An additional interaction of stimulus, hemisphere and group led to the uncovering of a stimulus by hemisphere interaction in codas only (Table 3). In them, paired-samples *t*-tests across averaged medial-lateral and anterior–posterior levels proved a general laterality effect for the unrelated target responses ($t=3.04$, $p=.009$) but not for the visual antonym responses ($p > .05$) with the right hemisphere having been more negative than the left. Paired *t*-tests between left and right averaged anterior–posterior levels revealed that this left-dominant processing in the visual unrelated targets reflected a leftward shift of the fronto-central positivity at central, centro-parietal and parietal levels ($t_s > 2.68$, $p_s < .019$) (Fig. 6).

3.3. Correlation analyses between tPC factor scores and d' scores

Pearson correlations between tPC factor scores and behavioral d' scores (Zachau et al., 2012) were calculated for the responses at all 20 electrodes and across all subjects included in statistical analyses here. Significant results are displayed in Table 4 for the auditory conditions and in Table 5 for the visual conditions.

N400 factor scores of the responses to the auditory antonymic targets revealed a significant correlation with the auditory decision sensitivity in controls only, indicating that the lower the N400 was over the occipital areas bilaterally, the higher was the task performance. Factor scores of responses to the unrelated targets

correlated in controls and codas: the higher the N400 over right frontal areas and the lower the N400 over bilateral parietal (codas) or occipital (controls) areas, the better the decision sensitivity. LPC factor scores of the auditory antonymic target responses correlated with the auditory decision sensitivity in controls (the lower the responses over left occipital and the higher over left central areas, the higher the task performance) and codas (the lower the response over left parietal areas, the higher the task performance). Factor scores of the unrelated target responses correlated in interpreters only (the higher the auditory LPC at left parieto-occipital areas and the lower the LPC at right fronto-central areas, the more sensitive the decisions).

N400 factor scores of responses to the visual antonymic targets revealed a significant correlation with the visual decision sensitivity in interpreters only (the lower the N400 over right parietal areas, the higher the task performance). Factor scores of responses to the unrelated targets correlated in controls (the higher the N400 over left frontal areas and the lower over right parieto-occipital areas, the higher the task performance) and interpreters (the lower the N400 over right frontal areas and the higher over left parietal areas, the higher the task performance). LPC factor scores of the visual antonymic target responses correlated with the auditory decision sensitivity in codas (the higher the LPC over left occipital areas, the higher the task performance) and interpreters (the higher the LPC at the right mastoid, the higher the task performance). Factor scores of unrelated target responses correlated in codas only (the lower the LPC over right centro-parietal and the higher over right parieto-occipital areas, the higher the task performance).

Table 4
Significant interactions between auditory tPC scores and d' scores.

	<i>df</i>	Auditory tPC3-512 (N400)						Auditory tPC1-772 (LPC)						
		Antonymic			Unrelated			Antonymic			Unrelated			
		Electrode	<i>r</i>	<i>p</i>	Electrode	<i>r</i>	<i>p</i>	Electrode	<i>r</i>	<i>p</i>	Electrode	<i>r</i>	<i>p</i>	
Controls	11	O1	-.645	.017	F4	.653	.016	C3	.553	.050				n.s.
		O2	-.572	.041	O1	-.711	.006	O1	-.678	.011				
					O2	-.594	.032							
Codas	12			n.s.	F8	.627	.016	P7	-.540	.046				n.s.
					P3	-.544	.044							
					P4	-.541	.046							
Interpreters	10			n.s.			n.s.			n.s.	F8	-.592	.043	
											T8	-.631	.028	
											P3	.598	.040	
											P7	.708	.010	
											O1	.634	.027	

Note. Pearson correlations between auditory tPC scores and auditory d' scores, as published in Zachau et al. (2012), were calculated across all participants (13 controls, 14 codas, 12 interpreters) and electrodes (F3/F4, C3/C4, P3/P4, O1/O2, F7/F8, T7/T8, CP5/CP6, TP9/TP10, P7/P8, PO9/PO10) included in ERP analyses. Unlisted comparisons were non-significant (n.s.=all $ps > .05$). An alpha level of .05 was used.

Table 5
Significant interactions between visual tPC scores and d' scores.

