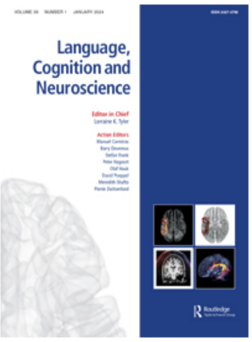

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Incremental sentence processing is guided by a preference for agents: EEG evidence from Basque

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ABSTRACT
Comprehenders across languages tend to interpret role-ambiguous arguments as the subject or the agent of a sentence during parsing. However, the evidence for such a subject/agent preference rests on the comprehension of transitive, active-voice sentences where agents/subjects canonically precede patients/objects. The evidence is thus potentially confounded by the canonical order of arguments. Transitive sentence stimuli additionally conflate the semantic agent role and the syntactic subject function. We resolve these two confounds in an experiment on the comprehension of intransitive sentences in Basque. When exposed to sentence-initial role-ambiguous arguments, comprehenders preferentially interpreted these as agents and had to revise their interpretation when the verb disambiguated to patient-initial readings. The revision was reflected in an N400 component in ERPs and a decrease in power in the alpha and lower beta bands. This finding suggests that sentence processing is guided by a top-down heuristic to interpret ambiguous arguments as agents, independently of word order and independently of transitivity.

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Sentence comprehension; semantic roles; N400; oscillations; intransitives

1. Introduction

Sentence processing is an incremental process. When hearing or reading sentences, comprehenders use top-down cues to immediately integrate the upcoming linguistic material with the previously formed sentence structure (Altmann & Steedman, 1988; Frazier & Rayner, 1982; Marslen-Wilson, 1973). An important top-down heuristic that has been suggested for this process is the *subject/agent preference*, according to which comprehenders preferentially interpret locally ambiguous first arguments as the subject or agent of the clause.

Evidence for the subject/agent preference heuristic comes from studies that manipulate the ambiguity of the initial argument in transitive sentences (e.g. Dröge et al., 2020; Ferreira, 2003; Haupt et al., 2008; Matzke et al., 2002). For example, Haupt et al. (2008) conducted a study on German using noun phrases (such as *Bertram* in the complement sentence fragment *dass Bertram*) that were compatible with either a subject/agent or an object/patient interpretation (Example 1).

(1)	a.	…dass	Bertram	Surferinnen	gratuliert	hat
		…that	Bertram	surfers.FEM.PL	congratulate	AUX.SG
		'…that	Bertram	congratulated	the	surfers.'
	b.	…dass	Bertram	Surferinnen	gratuliert	haben
		…that	Bertram	surfers.FEM.PL	congratulate	AUX.PL
		'…that	surfers	congratulated	Bertram.'	

Disambiguations towards object/patient-first orders elicited a larger N400 component in the event-related potentials (ERPs). This result showed that comprehenders transiently committed to a subject/agent reading for the initial ambiguous argument and had to revise their interpretation when encountering auxiliaries that disambiguated towards the unexpected object/patient-first interpretations.

Similar studies in other languages suggest that these effects also persist when object/patient-initial sentences are more common than in German, for example, due to

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argument omission (Turkish: Demiral et al., 2008; Mandarin Chinese: Wang et al., 2009). A preference for initial subject/agents persists also when ambiguous arguments denote inanimate referents (Demiral et al., 2008; Wang et al., 2009), although inanimate referents are less prototypical and therefore less likely agents (Dowty, 1991).

Such effects are also detectable in Hindi (Bickel et al., 2015), where unmarked ('nominative' or 'absolutive') arguments are often objects/patients because subjects/agents are assigned a special case marker known as 'ergative' case. However, there are also contexts in Hindi where unmarked arguments are subjects/agents because there is a split in the ergative alignment based on aspect. Basque is also an ergative marking language and is fully consistent in assigning the ergative case to subject/agent arguments. Despite this, there is ambiguity also in Basque in some instances due to case syncretism. As a consequence, initial arguments can be ambiguous as to their role in both Hindi and Basque. Intriguingly, the ambiguous arguments nevertheless triggered a reanalysis effect in these two languages (Bickel et al., 2015; Erdocia et al., 2009), suggesting an initial subject/agent preference.

While these cross-linguistic findings make the subject/agent preference a possible universal of sentence processing, the mechanisms behind it remain elusive. This is mainly due to two gaps in the current literature. First, most previous studies tested transitive sentences where subjects/agents precede objects/patients in the basic and most frequent ordering ('SVO' and 'SOV' word orders). Therefore, the effects could derive from a default sentence template for transitives that places subjects/agents first, challenging the notion of an independent subject/agent preference. Second, previous studies were unable to distinguish between the syntactic category 'subject of a sentence' and the semantic role 'agent in the event denoted by the verb'. In sentences like 'Bertram congratulated the surfers' (example 1a), 'Bertram' is both the subject and the agent.

There is tentative evidence that comprehenders rely on semantic roles, not syntactic categories, when interpreting the role of initial arguments during incremental processing. For example, Bornkessel et al. (2003) showed that sentence processing can be guided by semantic features alone, independent of syntax. But the evidence specifically rests on dative experiencer constructions (German 'ihr gefällt das Buch', literally 'to-her pleases the book', i.e. 'she likes the book'), and it is unclear whether this generalises to agents. Another case for semantic, instead of syntactic, effects was made for reanalysis effects in Mandarin Chinese (Wang et al., 2009). Here, the reasoning rests on the notion that the language lacks a syntactic subject category (LaPolla, 1993; Morbiato, 2018), but it is not fully conclusive because alternative grammatical analyses do assume a syntactic subject category (Huang et al., 2009; Paul, 2015).

A hitherto unexplored way to resolve the question is to compare intransitive sentences that vary in the semantic role of their subject. In intransitive sentences, both agents and patients map to the same syntactic subject category. This observation resolves the subject/agent and object/patient correlations and makes it possible to manipulate the semantic role while keeping the syntax constant. Intransitive verbs generally fall into two categories, depending on the semantic role they assign to the subject (Burzio, 1986; Dowty, 1991; Levin & Rappaport Hovav, 1995; Perlmutter, 1978; Van Valin, 1991). In English, for example, verbs such as 'play' (Example 2a) take agents and verbs such as 'faint' (Example 2b) take patients as syntactic subjects.

(2) a. The girl played.
b. The girl fainted.

The two verb classes are sometimes referred to as *unergatives* and *unaccusatives* (Burzio, 1986; Perlmutter, 1978), respectively. For terminological transparency, we use the labels 'agent verb' and 'patient verb'. The difference between these verb types matters for sentence comprehension (Agnew et al., 2014; Friedmann et al., 2008; Koring et al., 2012; Vernice & Sorace, 2018; Zeyrek & Acarturk, 2014) and production (Momma & Phillips, 2018).

For example, Koring et al. (2012) found different attention patterns for agent and patient verbs in an eye tracking study using the visual world paradigm. Participants listened to sentences that included agent or patient verbs while seeing a visual referent closely related to the subject argument. Participants fixated earlier on the referent related to the subject upon hearing agent verbs than upon hearing patient verbs. Koring et al. interpreted this effect as showing a different semantic status for subjects of agent verbs and subjects of patient verbs (cf. Gómez-Vidal et al., 2022). Similarly, Shetreet et al. (2010) and Agnew et al. (2014) found differential neural activation for agent verbs and patient verbs in the left inferior frontal gyrus.

However, it remains unclear whether the distinction is also relevant for the interpretation of initial intransitive subjects and, specifically, whether comprehenders prefer to transiently interpret role-ambigous initial subjects as agents like in the case of transitives. In the current study, we address this question directly and contrast the parsing of agent and patient arguments in intransitive sentences.

There are two main theories that can explain the subject/agent preference, and they lead to different predictions for parsing intransitive sentences. Firstly, the subject/agent preference could be based on the salience of agents in human (and animal) cognition, independent of sentence processing (Rissman & Majid, 2019; Wilson et al., 2022). Humans extract agent and patient information rapidly and spontaneously when visually inspecting events (Hafri et al., 2018) and pay more attention to agents than to other elements of events, across ages (Cohn & Paczynski, 2013; Galazka & Nyström, 2016; Griffin & Bock, 2000; Sauppe & Flecken, 2021). The same preference might also guide sentence comprehension, privileging agent interpretations for ambiguous initial arguments. Indeed, the same preference could also underlie the cross-linguistic preference for agent-first placement in basic word orders (Dryer, 2013; Napoli & Sutton-Spence, 2014) and in spontaneous gesturing (Futrell et al., 2015; Goldin-Meadow et al., 2008; Hall et al., 2013; Schouwstra & de Swart, 2014).

The second theory builds on a general minimality heuristic, inspired by independently established principles such as Minimal Attachment (Frazier & Rayner, 1982). The minimality heuristic states that online sentence processing is guided by a preference for local dependencies and smaller structures. However, minimality can be interpreted differently depending on the underlying representations and assumptions. We identify two accounts within the minimality approach, which lead to different predictions for intransitive predicates.