	<i>df</i>	Visual tPC7-520 (N400)						Visual tPC1-752 (LPC)						
		Antonymic			Unrelated			Antonymic			Unrelated			
		Electrode	<i>r</i>	<i>p</i>	Electrode	<i>r</i>	<i>p</i>	Electrode	<i>r</i>	<i>p</i>	Electrode	<i>r</i>	<i>p</i>	
Controls	13			n.s.	F7	.551	.033			n.s.				n.s.
					PO10	-.582	.023							
					O2	-.640	.010							
Codas	13			n.s.			n.s.	O1	.573	.039	C4	-.549	.034	
											CP6	-.582	.023	
											PO9	.515	.049	
Interpreters	11	P4	-.675	.011	F8	-.622	.023	TP10	.569	.042				n.s.
					P7	.594	.032							

Note. Pearson correlations between visual tPC scores and visual d' scores, as published in Zachau et al. (2012), were calculated on all subjects (15 controls, 15 codas, 13 interpreters) and electrodes (F3/F4, C3/C4, P3/P4, O1/O2, F7/F8, T7/T8, CP5/CP6, TP9/TP10, P7/P8, PO9/PO10) included in ERP analyses. Unlisted comparisons were non-significant (n.s.=all $ps > .05$). An alpha level of .05 was used.

4. Discussion

The aim of this study was to investigate the neurocognitive basis of semantic processing across languages based on the use of different sensory modalities in hearing signers and in non-signers. Participants had to judge the semantic relationship between lexeme pairs, which occasionally occurred cross-linguistically. We asked, first, if semantically primed N400 and LPC effects were evocable across spoken and signed lexemes. Semantically related processing effects to cross-linguistically primed targets were predicted to occur in the two signing groups only. Since all participants were native speakers of Finnish, we expected no group-related differences in the processing of primed speech targets. We, second, examined potential qualitative differences in target processing between natively acquired L1 signers and a group of late learned L2 signers. Third, correlation analyses between the electrophysiological and the behavioral target responses were conducted to link the electrophysiological responses to the behavioral performance level.

We will first describe the appearance of the N400 and LPC responses as uncovered by tPCA and discuss them in the context of relevant studies. Thereafter, we present a discussion of the electrophysiological responses to the auditory and the visual targets in and across the three groups of participants. We then discuss our overall results in the context of previous electrophysiological studies concerned with sign language semantic processing and draw general conclusions, also by the inclusion of correlation analyses between electrophysiological and behavioral study outcome.

4.1. ERP Components

The PCA method proved successful for extracting ERP components from our data. Electrophysiological responses to the auditory and visual targets appeared strikingly different (Figs. 2 and 3). The PCA-extracted component structures, though, bore remarkable resemblance to each other, particularly in the later time window

(Fig. 4), where we expected components of interest to occur. Most previous studies on the electrophysiology of lexical processing in sign language have selected N400 time windows based on the visual inspection of the data (one or two phases ranging between 300 and 900 ms; Capek et al., 2009; Grosvald et al., 2012; Gutierrez, Williams et al., 2012; Gutierrez, Müller et al., 2012; Neville et al., 1997). Even though the N400 is strongly task- and experience-dependent, and therefore may indeed vary in its timing, it may do so also in its topography (e.g., Kutas & Federmeier, 2011). This makes visual inspection highly subjective and may result in inconsistent criteria for windows selection between the studies. The application of tPCA to our data objectively revealed the N400 in response to the visual targets ranging approximately 430–700 ms and peaking at about 520 ms. This, like the timing of the N400 in response to the auditory targets, was not easily predictable by visual inspection of the electrophysiological data (Fig. 3). Temporal PCA extracted the systematic variance which also encompassed not only the relevant wide ranging peaks, but also the processing related slopes in the waveforms. Further, tPCA separated different time ranges revealing underlying processes. In our study, the visual N400 was entirely superimposed by the later LPC and an earlier component resembling an auditory component preceding the N400 (Fig. 4). The LPC was the predominant response across groups and visual conditions, explaining almost 60% of the entire variance in the dataset as opposed to less than 1.5% attributable to the N400. Analyzing the narrow N400 time window, even if it was visually detectable, would probably not, therefore, have given a comprehensive picture of component-relevant processes. Instead, it would have been contaminated, in our case, by two neighboring components. Such seamlessly overlapping responses could explain the rather extended time windows used in some N400 studies (such as 300–875 ms for signed sentences, Capek et al., 2009), and may also have led to suggestions of a biphasic morphology of the N400 in response to signed stimulation (Gutierrez, Müller et al., 2012; Neville et al., 1997). In sum, temporal PCA showed that components underlying the processing of the auditory and visual stimuli in our task were dissimilar during the early course of processing but became remarkably alike in its overall structure during later processing stages (Fig. 4). It is highly likely that earlier components reflected modality-specific processes of stimulus extraction and processing, while components in the later course of time mirrored analog processes across modalities. As expected, both the N400 and the LPC were elicited by our study design in response to not only auditory but also to cross-modally primed, signed targets.