Under the account that we refer to as 'projection-based minimality', the parser only projects arguments and dependencies for which there is explicit evidence (Bornkessel & Schlesewsky, 2006; Bornkessel-Schlesewsky & Schlesewsky, 2009a). For the processing of ambiguous arguments, the parser would preferentially project an intransitive structure because this structure does not entail any additional argument and is therefore minimal.

When there is evidence against an intransitive interpretation, for example when a second argument is encountered, the parser would default to a transitive reading. The preferred choice would then be the agent, because this role is more prominent than the patient in the prominence hierarchy (Bornkessel & Schlesewsky, 2006; Bornkessel-Schlesewsky & Schlesewsky, 2009a). On this account, comprehenders would be sensitive to semantic role differences only in transitives. Importantly, what is at issue here is predictions about semantic (proto-)roles, i.e. generalised notions that hold across larger sets of lexical items, and not the predictions about lexical semantics that are widely attested (Broderick et al., 2018; Weissbart et al., 2020).

Table 1. Hypotheses and predictions for the current study.

Hypothesis	Prediction for intransitives subjects
Agent Preference	Agents preferred over patients
Projection-based minimality	No preference for agents over patients
Integration-based minimality	Patients preferred over agents

The second account within the general minimality approach focusses on the relation between the verb and its arguments. We refer to this account as 'integration-based minimality'. Patients (and similar roles such as themes) can be analysed as 'internal' arguments. These arguments are tightly integrated with the verb's argument structure and its meaning (Kemmerer, 2012; Kratzer, 1996; Marantz, 1984; Primus, 1999). By contrast, agent subjects are 'external' arguments, which are not as tightly integrated into the verb's argument structure. Thus, under the integration-based minimality account, patient subjects and verbs form a minimal combination in a sentence, since they exclude the external argument. Consequently, comprehenders are predicted to interpret ambiguous arguments as patient subjects of intransitive sentences.[1]

In the current study, we use Basque to tease apart these three accounts of interpreting ambiguous, initial arguments. Basque has a verb-final basic word order. The case marking system overtly distinguishes agents from patients, also in intransitives, following what is known as an 'active' case marking system (De Rijk, 2007; Levin, 1983). The syntactic subjects of intransitive sentences are thus marked differently depending on whether they are agents or patients. Agent subjects carry a case marker known as 'ergative', while patient subjects carry absolutive case (also sometimes referred to as 'unmarked'). The following examples (3a) and (3b) illustrate the pattern.

(3) a. Neska hori zorabiatu da
Girl DEM.ABS.SG faint AUX.NOM.SG
'This girl has fainted.'
b. Neska horrek jolastu du
Girl DEM.ERG.SG play AUX.ERG.SG
'This girl has played.'
c. Neska horiek zorabiatu dira
Girl DEM.ABS.PL faint AUX.NOM.PL
'These girls have fainted.'
d. Neska horiek jolastu dute
Girl DEM.ERG.PL play AUX.ERG.PL
'These girls have played.'

In noun phrases involving post-nominal demonstrative pronouns (as in 3), case is signalled by the demonstrative pronoun. In (3a), *zorabiatu* 'faint' is a patient verb, and therefore the demonstrative pronoun in the subject noun phrase takes the absolutive case (*hori*). By contrast, *jolastu* 'play' in (3b) is an agent verb and

Table 2. Partial paradigm of case marking on demonstrative pronouns in Basque. Syncretism in the plural leads to an ambiguity between the ergative and the absolutive forms.

		Noun	Determiner
Singular	Patient	Neska	hori
		Girl	*this.ABS*
	Agent	Neska	horrek
		Girl	*this.ERG*
Plural	Patient	Neska	horiek
		Girl	these.ABS
	Agent	Neska	horiek
		Girl	*these.ERG*

thus the demonstrative in the subject noun phrase is marked by ergative case (*horrek*).

The case marking paradigms in Basque exhibit *syncretisms*, where the forms of different cells of the paradigm are realised identically, such as in the plural demonstrative pronouns in (3c–d). Both the ergative (agent) and absolutive (patient) plural demonstrative 'these' have the form *horiek* (cf. Table 2). This makes plural noun phrases with demonstrative pronouns ambiguous between being the argument of an agent or a patient verb.

Another critical feature of Basque is that both types of intransitive sentences are syntactically equivalent (Laka, 2006). This is in contrast to findings from some other languages, where patient intransitive sentences have been argued to be more complex and costlier to process, because their subject moves from the base-generated object position to the surface subject position (Koring et al., 2012). In Basque, none of the intransitive structures involve syntactic movement (Laka, 2006, 2017), and hence agent and patient sentence structures should be equally minimal, both in their base-generated and in their surface structures. Due to this feature, Basque is particularly well-suited to compare intransitive sentences with regard to their semantic roles.

Previous work on sentence procesing on Basque has shown partial evidence that agent-initial sentences are preferred. Erdocia et al. (2009), Laka and Erdozia (2017) and Vela-Plo et al. (2022) exploited a similar case syncretism in Basque, and found that subject/agent readings are preferred for initial arguments in sentences that are ambiguous between subject/agent-initial (SOV) or object/patient-initial (OSV) word order. These results demonstrate that in transitive sentences, there is a preference for agent or subject-first orders even though patient or object-first orders also exist in Basque. However, we do not know whether the preference is driven by an agent preference or by a preference for the most frequent ordering in transitive sentences.

By contrast, Ristic et al. (2020) found that absolutive/patient readings are preferred when Basque speakers encounter ambiguous noun phrases in isolation. This is probably because absolutives are the forms used for citation, listing, and naming. The associated patient preference would be in line with the predictions of the integration-based minimality theory for sentence comprehension. However, Ristic et al. (2020) also report on a sentence production experiment, where they presented participants with ambiguously marked arguments to be used to complete a sentence. In this situation, the participants produced a higher number of sentences in which the ambiguous argument was interpreted as an agent, as predicted by the subject/agent preference account. Hence, these two experiments provide conflicting evidence on the subject/agent preference. It is unclear whether the difference in results stems from offline interpretations compared to online interpretations, or other task differences. Since Ristic et al.'s study was aimed at investigating the availability of contextual information with number manipulations, it cannot provide direct evidence on sentence comprehension mechanisms.

More closely related to the present study, Martinez de la Hidalga et al. (2019) investigated the processing of intransitive sentences in Basque using a grammatical violation paradigm. They found that ERP responses to number and person violations (Basque equivalents of contrasts such as 'they *has/have suffered this morning') differed for sentences with agent and patient verbs. However, Martinez de la Hidalga et al. did not focus on the interpretation of ambiguous arguments, so their results do not directly reflect on the parsing of ambiguous initial arguments as agents or patients.

In what follows, we examine the processing of sentences in Basque and focus on the electrophysiological processes underlying the interpretation of ambiguous initial arguments. We expose participants to written sentences, manipulating whether sentence-initial arguments are ambiguously case-marked or not, and whether they refer to agents or patients (see Table 3 for examples of each sentence type). The role of ambiguously marked (plural) arguments is disambiguated at the end of the sentence when either an agent verb or a patient verb is encountered. Agent verbs indicate that the initial noun phrase was ergative/agent, while patient verbs indicate absolutive/patient readings. By contrast, the role of unambiguously marked (singular) arguments is immediately indicated by the ergative or absolutive form of the first argument's demonstrative (see Table 2).

Exploring how ambiguous arguments are interpreted allows us to test the alternative accounts and their predictions (see Table 1). If sentence processing is driven by the general salience of agents, ambiguous arguments should be preferentially interpreted as agents. Disambiguations to patients should thus require a revision of the transient interpretation, leading to reanalysis. By contrast, under the projection-based minimality account, comprehenders interpret ambiguous arguments as the sole argument of an intransitive sentence (intransitive subjects), regardless of their semantic role. No reanalysis is expected when disambiguating towards agent or patient roles, since both options lead to a minimal sentence structure, with a sole argument and a predicate. The integration-based minimality account posits that intransitive sentences with patient arguments constitute the minimal sentence type. Hence, comprehenders are expected to preferentially interpret ambiguous arguments as patients. Under this account, disambiguations to agent readings should require revision and elicit a reanalysis effect.

To rule out that any reanalysis effects are driven by lexical differences between agent verbs and patient verbs, we also compare each ambiguous condition with the corresponding unambiguous condition (i.e. comparisons within the two conditions where the initial argument is a patient, or within the two conditions where it is an agent, see examples in Table 3). In these comparisons, the verb form is the same across conditions, but a disambiguation of the semantic role only occurs in the ambiguous condition, since semantic role information is explicitly encoded in the case marking in the unambiguous conditions. If agent or patient interpretations are independent of specific lexical verb choices, the reanalysis should be present both (i) in the comparison with the other ambiguous condition and (ii) in the comparison with the unambiguous condition of the same semantic role and verb.

We record electrophysiological activity to detect reanalysis processes with fine grained temporal resolution. In ERPs, we expect reanalysis effects in the form of an N400 component in response to the disambiguating verb. N400 responses are known to be elicited by semantic manipulations (cf. Kutas & Federmeier, 2011, for an overview) and most previous studies on the subject/agent preference also report N400 effects (e.g. Bickel et al., 2015; Haupt et al., 2008; Sauppe et al., n.d.; Wang et al., 2009).

In addition to ERPs, we also explore event-related power differences as a measure that is sensitive to both phase-locked and non-phase-locked neural activity (Pfurtscheller & Lopes da Silva, 1999; Prystauka & Lewis, 2019). Neural oscillations are known to be involved in a wide range of cognitive functions (Buzsáki & Draguhn, 2004; Siegel et al., 2012), including language comprehension (Hauk et al., 2017). The theta band (approximately 3–7 Hz) has been linked to memory retrieval and lexical processes, while alpha and beta frequency bands (approximately 8–12 Hz and 13–30 Hz, respectively) have been linked to syntactic and semantic processes (Meyer, 2018). Alpha and beta power have been found to decrease when the upcoming word does not match the predicted word (Lewis et al., 2017; Wang et al., 2012). Kielar et al. (2015) also suggest that the decreases in alpha and beta power indicate semantic and syntactic reanalyses. Hence, the reanalysis effect in our experiment should be reflected in a decrease in power in the alpha and beta bands. We additionally analysed the theta band to probe for possible lexical effects, but we refrain from including it in the main results of this study, given that it is not central to the current research questions. We nonetheless report results from the theta band in the Supplementary materials D.

Until now, most studies on event-related power differences employed violation paradigms (Indefrey et al., 2004; Kielar et al., 2015; Pu et al., 2020; Schneider & Maguire, 2018). In contrast, our study characterises the neural response to successful language comprehension by investigating syntactically and semantically acceptable sentences. By analysing and comparing ERPs and effects in the time-frequency domain, we aim to better characterise the neural mechanisms involved in reanalysing semantic interpretations (cf. Coopmans & Nieuwland, 2020).

2. Methods

2.1. Participants

Thirty-two native speakers of Basque (22 females, age: mean = 23.8 years, SD = 5.2 years, range = 18 − 40 years) participated in the experiment for payment. All participants were right-handed, as assessed by a Basque version of the Edinburgh handedness inventory (Oldfield, 1971). This study was approved by the ethics board for human research of the University of the Basque Country (CEISH-UPV/EHU, project number M10_2021_186), and all participants gave written informed consent.

2.2. Materials

We constructed sets of four sentences in Standard Basque that differed along two dimensions: whether the initial argument denoted an agent or a patient, as assigned by the two different classes of intransitive verbs, and whether the initial argument's role was signalled unambiguously or ambiguously (see Table 3).

Table 3. Experimental conditions with examples of experimental materials.

Ambiguity	Semantic Role	Noun	Demonstrative	Adjunct1	Verb	Auxiliary	Adjunct2
Ambiguous	Patient	Emakume Woman	hauek these.NOM/ERG	gaur goizean this morning	irristatu slip	dira have	mendian in the mountain
		'These women slipped in the mountains this morning'					
Ambiguous	Agent	Emakume Woman	hauek these.NOM/ERG	gaur goizean this morning	eskiatu ski	dute have	mendian in the mountain
		'These women skied in the mountains this morning'					
Unambiguous	Patient	Emakume Woman	hau this.NOM	gaur goizean this morning	irristatu slip	da has	mendian in the mountain
		'This woman slipped in the mountains this morning'					
Unambiguous	Agent	Emakume Woman	honek this.ERG	gaur goizean this morning	eskiatu ski	du has	mendian in the mountain
		'This woman skied in the mountains this morning'					

All sentences started with a noun phrase (NP) consisting of a noun and a post-nominal demonstrative. Case is always marked on the last element of an NP. In Basque, the demonstrative bears unambiguous case information in the singular (*honek/horrek/hark* or *hau/hori/hura* for 'this/that/further-that' in ergative and absolutive case, respectively), while the case marking is ambiguous due to a syncretism in the plural (*hauek/horiek/haiek* for 'these/those/further-those' in both ergative and absolutive cases, see Table 2). The initial argument was followed by a two-word adjunct. This allowed for a 'digging-in' effect to facilitate participants' consolidation of their interpretation of the ambiguous sentences, leading to potentially larger reanalysis responses (cf., e.g. Chow et al., 2018).

The two-word adjunct was followed by the critical region, the verb. The agent conditions featured an agent verb such as 'jump' or 'ski', while the patient conditions featured a patient verb such as 'faint' or 'slip' (see Tables A1 and A2 in the Suplementary materials for the whole set of verbs used in the experiment). In the ambiguous conditions, the semantic role of the subject was resolved by the lexical meaning of the verb. A sentence-final adjunct was included to obtain more naturalistic and varied sentences, as well as to guard against possible, although debated (Stowe et al., 2018), wrap-up effects.

We classified the intransitive verbs as agent or patient verbs based on whether they assign the ergative case to their sole arguments. Since the critical disambiguation occurred at the main verb, we matched agent and patient verbs in frequency (tokens per million words, Acha et al., 2014) and length (in letters). This decreased the possibility that disambiguation effects were driven by lexical differences between verb types. Verbs were also matched for frequency and length when pairing them to form items. In addition, we used comparisons within patient and agent conditions to control for lexical differences. In these comparisons, the ambiguity of the initial argument differed, but the critical word for analysis was identical across conditions, i.e. either an agent verb or a patient verb. Therefore, these comparisons can rule out potential effects of lexical differences.

We created the stimuli by combining one agent and one patient verb per item. We used each of the 48 patient verbs and 48 agent verbs for this in four different items, with a different subject noun in each case. This resulted in 192 items with a total of 768 sentences. The sentences were distributed over four lists following a Latin square design, so that each participant read 192 experimental sentences (48 per condition) and 192 filler sentences (384 trials in total). Half of the filler sentences were subject-initial, while the other half used an adjunct or a noun in another case as the initial phrase. Filler sentences were balanced as to whether the subject noun phrase was an agent or a patient.

2.3. Procedure

We used personal computers and E-Prime 3.0 (version 3.0.3.80) (Schneider et al., 2002) to present the stimulus sentences. The sentences were displayed in the middle of the screen word by word (rapid serial visual presentation). Each word was presented for 450 ms, with an inter-stimulus interval of 350 ms. A fixation cross lasting 1000 ms indicated the beginning of each trial and a comprehension question was displayed after half of the trials to ensure that the participants read the sentences attentively. Participants pressed a button to start a new trial. The comprehension questions were balanced in whether they asked about information on the subject argument, the verb, or on one of the two adjuncts in the sentence (cf. Table 3).

The 384 sentences in each list were divided into four blocks. Immediately before and after the sentence comprehension experiment, we recorded EEG resting-state activity (two minutes with eyes open and two minutes with eyes closed). This allowed the extraction of individual peak alpha frequencies to be used to determine individually defined frequency bands. The entire session lasted approximately 140 minutes, including electrode cap application.

We recorded electrophysiological activity from 32 active electrodes secured in an elastic cap (Acticap System, Brain Products), at a sampling rate of 500 Hz. Electrodes were placed in standard positions according to the extended international reference 10–20 system. All recordings were referenced online to the right mastoid electrode. Vertical and horizontal eye movements and blinks were monitored using two electrodes positioned beneath and to the right of the right eye. Electrode impedance was kept below 40 $k\Omega$ for all scalp electrodes and below 20 $k\Omega$ for the eye electrodes.

2.4. Data processing and analyses

EEG data were preprocessed in EEGLAB (version 14.1.2, Delorme & Makeig, 2004), FieldTrip (Oostenveld et al., 2011) and R (version 4.1.0, R Core Team, 2022). Continuous EEG data were filtered with a 0.1–40 Hz band-pass filter, down-sampled to 250 Hz, and re-referenced to the average of the left and right mastoids offline. Pauses between blocks were removed and artifactual channels were automatically excluded (by deviation of more than 5 SD from the mean of all channels in kurtosis or probability). Independent components were computed on a 1 Hz high-pass filtered copy of the data.

The SASICA algorithm (Chaumon et al., 2015; Nolan et al., 2010) was then used to identify artifactual independent components. Independent components were excluded if they were focal to individual electrodes or if they were highly correlated with activity in the EOG electrodes. Previously rejected channels were spherically interpolated after we substracted artifactual components from the EEG data. For ERP analyses, the data were then epoched from –100 to 1000 ms relative to the critical word (main verb).

For event-related power analyses, the data were epoched from −1500 to 1200 ms relative to the critical word. Single-trial data were transformed into a time–frequency representation (in 0.5 Hz steps) using wavelet decomposition (multi-taper method convolution) with Hanning-tapered time windows using a length of 3 cycles and advancing in steps of 50 ms. The power spectra were then transformed into dB relative to the median power in a baseline period of −800 −500 ms before the critical word to make power in all frequencies directly comparable (Cohen, 2014). Finally, power was averaged within the frequency bands to reduce data dimensionality.