4.1.1. Auditory responses

Clear group-independent N400 effects were found between responses to the auditory antonymic and unrelated targets, which were reflected in their topographies. The auditory antonyms' N400 response comprised a fronto-central negative shift and a left lateralized parieto-occipital positivity, while the auditory unrelated targets processing was reflected in a negativity bilaterally over centro-parietal sites. These group-independent N400 effects clearly mirrored the expected priming effects of our task design. Interestingly, despite all groups being native speakers of Finnish, group differences were found between them. While interpreters engaged a large N400 network across large areas of the scalp, both non-signing controls and codas revealed more differentiated albeit topographically non-identical responses. The engagement in a cross-linguistic task requiring constant activation of both the linguistic systems, speech and sign language, resulted in three non-identical processing patterns even at the level of the auditory N400. What is remarkable in this context is the fact that the most deviating group was not the one with special circumstances of language acquisition in early childhood (codas), but the one which

had learned sign language during adulthood (interpreters). Codas were generally very similar in their auditory N400 processing profile to controls, but also displayed similar characteristics to interpreters in terms of wide-spread effects.

The auditory LPC was manifested in a parieto-occipital positivity. It was significantly reduced in controls' responses to the unrelated targets with the appearance of an additional, very frontal positivity. The two signing groups did not differ from either each other or from controls in their responses to the auditory antonyms. Both signing groups engaged processes of non-automatic stimulus evaluation in both stimulus conditions, while controls clearly differentiated between the two types of stimuli and showed a reduced parietal positivity in response to the unrelated targets. Sign language knowledge, therefore, significantly modulated the semantic analyses of the auditory unrelated targets as reflected in the LPC. Although generally identical with codas' auditory LPC activation pattern, only interpreters displayed stimulus-related differences in activation level mainly at left centro-parietal and right fronto-central sites. Auditory LPC effects were thus present but very different in controls and interpreters, whereas codas did not display any significant processing difference between the antonymic and the unrelated targets.

4.1.2. Visual responses

The visual targets evoked the N400 response with similar timing compared to its auditory counterpart. Unlike the auditory N400, the visual N400 was the same in controls and interpreters. Codas were the only group displaying a stimulus-related effect in this component. This effect was manifested in a centro-parietal negativity in the left hemisphere, which appeared in response to the visual unrelated but not to the antonymic targets. Interestingly, codas' topography – including the reported left-hemispheric centro-parietal negativity – resembled controls and interpreters in the unrelated condition, but the topography for the antonymic target responses appeared different. The semantic categorization system underlying the N400, thus, led to fairly similar responses to all visual targets in all groups except that it was less activated in codas processing the antonyms. This effect in native signers – an increased negative response to unrelated over related targets – corresponds to a classical N400 effect. It is unmistakably the result of the task manipulation, which involved cross-linguistic priming and hence reflects processes related to semantic categorization.

The visual LPC peaked approximately 20 ms earlier than the auditory LPC and was mainly reflected by a broad, central positivity in all groups. Different group- and stimulus-related effects were found, however. Controls showed a significantly less frontally distributed positivity than the two signing groups across stimuli, while interpreters displayed a larger positivity fronto-temporally and a larger lateral negativity at parieto-occipital sites than the other two groups. Furthermore, codas were the only group displaying stimulus-related laterality effects. Their fronto-central positivity evoked by the visual unrelated targets shifted to the left, while the antonymic targets were processed more bilaterally. Unexpectedly, the late learned signers did not show differences between the antonymic and unrelated signed targets in N400 or LPC amplitudes.