Frequency bands were defined for each participant (Klimesch, 1999), based on their individual peak alpha frequency (IAF), following the method proposed by Corcoran et al. (2018), which extracts IAFs from EEG resting state recordings. The alpha band was defined as ranging from IAF-4 Hz to IAF+2 Hz (Klimesch, 1999) and the lower beta band as ranging from IAF+2 Hz to IAF+10 Hz (Bice et al., 2020). The IAF of two participants could not be computed due to excessive artefacts and was imputed with the mean IAF of all other participants. We chose to focus on the lower beta band (and not the whole beta band) following previous studies that report relevant effects on this frequency range (Bastiaansen & Hagoort, 2015; Pérez et al., 2012; Poulisse et al., 2020).

Statistical analyses were performed in R, using the package `mgcv` (Wood, 2004, 2011) for modelling and the packages `itsadug` (van Rij et al., 2020) and `erpR` (Arcara & Petrova, 2014) for plotting. We modelled the topographies of the event-related potentials and the event-related power changes with single-trial generalised additive mixed models (GAMMs). GAMMs are an extension of generalised linear models, allowing the modelling of non-linear relations between variables. In our analyses, we used GAMMs for modelling amplitude or power differences between conditions as a function of electrode position on the scalp (represented by x and y coordinates).

For ERP analyses, we modelled the mean amplitude in a time window of 300-500 ms after critical word, where the N400 component is usually observed. We additionally modelled separately a later time window, 500–700 ms after critical word. We chose these time windows based on previous literature (Bickel et al., 2015; Kutas & Federmeier, 2011) as well as the results in a supplementary analysis of the time course (see Supplementary materials B). The statistical modelling was identical for both time-windows. The amplitude during a baseline period (averaged over −100–0 ms before critical word presentation; Alday, 2019) was included as parametric predictor. To account for the potential non-linear relations between variables, we added a smooth term that modelled the amplitude differences by condition over the x and y coordinates on the scalp. Finally, we included random slopes for the coordinates by participant and by item.

The statistical modelling for time-frequency analyses (TFA) was mostly parallel to the one for ERPs, the only differences being that the response variable was power in decibels per trial and that no baseline period was included (because the baseline is already in the dB value). Models were fitted separately for each frequency band (alpha and lower beta). The time-windows for analysis were the same as for ERPs: 300–500 ms after the critical word for the early time-window and and 500–700 ms for the late time-window.

For both ERP and event-related power models, statistical significance was determined by non-overlapping confidence intervals in (smooth) difference surfaces. Since the nonlinear effects in GAMMs don't have single summary statistics, we follow standard procedure (Wood, 2004) and report effect sizes graphically as model-fitted response values. We report the effects in terms of 95% confidence intervals around the fitted differences between critical conditions (i.e. $\Delta\mu V$ and ΔdB) plotted over the spatially smoothed electrode array. In addition, model comparisons with F tests assessed the fit of each model compared to a corresponding null model.

In addition to the main analyses, we conducted two sets of supplementary analyses. First, we analysed the time course of effects for ERPs for central-posterior electrodes by modelling the differences between conditions as a function of time (instead of electrode position on the scalp). This analysis showed that the differences between conditions were relevant in the time windows we chose for the main analyses (see Supplementary materials B), and not earlier.

Second, we performed a set of analyses with a restricted set of items. For creating the stimuli, we classified the intransitive verbs as agent or patient verbs based on whether they assign the ergative case to their sole arguments. In most cases, this coincides with semantic intuition. However, a handful of verbs in Basque may not match the semantics of the verb group to which they belong because they denote patientive events but assign ergative case (such as 'suffer'). In our list of verb items, the alignment preferences of eight of verbs in out of 96 items could be considered to mismatch. To ensure that these items were not driving or distorting the effects we report, we ran a complementary set of analyses without these items. The results and conclusions are not affected by the inclusion or exclusion of these items (see Supplementary materials C).

3. Results

Participants answered the comprehension questions with high accuracy (mean of by-participant accuracy means = 92%, SE = 2%).

3.1. Early time-window (300–500 ms)

Figure 1 shows the time course of ERPs time-locked to the verb position for all electrodes; Figure 2 presents pairwise comparisons of experimental conditions.

In ERPs, disambiguations to a patient reading elicited a larger negativity over posterior electrode sites compared to disambiguations to an agent reading. This effect was strongest at central and posterior electrode sites (Figures 2B–C), in line with an N400 effect. Furthermore, disambiguations to a patient reading also elicited a larger negativity compared to unambiguously marked patients (Table 3). This effect also extended over central-posterior electrode sites (Figure 2E–F).

The unambiguous agent condition elicited a negativity compared to either ambiguous agent (Figure 2G–I) or unambiguous patient (Figure 2J–K) conditions. These effects were significant across central electrodes in the comparison with the ambiguous agent condition and across central and left-parietal electrodes compared to the unambiguous patient condition. The model that included the experimental conditions performed significantly better than the null model ($F(16.24) = 4.98$, $p < 0.01$).

The results in the alpha and lower beta frequency bands were largely similar to ERP results in the early time window. Pairwise comparisons of the topographical distributions of power differences in the 300–500 ms analysis time window for the alpha and lower beta band are shown in Figures 3 and 4; the corresponding topographical distributions over time are shown in Supplementary materials E (Figures E1 and E2).

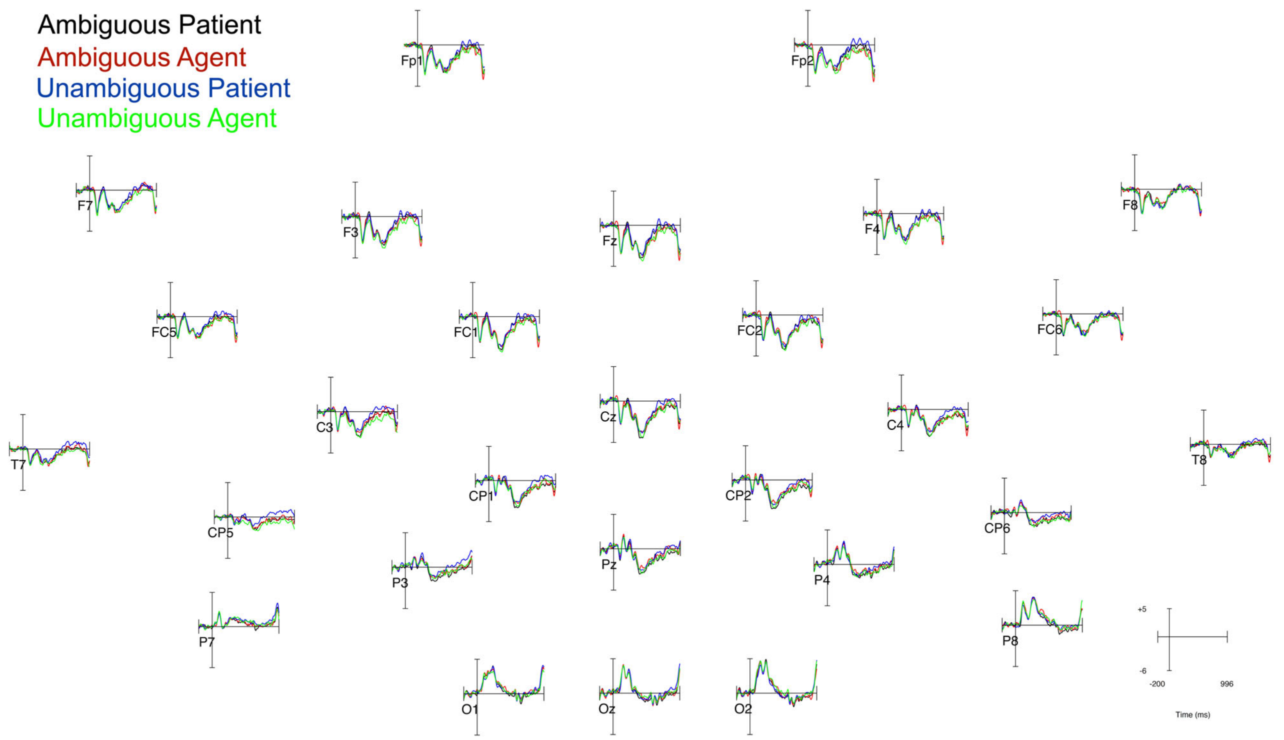

Figure 1. Grand average event-related potentials at the critical verb position. t_0 corresponds to the presentation of the disambiguating verb. Only for plotting, baseline correction (mean amplitude between −100 and 0 ms) was performed.