4.2. Electrophysiology of sign language semantic processing

To our knowledge, Neville et al. (1997) were the only researchers until now to have investigated electrophysiological correlates of signed semantic anomaly in the two signing groups examined here. As part of a more encompassing study, deaf native signers, hearing native signers (codas), hearing late learners of sign language (interpreters) and hearing non-signers had to judge

signed sentences with semantically appropriate or anomalous final signs for meaning. The N400 was analyzed for the time windows 300–600 ms and 600–900 ms. The main finding was that ERPs to semantically anomalous signs were significantly more negative than those to appropriate signs for both time windows in all signing groups. The authors concluded that later stages of semantic processing were not affected by age of sign language acquisition and only in terms of timing and duration by auditory deprivation. Their overall ERP structure (Neville et al., 1997, p. 302) resembled our own findings (Fig. 3) with the exception that our responses to semantically unrelated targets showed the opposite effect direction by being more positive than antonymic ones. The finding of the N400 effect for signers regardless of age of acquisition stands in explicit contrast to our result. Here, late learned signers did not show semantically related effects in the N400 or LPC responses to signed targets, which were respectively peaking in the two time windows analyzed by Neville et al. (1997). Because the N400 effect was shown in response to cross-modal semantic priming in general (Holcomb & Anderson, 1993), to context-violating language switches in speech–speech interpreters (Proverbio et al., 2004), and to speech–sign priming in codas (this study), the absence of a visual N400 effect in interpreters in the present study is likely to derive from a combination of group characteristics and the cross-modal nature of our task.

Other electrophysiological studies have explored sign language processing in deaf signers. Kutas et al. (1987) were the first to show the N400 effect in response to signed sentence endings and to report similar effects to native speakers in written and spoken sentences. The authors further reported a late positivity following the N400 (350–500 ms) to semantic anomalies, which they suspected to be a “member of the P300 family, elicited by the subjects’ mental decision as to whether the sentence [...] was sensible or nonsensical” (p. 328). Like Capek et al. (2009), Grosvald et al. (2012) replicated the finding of a broadly distributed N400 effect in response to semantically congruent vs. incongruent signs and stressed in line with previous studies the similarity of these processes between signed and spoken language. Their data showed a prominent negative shift after approximately 300 ms, while our data showed a prominent positive shift around 200 ms and the reversed direction of stimulus effect. Further, Grosvald et al. (2012) observed a prominent positive shift at approximately 600–800 ms for non-linguistic grooming gestures, which was discussed as a P300-related response replacing the N400-like effects in this condition only. The authors speculate that these stimuli were processed qualitatively different, due to some early filtering mechanism not allowing them to exceed a certain ‘acceptability threshold’. In a follow-up study, Gutierrez, Müller et al. (2012) examined signed sentences with endings of varying semantic and/or phonological violations and found N400 effects (450–600 ms) for all conditions. Remarkably, their ERPs, unlike in Grosvald et al. (2012), strongly reflected our own results, including the positive shift approximately 200/250 ms after stimulus onset but did not show the same effect direction. Gutierrez, Williams et al., 2012 examined priming effects of two phonological features, handshape and location of sign articulation, striving to examine their role in the lexical access process in native and non-native signers. They reported significant N400 effects (300–500 ms) in response to location-related priming in signs, which was somewhat larger in native than non-native signers, while no significant effects were observed for the later time window of 600–800 ms. Handshape-related priming, however, did not evoke any primed effects for meaningful signs in either of the two groups and time windows. Though not related to semantic contents but to phonological features, this was the first study in this context showing a possible vulnerability of the N400 to age of acquisition. Furthermore, results of this study showed both features our data also

revealed: a positive course of activation and the atypical effect direction (ERPs to unrelated targets being more positive than those to related ones). While the overall positive activity, thus, seems to be a feature not uncommon to sign processing, the effect direction may be specific to some feature common to both studies. Gutierrez, Williams et al., 2012 interpreted the atypical effect direction to reflect mechanisms of lateral inhibition of phonologically similar, thus competing, lexical words. Given that phonological features played no systematic role in our study, alternative explanations may be required. Both studies were examining priming sign pairs, and both setups required a conscious lexical decision.