In the alpha band (Figure 3), there was a power decrease for disambiguations to patients compared to disambiguations to agents in right-posterior electrodes, while central-left electrodes showed higher power (Figure 3A). Disambiguations to patients showed a widely distributed alpha power decrease compared to sentences with unambiguously marked patients (Figure 3B). The condition with unambiguously marked agents elicited lower alpha power compared to either the ambiguous agent condition (Figure 3C) or unambiguous patient condition (Figure 3D). The alpha band model that included the experimental conditions performed significantly better than the null model ($F(70.26) = 15.91$, $p < 0.01$).

In the lower beta band, disambiguations to patients showed a decrease in power compared to either disambiguations to agents (Figure 4A) or unambiguous patients (Figure 4B). Effects in both comparisons were widespread and most pronounced in right-posterior sites for the comparison with the ambiguous agent condition and in central sites for the comparison with the unambiguous patient condition. Additionally, the unambiguous agents showed a power decrease compared to either ambiguous agents (Figure 4C) or unambiguously marked patients (Figure 4D), over right and posterior electrodes and in a widespread posterior-central area, respectively.

The lower beta band model including experimental condition as predictor performed significantly better than the null model ($F(71.07) = 16.30$, $p<0.01$).

3.2. Late time-window (500–700 ms)

Figure 5 presents pairwise comparisons of ERPs for the late time window. The results showed a frontally distributed positivity for the ambiguous patient condition compared to the ambiguous agent condition (Figures 5A–C). In contrast, the ambiguous patient condition elicited a continuous negativity compared to the unambiguous patient condition over posterior electrodes (Figures 5D–E). There were no statistically significant differences between the unambiguous agent and the unambiguous agent conditions (Figures 5G–I), while we found a widely distributed positivity for sentences with unambiguous patients compared to sentences with unambiguous agents (Figures 5J–L). The ERP model that included the experimental conditions performed significantly better than the null model ($F(34.77) = 3.22$, $p<0.01$).

Figures 6 and 7 present comparisons of power differences in the alpha and lower beta band in a 500–700 ms time window.

In the alpha frequency band, disambiguations to patient showed a power decrease compared to disambiguations to agent over posterior areas (Figure

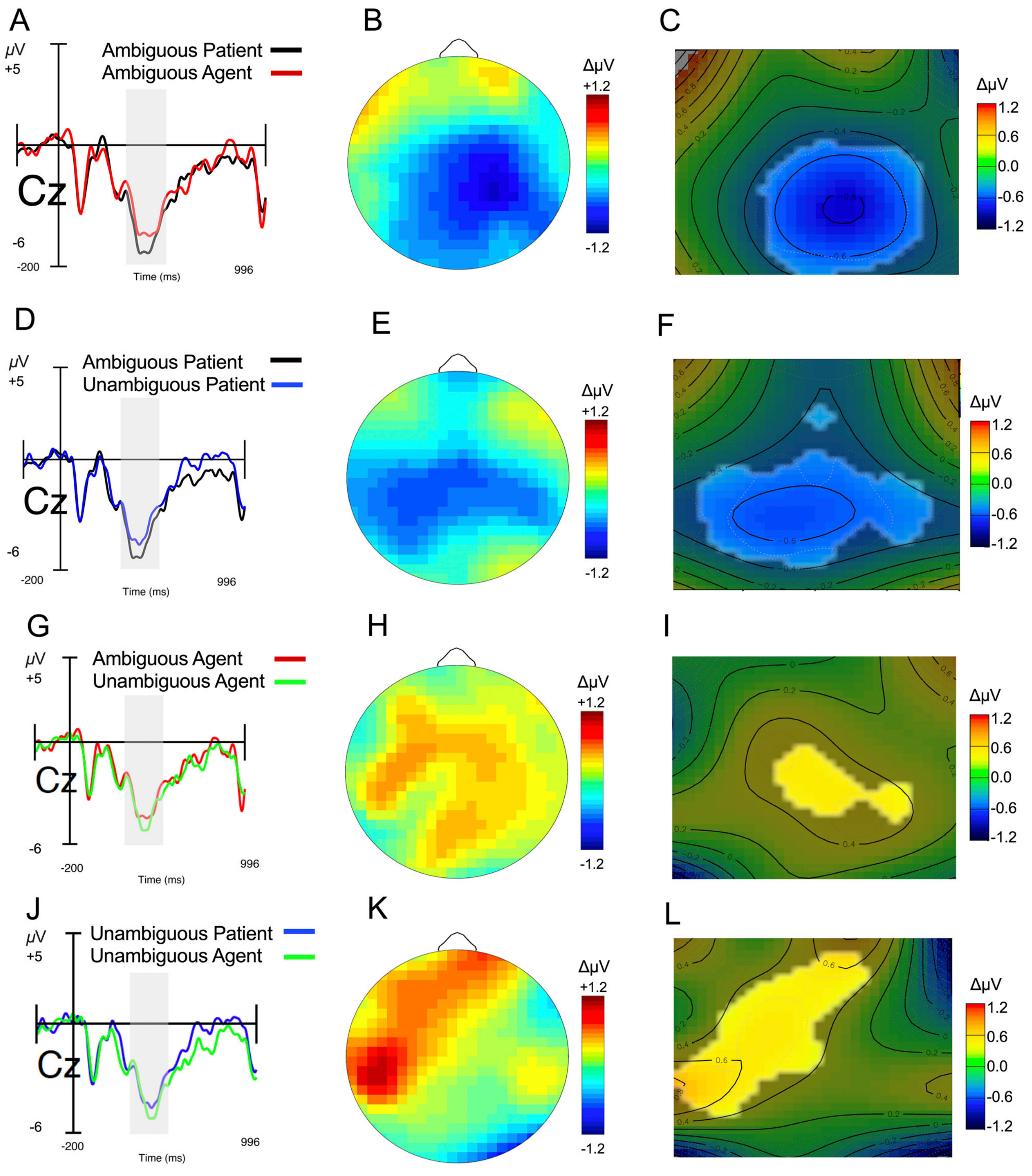

Figure 2. Pairwise comparisons of ERP differences between conditions at the critical verb position. Figures in the first row (*A*, *B*, *C*) show the comparison between Ambiguous Patient and Ambiguous Patient conditions. The second row (*E*, *F*, *G*) compares the Ambiguous Patient and Unambiguous Patient conditions. The third row compares the Ambiguous Agent and Unambiguous Agent conditions (*G*, *H*, *I*), and the last row (*J*, *K*, *L*) compares the Unambiguous Patient and Unambiguous Agent conditions. In each row, figures on the left (*A*, *D*, *G* and *J*) show grand mean ERP time courses at Cz. Figures in the centre (*B*, *E*, *H*, *K*) show grand mean topographical distribution of the differences between conditions. Figures on the right (*C*, *F*, *I*, *L*) show estimated GAMM difference surfaces of the topographic distribution of differences between conditions in the 300–500 ms time window. Non-shaded (bright) areas indicate where the 95% CIs exclude 0. Differences in the centre and right column are always between μV in the upper minus μV in the lower condition according to the legend in the left columns.

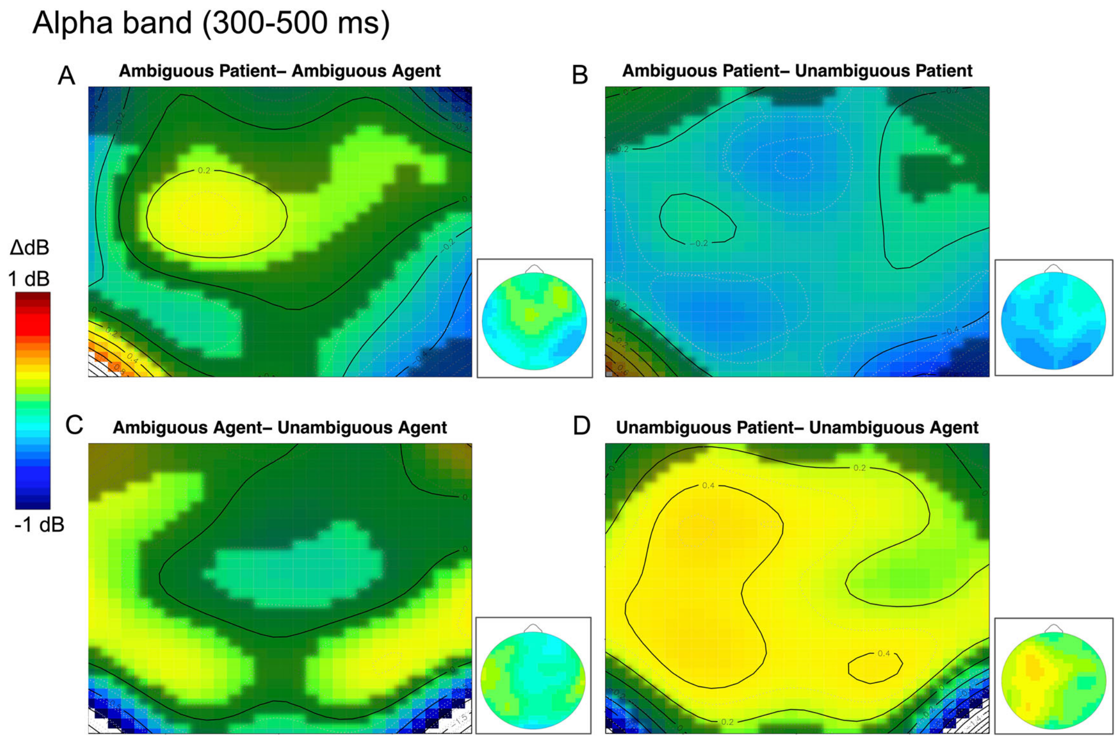

Figure 3. Comparison of power differences in individually defined alpha band in the 300–500 ms time window after critical word (verb) presentation. Large plots show estimated (GAMM) difference surfaces of the topographic distribution of differences between conditions (A–H). Adjacent small plots show the corresponding observed grand average differences.

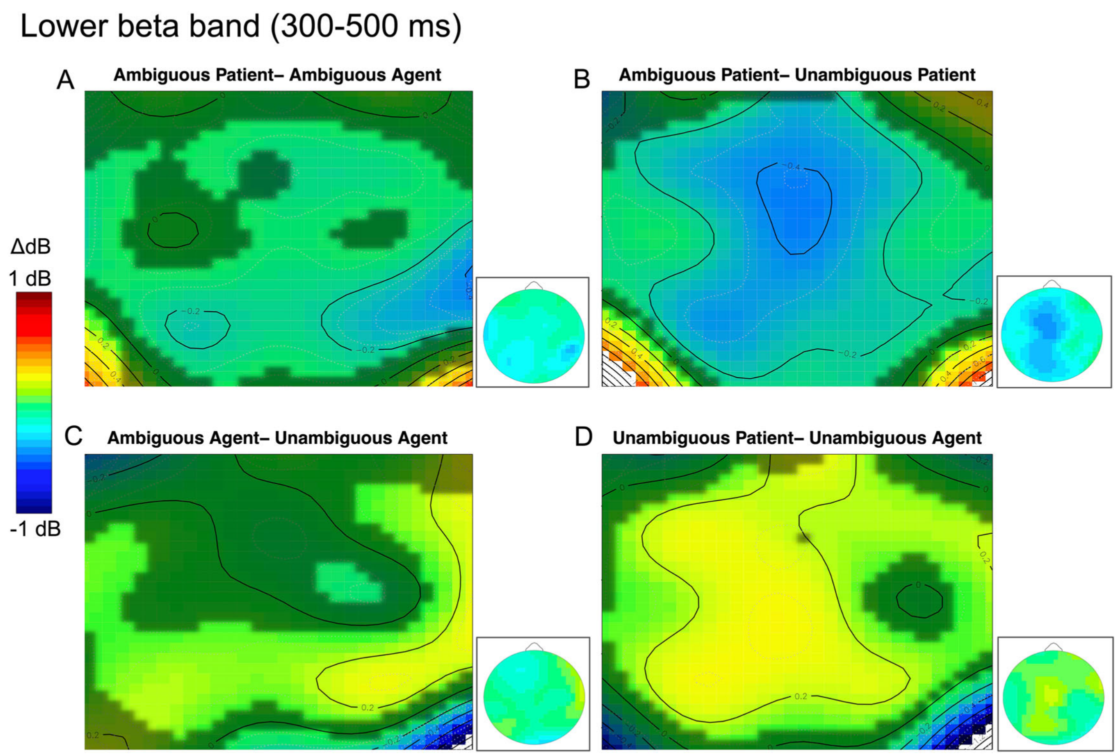

Figure 4. Comparison of power differences in individually defined lower-beta band in the 300–500 ms time window after critical word (verb) presentation. Large plots show estimated (GAMM) difference surfaces of the topographic distribution of differences between conditions (A–H). Adjacent small plots show the corresponding observed grand average differences.

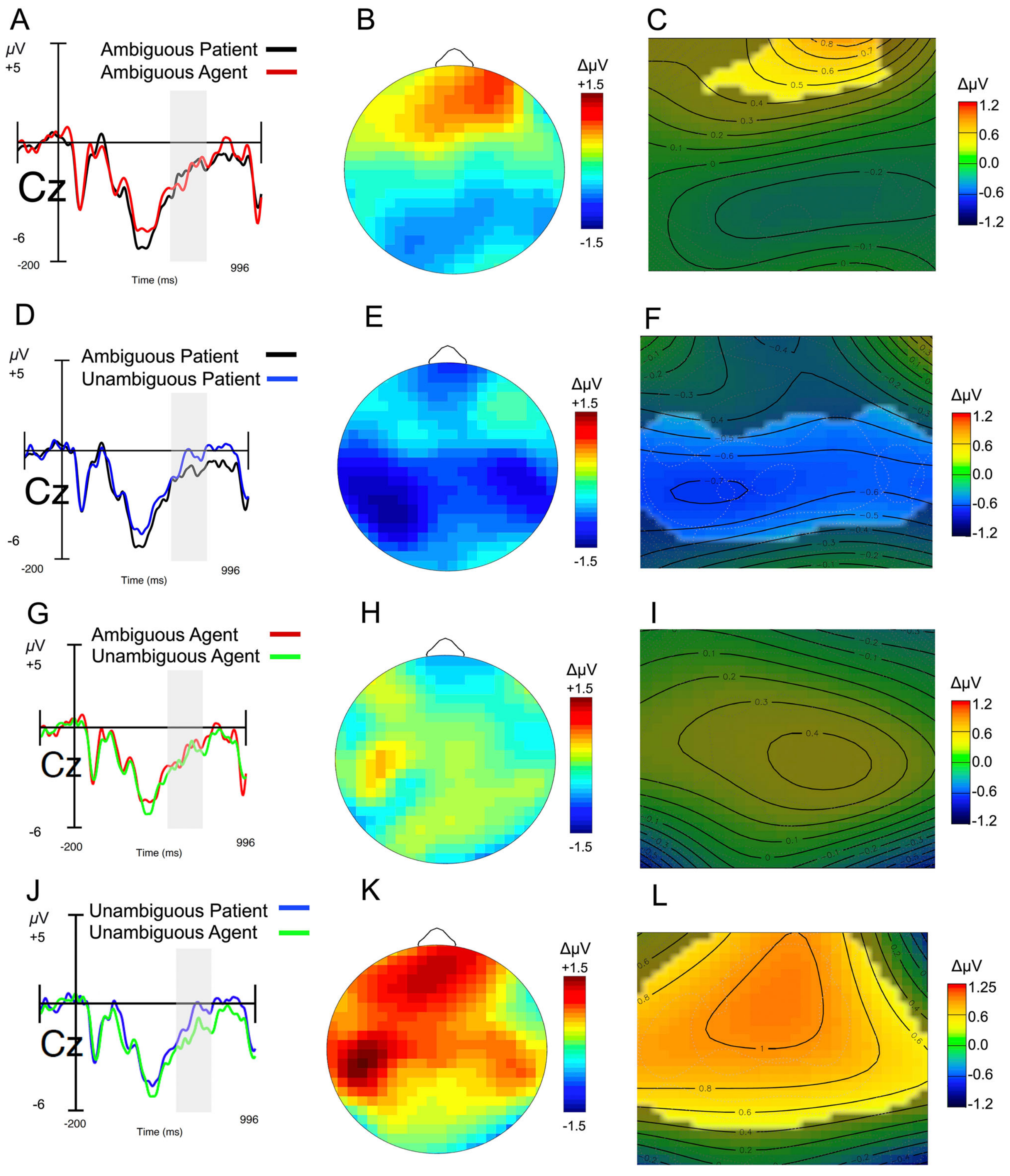

Figure 5. Pairwise comparisons of ERP differences between conditions at the critical verb position for the late time window (500-700 ms time window). Plotting conventions are identical to Figure 2.

6A). We also found a power decrease for ambiguous patients compared to unambiguous patients, in a widespread are in left central-posterior electrodes (Figure 6B). Additionally, the unambiguous agent condition showed a widely distributed power decrease compared to unambiguous patients (Figure 6D) conditions. There was also a power decrease for unambiguous agents compared to disambiguations to agents, but effects were reduced to marginal left and right areas (Figure 6C). The alpha band model that included the experimental conditions performed significantly better than the null model ($F(67.33) = 4.43$, $p<0.01$).

The results in the lower beta frequency band at the 500–700 ms time window also showed some differences between conditions, but the effects were more mixed and smaller in size (Figure 7). Disambiguations to patients resulted in an increase in power compared to disambiguations to agents (Figure 7A), over frontal areas. Compared to unambiguously marked patients, disambiguations to patients showed a decrease in power over posterior electrodes, and an increase over frontal-left electrodes. (Figure 7B). Finally, unambiguous agents elicited a decrease in power compared to unambiguous patient (Figure 7C) or unambiguous conditions, distributed over central and frontal-right electrodes in both cases. The lower beta band model that included the experimental conditions performed significantly better than the null model ($F(66.40) = 7.85$, $p<0.01$).