Kutas et al. (1987) speculated about the appearance of a late positivity in setups requiring conscious decision-making (see above). The N400 effect in our study showed as an increased left fronto-central negativity in native hearing signers, while the responses to antonymic targets showed no resemblance to the topography of its auditory counterpart (Fig. 5). The overlap of at least the strongly present LPC could be responsible for altering the N400-related effects beyond the point of visible recognition. This reversed effect direction is in any case clearly related to sign language knowledge as it does not appear in the control group (Fig. 3). The fact that there is even a visible though non-significant effect in non-signers, too, may be attributable to a relatively high percentage of raw response accuracy to visual targets, which were previously discussed in Zachau et al. (2012). Zachau et al. showed how seemingly good behavioral task performance by controls needed to be adjusted by analyzing bias-corrected visual decision sensitivity. We suggested that this group used general visual skills to decode the signed, possibly partly iconic input and to attempt mapping the recorded input on lexicon entries of potential targets predetermined by a certain expectancy raised by the primes. Iconicity was not controlled for in the used stimulus material, and it is very likely that non-signers made use of iconic clues whenever possible. Iconicity, though, does not enhance semantic priming effects even in fluent signers (Bosworth & Emmorey, 2010). The absence of significant stimulus effects for the visually evoked N400 and LPC in controls further underlined that their processing mechanisms for sign language were not truly linguistically driven. The absence of the reversed effect direction for ERP components strongly related to semantic contents of the input in controls also indicated that this peculiarity was connected to sign language knowledge.

4.3. General discussion

The task was designed to put the participants in a state of mind that may be comparable to what has been called the *bilingual language mode* (see, e.g., Grosjean, 2008, ch. 4). The controls had never learned to set themselves to the bilingual mode of Finnish and FinSL, and it is therefore of no surprise that they did not display any target-related response effects in the visual conditions. However unexpectedly, visual N400 and LPC effects were both significantly present in native signers only, even though late acquired interpreters behaviorally outperformed codas (Zachau et al., 2012). This demonstrated that group-specific factors like background of language acquisition and/or language usage overruled task specific fluency and entailed different processing strategies in the non-native sign language users. In keeping with the idea of the Revised Hierarchical Model (RHM) of second language acquisition (Kroll & Stewart, 1994), even highly proficient late learners may make strong use of the entire context, as expectations about targets were raised by the prime presented in their mother tongue, and strong use of access to the conceptual level via lexical representations of their mother tongue rather than L2, which requires enhanced conscious re-analyzing efforts as

reflected in the LPC component. In our study, interpreters appeared to rely essentially on precise harmonized cross-linguistic semantic categorization abilities to effectively practice their profession rather than on effective switching mechanisms. Cross-modal native bilinguals, on the other hand, were able to switch between languages in a task like ours at no obvious enhanced processing costs of semantic integration, which suggests that speech and sign language in them are as tightly interconnected as two languages in unimodal (speech–speech) bilingual individuals.

A recent interpretation of the N400 ERP component suggests that it reflects processes at the junction of pre- and post-lexical processing stages: the transition from stimulus-driven, modality-dependent feature extraction to “temporal synchrony with a broad, multimodal neural network, whose current states have been shaped by recent long-term experience of a wide range of types” (Kutas & Federmeier, 2011, p. 641). The relative temporal stability of the N400 (to certain stimuli in certain tasks) has been interpreted as indicating that a meaning-related binding of all available relevant information occurs at a given time (Federmeier & Laszlo, 2009). According to this view, earlier processes proceed in a bottom-up fashion, guided by specific features eventually leading to association of the input with information in the stored lexicon. Only after a holistic, and thereafter multimodal, conceptual representation of the input has been retrieved, do the effects relating to the processing and conscious evaluation of meaning become evident. The late positivity (LPC) has been linked to controlled processing stages such as explicit memory retrieval, language-related revision processes in the fashion of the P600 component (e.g., Federmeier & Laszlo, 2009), and response accuracy (Finnigan, Humphreys, Dennis, & Geffen, 2002; Wolk et al., 2006). Our data fits well with this, as components in earlier time windows were different between modalities but became strikingly harmonized during later processing stages. Decision accuracy in our study, though, was not straightforwardly reflected in LPC activity, but rather in complex, group-specific correlation patterns involving both the N400 and the LPC. In the auditory conditions, the controls' and codas' similarity in correlation of the decision sensitivity with the N400 response to the unrelated targets stood out (positive correlation over right frontal sites and negative correlation over bilateral parieto-occipital sites), while interpreters – and no other group – displayed correlations with the LPC response to the unrelated targets (negative at right fronto-temporal and positive at right parieto-occipital sites) only. These patterns, that is, the similarity in loci of correlation between the controls' and the codas' N400 on the one hand and the interpreters' LPC on the other hand, suggest some kind of interdependency across the boundaries of ERP components. The most prominent result from correlation analyses in the visual conditions further support the notion of interconnection: the decision sensitivity to the non-related targets was correlated with the N400 response in controls (positively over left frontal sites and negatively over right parieto-occipital sites) and interpreters (negatively over right frontal sites and positively over left parietal sites), whereas it was correlated with the LPC response in codas (negatively over right centro-parietal sites and positively over left parieto-occipital sites). Strikingly differing patterns of correlation were found between the three groups and between the auditory and visual conditions. There appeared to be an interdependency between the N400 and the LPC in the complex correlation patterns across groups and targets, but this suggestion remains to be examined.