4. Discussion

We investigated whether semantic roles impact online sentence processing in intransitive sentences, independently of a syntactic subject category and the relative order of arguments. We tested whether comprehenders commit to an agent or patient role, or neither, upon reading sentence-initial ambiguous arguments. Both ERPs and event-related desynchronisation in the alpha and lower beta bands suggest that disambiguations to patient readings at the verb required reanalysis. This finding indicates that the parser transiently interpreted ambiguously marked arguments as agents, in line with the theory that a general cognitive preference for agents impacts sentence processing (Wilson et al., 2022).

4.1. Neural correlates of semantic role reanalysis

Disambiguations to patient readings elicited larger N400 ERP amplitudes compared to disambiguations to agent readings. The N400 is a well-known correlate of surprisal, prediction failure, and reanalysis in sentence processing and other domains of cognition (Kutas & Federmeier, 2011). Previous studies on the subject/agent preference using transitive stimuli also reported N400 effects (e.g. Bickel et al., 2015; Haupt et al., 2008; Hörberg et al., 2013; Krebs et al., 2018; Sauppe et al., n.d.; Wang et al., 2009). The N400 in these subject/agent preference studies has been hypothesised to signal a sentence-level reanalysis, which arises when the disambiguating phrase does not match the argument structure established up to that point (Haupt et al., 2008; Schlesewsky & Bornkessel-Schlesewsky, 2006).

The N400 we found in ERPs in the early time-window converges with the event-related power differences in the same time-window. We found that disambiguations to patients elicited a decrease in the alpha and lower beta bands compared to disambiguations to agents or unambiguously marked patients. More specifically, we observed a decrease in power for both frequency bands over right-lateralised temporal, parietal and posterior electrode sites for disambiguations to patients. We suggest that this decrease in power reflects a desynchronisation in oscillatory activity, linked to the revision of unexpected or dispreferred readings. This is consistent with previous studies that manipulated semantic features: Wang et al. (2012) report larger desynchronisation in the lower beta band for incongruent than congruent sentence endings and suggest that beta oscillations are involved in the semantic unification of words with the previous context. Weiss and Mueller (2012) review the studies on beta oscillations in language processing and conclude that beta-band activity correlates with attention and expectancy violation. Other studies have also suggested that beta oscillations track the maintenance or change of the sentence-level meanings (Kielar et al., 2015; Lewis et al., 2017, 2015), while the alpha band would be involved in the storage of syntactic phrases in verbal working memory (Meyer, 2018).

Lewis and Bastiaansen (2015) propose that increases in beta power reflect active maintenance of the current cognitive set, defined as the current sentence-level meaning representation under construction. In contrast, decreases in beta power reflect a change in the current cognitive set and in the related underlying functional network configuration. In the context of sentence processing, a decrease in beta power would signal a change in the current sentence level meaning as a result of a cue in the linguistic signal indicating to the system that the current representation needs to be revised. This is coherent with our interpretation of the results following semantic role predictions. In our experiment, the cue triggering the revision of the sentence-level meaning would be the patient verb. This would require a change in the cognitive state built up to that

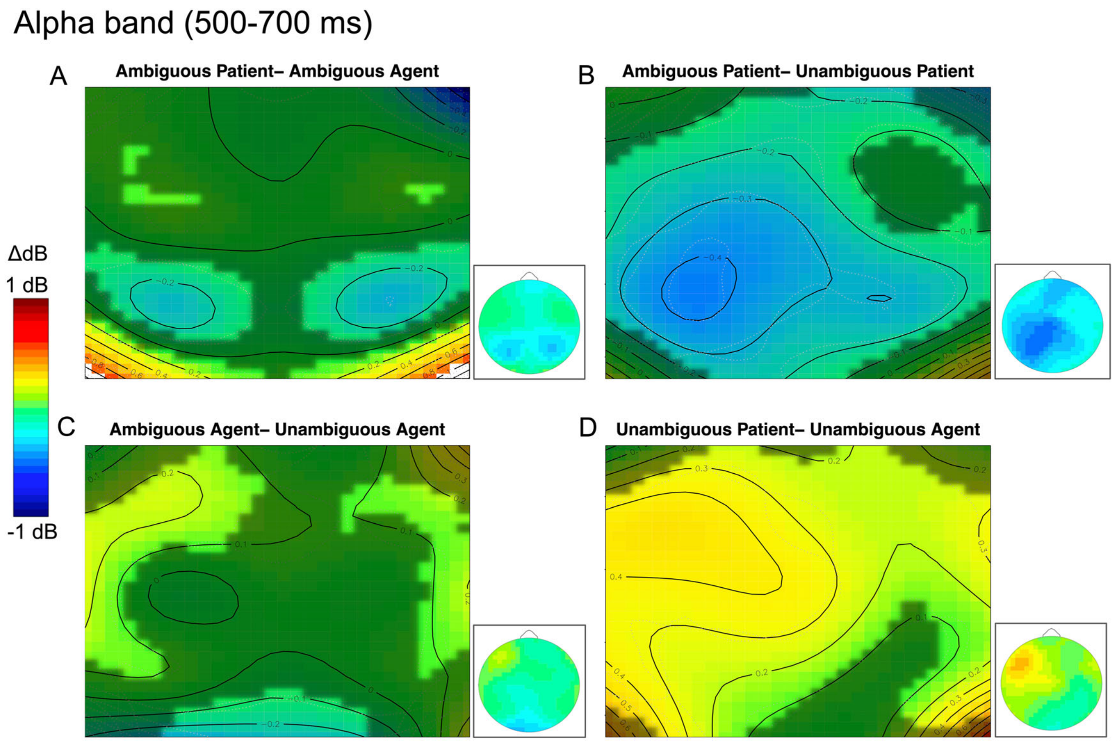

Figure 6. Comparison of power differences in individually defined alpha band in the 500–700 ms time window after critical word (verb) presentation. Large panels show estimated (GAMM) difference surfaces of the topographic distribution of differences between conditions (A–D). Adjacent small plots show the corresponding observed grand average differences.

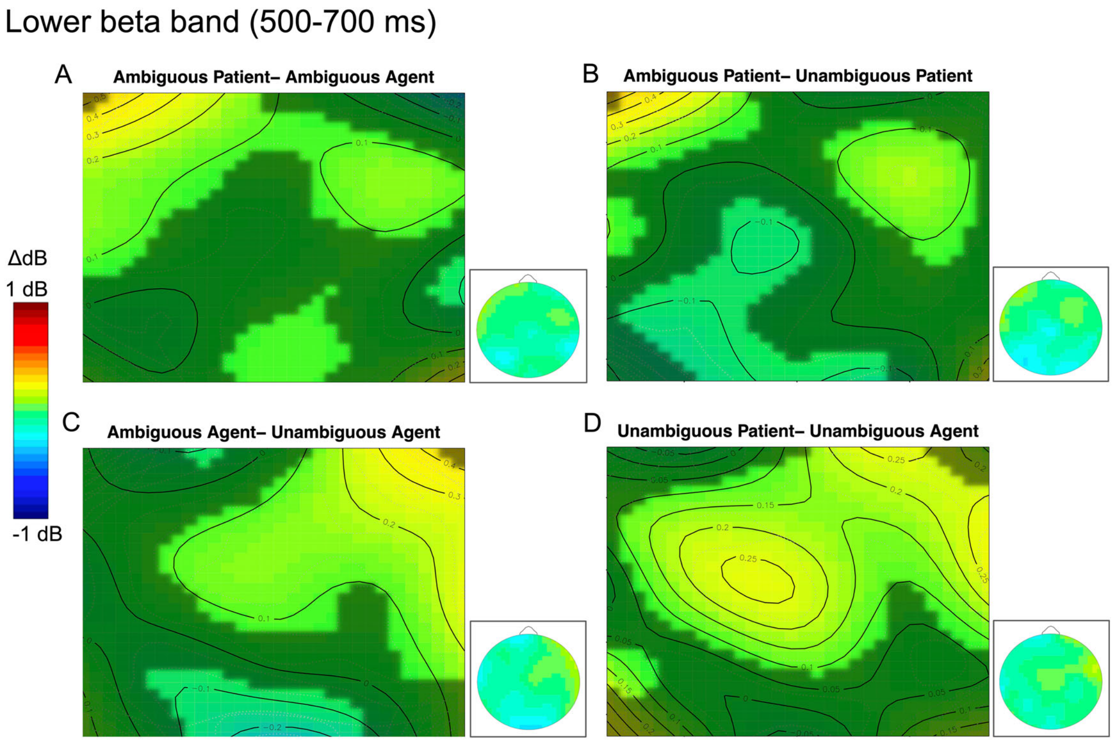

Figure 7. Comparison of power differences in individually defined lower beta band in the 500–700 ms time window after critical word (verb) presentation. Large panels show estimated (GAMM) difference surfaces of the topographic distribution of differences between conditions (A–D). Adjacent small plots show the corresponding observed grand average differences.

point, and this would be reflected in the power decrease in the alpha and especially beta bands. As for the alpha band, it could be that the power decrease in this band is the result of a broadband desynchronisation across alpha and beta bands, especially given that the effects in the alpha band were smaller and less consistent than the ones in the beta band. Under this scenario, the effects in the alpha band would also reflect the change of cognitive status (Lewis & Bastiaansen, 2015). Alternatively, it might be that reduction in alpha power in our results indicates a release from inhibiting alternative and competing sentence interpretations, by which these interpretations would become available for the reanalysis process. This would be coherent with the role of the alpha activity in inhibiting attention to distractors and directing information to task-relevant cues (Gutteling et al., 2022; Jensen & Mazaheri, 2010).