Similar to the findings for decision sensitivity and the ERPs, interpreters showed the most deviating pattern of correlation between the two measures. One open issue in the context of our study is how interpreters achieved precise behavioral decision sensitivity for the visual targets without displaying clear semantically related N400 or LPC effects. One possible explanation, also with respect to the enhanced metalinguistic awareness mirrored in the interpreters' increased auditory decision sensitivity (Zachau et

al., 2012), could be that they processed the input holistic to the degree that it was in some way re-coded prior to undergoing semantic analysis. Exploring earlier – pre-lexical – ERP components apparently involved in gating cross-linguistic priming could be one useful approach to shedding more light on relevant processes underlying cross-linguistic semantic integration in hearing signers.

4.4. Conclusions

Many aspects of our study outcome are in line with previous studies of semantically-related ERP responses to sign language. But a number of peculiarities were also revealed, some of which may be attributable to the analysis method used. The PCA method uncovered ERP component structures to primed spoken and signed targets, which became evidently analog over time, but still revealed different characteristics between modalities and groups.

As expected, controls showed a clear N400 response and modulation by the auditory targets with a centro-parietal distribution. Further, they displayed a later, parieto-occipital positivity, LPC, in response to the auditory stimuli, which was significantly reduced for the unrelated targets. This reduction differentiated controls from the two signing groups, and indicated that sign language knowledge led to a more controlled processing of meaning in signers within the given, occasionally cross-linguistic, task, even if the unrelated targets were presented without language switch.

Our data confirmed the cross-linguistic similarity of the N400 appearance at least in terms of its timing. The N400 topography and effect sites, though, were rather dissimilar between modalities. The N400 effect (i.e., different amplitudes) to the signed stimuli was present in the native signers only, but showed an unexpected effect direction: responses to the semantically unrelated targets were more positive instead of more negative than responses to the antonymic targets.

The LPC response to the signed targets had an earlier onset and peaked earlier than that to the auditory words. Also the topography of the LPC responses was different between modalities: parieto-occipital in response to the auditory and central responding to the visual targets. The controls' characteristic differentiation between LPC patterns in response to auditory antonymic and unrelated targets, however, was not present in visual conditions in either group. The visually evoked LPC was modified with the knowledge of sign language, became more frontal in signers compared to non-signers, but revealed cross-linguistically evoked semantic stimulus effects in native signers only.

The processing context (i.e., the task) strongly influenced the configuration of the participants' entire semantic processing system. Both the group differences in processing the spoken targets and the lack of N400 and/or LPC effects in response to the signed targets in non-native signers was not expected. Interpreters may be the most homogenous group of highly proficient sign language late learners, but they are also very specialized by being highly trained in translational tasks. Future studies are needed of hearing signers with varying backgrounds in order to more closely determine the impact of different factors such as age of acquisition, learning context, level of language mastery, and language usage on the semantic processing system.

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Appendix A

See [Table A1](#).

Table A1
Experimental stimuli.

Primes		Antonymic targets		Indirectly related targets	
yo	(night)	päivä	(day)	aurionpaiste	(sunshine)
aamu	(morning)	ilta	(evening)	päivällinen	(dinner)
ystävä	(friend)	vihollinen	(enemy)	sota	(war)
vähemmistö	(minority)	enemmistö	(majority)	voittaja	(winner)
aikuinen	(adult)	lapsi	(child)	lelu	(toy)
epäjärjestys	(chaos)	järjestys	(order)	poliisi	(police)
maksimi	(maximum)	minimi	(minimum)	häviöjä	(loser)
vahvuus	(strength)	heikkous	(weakness)	sairaus	(sickness)
puhtaus	(tidiness)	likaisuus	(dirt)	jätteet	(garbage)
surullisuus	(sadness)	iloisuus	(happiness)	vitsi	(joke)
epäonnistuminen	(adversity)	onnistuminen	(prosperity)	raha	(money)
hyöty	(advantage)	haitta	(disadvantage)	vajaus	(deficit)
harrastelija	(amateur)	ammattilainen	(professional)	kyky	(competence)
alku	(beginning)	loppu	(end)	päämäärä	(aim)
viha	(hate)	rakkaus	(love)	sydän	(heart)
valoisuus	(brightness)	pimeys	(darkness)	yo	(night)
raittius	(sobriety)	juoppous	(drunkenness)	olut	(beer)
luottamus	(confidence)	epäluottamus	(distrust)	valhe	(lie)
tyhmyys	(stupidity)	viisaus	(wisdom)	tietosanakirja	(encyclopedia)
mies	(man)	nainen	(woman)	tyttö	(girl)
rauha	(peace)	sota	(war)	ase	(weapon)
sisällä	(indoor)	ulkona	(outdoor)	sää	(weather)
vapaus	(freedom)	vankeus	(captivity)	vankila	(prison)
yksilo	(individual)	ryhmä	(group)	yhtye	(band)
kaupunki	(city)	maaseutu	(countryside)	metsä	(forest)
valhe	(lie)	totuus	(truth)	luottamus	(confidence)
lupa	(permission)	kielto	(prohibition)	rajoitus	(restriction)
tunnottomuus	(numbness)	tunto	(sensation)	rakkaus	(love)
hyväksyminen	(approval)	hylkääminen	(rejection)	surullisuus	(sadness)
erottaminen	(division)	yhdistäminen	(unification)	häät	(marriage)
laillisuus	(legality)	rikollisuus	(delinquency)	vankila	(prison)
poissaolo	(absence)	läsnäolo	(presence)	vieras	(guest)
siviili	(civilian)	sotilas	(soldier)	ase	(weapon)
valvellaolo	(vigilance)	nukkuminen	(sleep)	uni	(dream)
terveys	(health)	sairaus	(sickness)	sairaala	(hospital)
tuttava	(acquaintance)	vieras	(stranger)	ulkomaa	(foreign country)
kuolema	(death)	syntymä	(birth)	vauva	(baby)
vuokralainen	(tenant)	vuokranantaja	(landlord)	omistaja	(owner)
lääkäri	(doctor)	potilas	(patient)	kipsi	(cast)
mies	(husband)	vaimo	(wife)	raskaus	(pregnancy)
vanhempi	(parent)	lapsi	(child)	lelu	(toy)
isovanhempi	(grandparent)	lapsenlapsi	(grandchild)	lelu	(toy)
veli	(brother)	sisko	(sister)	tyttö	(girl)
opettaja	(teacher)	oppilas	(pupil)	tutkinto	(graduation)
professori	(professor)	opiskelija	(student)	tutkinto	(graduation)
ostaja	(buyer)	myyjä	(seller)	kauppias	(shop owner)
työntekijä	(employee)	esimies	(boss)	valta	(force)
ohjattava	(PhD student)	ohjaaja	(supervisor)	työnantaja	(employer)
isäntä	(master)	palvelija	(servant)	työntekijä	(employee)
kapteeni	(skipper)	miehistö	(crew)	ryhmä	(group)
hyökkääjä	(aggressor)	puolustaja	(defender)	suoja	(protection)
vastaanottaja	(recipient)	lähettäjä	(sender)	kuulluttaja	(speaker)
velallinen	(debtor)	velkoja	(creditor)	onnistuminen	(prosperity)
työnantaja	(employer)	työntekijä	(employee)	veroilmoitus	(tax return)
puhujia	(speaker)	kuulija	(listener)	hyssytys	(hush)

Note. English translations are approximate and were not used experimentally.

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