In contrast to the early time-window, the results in the late time-window did not show clear or consistent effects. ERP results in this time-window showed that disambiguations to patients elicited a positivity compared to disambiguations to agents (Figure 5, panels A–C). This could be interpreted as a P600-like effect, although the topographical distribution of the effect was more frontal than other effects in the literature (Aurnhammer et al., 2021; Frisch et al., 2002). By contrast, the comparison between ambiguous and unambiguous patient conditions showed a bilateral negativity (Figure 5, panels D–F), which we identify as an extended negativity from the previous time window. In the time-frequency domain, we found that effects in the alpha band were similar to those in the early time-frame, i.e. there was a decrease in power for disambiguations to patients compared to either disambiguations to agents or unambiguously marked agents. The lower beta band also showed a decrease in power for disambiguations to patients compared to unambiguously marked patients, but there was an increase in power when compared to disambiguations to agents (in line with the ERP results for this comparison in this time-frame).

Overall, it is likely that the effects in this later time-frame do not (only) reflect semantic role reanalyses. Even if the comparison between the ambiguous conditions showed a P600-like effect, this did not generalise to the other critical comparison, i.e. within the patient condition. Late positivity effects have been linked to the evaluation of the well-formedness of the sentence, and would only emerge when the reanalysis leads to a structure that is less acceptable (i.e. less frequent and requiring more conversational context: Haupt et al., 2008; Schlesewsky & Bornkessel-Schlesewsky, 2006). The lack of a late positivity in our results is consistent with this, given that the sentences in our experiment were equally basic and well-formed across conditions. It is possible that the effects in this late time-frame are the outcome of various processes, including those related to lexical integration of the different verbs and the proccesing the auxiliary verb. Indeed, the form of the auxiliary verb was different across all conditions, and its form was predictable from the main verb. Hence, it might be that participants in this time-frame were already affected by the processes related to the immediately upcoming auxiliary verb.

Hence, we propose that the semantic role reanalysis was reflected in the early time-window in our study, in the N400 component in ERPs and in the decrease in power in the alpha and lower beta bands.

An alternative explanation of these effects could be linked to the lexical differences between conditions. Disambiguations to agents and patients involved different lexical items (agent and patient verbs). This could have led to differences in ERPs that were not related to semantic role assignment. However, we found very similar effects when comparing ambiguous and unambiguous patient conditions. This rules out the possibility that the observed effects are solely based on lexical differences between agent verbs and patient verbs.

Another alternative interpretation of our results appeals to frequency. Input frequency is known to affect sentence processing at different levels (Ellis, 2002). If ambiguously marked arguments are more often disambiguated to agents than patients in natural discourse in Basque, comprehenders could be biased to agent readings, independently of semantic role preferences. However, Ristic et al. (2020) found that Basque speakers preferred patient readings when reading role-ambiguous arguments in isolation, i.e. without a sentence-level context. By inference, effects in our experiment are unlikely to be driven by frequency patterns since this should also have manifested itself in offline interpretations.

Moreover, the Dictionary of Patterns of Frequency in the Basque Lexicon (PFBL, Acha et al., 2014) shows that patient-taking verbs are in fact slightly more frequent than agent-taking intransitive and transitive verbs together (log frequencies per million tokens of 3.82 and 3.78, respectively). Likewise, Pastor and Laka (2013) conducted a corpus study on Basque and compared the distribution of transitive and intransitive sentences in each language. Intransitive sentences were slightly more common (52.5%) compared to the transitive ones (47.5%). They also analysed the pro-drop of arguments, given that Basque is a three-way pro-drop language (i.e the subject as well as the direct and indirect object can be dropped in discourse). When analysing the distribution of sentences with dropped subjects, they found that the majority of dropped subjects were agents in transitive sentences (75.1%), in contrast to the smaller number subject of intransitive sentences (29.1%). Even more importantly, Huber et al. (2023) tested whether surprisal estimates from language models trained on Basque corpora could explain the ERP results in the current study. Their results showed that surprisal, and therefore frequency, alone did not suffice to explain the results, and that other parsing principles are needed to fully account for the results.

Hence, we propose that an agent preference is a mechanism that operates in sentence processing above and beyond frequency. Further evidence for this interpretation comes from the results in the unambiguous conditions of our experiment. The unambiguous conditions involved the same critical words (verbs) as those used in the ambiguous conditions, with the only difference that, in the unambiguous conditions, the verb did not further disambiguate the semantic roles of the initial arguments, as this was already expressed by the case marking. If patient verbs were causing the effects in the ambiguous conditions due to lexical or frequency factors, the same effect should also have emerged in the comparison of unambiguous conditions. However, the unambiguous patient condition did not show an N400 response compared to the unambiguous agent condition. In fact, the pattern of results in the unambiguous conditions was reversed, since the unambiguous agent condition elicited an N400 and an power decreases in alpha and lower beta bands, compared to the unambiguous patient condition.

This reversed pattern of results is likely linked to differences in the *precision* of predictions across conditions[2]. In their predictive coding model for the N400, Bornkessel-Schlesewsky and Schlesewsky (2019) propose prediction precision depends on the reliability of the cues that guide sentence processing: highly reliable cues, such as word order for English, lead to higher precision in predictions, while less reliable cues lower the precision of predictions. In Basque, case marking is usually a robust cue to semantic roles, given that Basque is a consistent ergative-marking language. Hence, it is likely that comprehenders, upon reading the unambiguous ergative case mark, made a highly precise prediction about the features of the agent role and interpreted it as a prototypical agent, i.e. as an agent of a transitive event (Dowty, 1991). When the verb showed an intransitive agent reading, their expectations would need to be updated to a less prototypical or ideal agent (Bornkessel & Schlesewsky, 2006). In contrast, upon reading the unambiguous absolutive case marker, comprehenders would not have the prototypical patient reading available (patient of a transitive event), because this would conflict with word order preferences: it would require projecting an object-initial sentence structure, which has been found to be strongly dispreferred in Basque when presented without sufficiently rich context (Erdocia et al., 2009). Hence, the only interpretation available to comprehenders was a patient subject in an intransitive event. This would explain why the unambiguous agent condition elicited an N400-like effect compared to unambiguous patients. Our results in the unambiguous conditions are also compatible with the findings in Martinez de la Hidalga et al. (2019), who tested unambiguous sentences in Basque and found longer reaction times for agent-taking intransitive sentences than patient-taking intransitive sentences.

As for the ambiguous conditions, the case marking in these conditions was compatible with a wide range of absolutive and ergative constructions in the language. Hence, it was not a reliable cue. In the absence of valid case marking cues, we propose that a general agent preference interfered and pushed the interpretation towards interpreting the ambiguous argument as an agent. The agent preference would be a cue on its own, but would be weaker than a morphological cue, and would thus lead to a weaker and probably less precise prediction (Bornkessel-Schlesewsky & Schlesewsky, 2019). In this scenario, comprehenders would interpret the ambiguously marked noun phrase as an agent-like figure, but without making highly precise predictions about the features or the prototypicality of the agent. At the disambiguating verb region, finding a less-ideal agent (an agent in an intransitive event) would suffice to fulfil the prediction. The difference in the precision of predictions would therefore explain the N400 we found for the unambiguous agent condition compared to the ambiguous agent condition.

4.2. The agent preference in sentence processing

We found that comprehenders interpret ambiguous arguments as agents. This finding is inconsistent with the sentence processing mechanisms posited by either the projection-based or integration-based minimality accounts. According to the projection-based minimality account, an initial ambiguous argument is preferentially interpreted as the sole argument of an intransitive verb, not distinguishing between the different semantic roles that the sole argument can carry. Reanalysis is necessary only if a second argument is encountered, indicating that a transitive sentence is being parsed. In contrast, in our study we tested intransitive sentences and found that participants assigned the agent role to the ambiguous initial argument. This occurred even though there was no additional argument in the sentence and hence no evidence for a transitive structure. In addition, disambiguations to agent and patient roles led to equally basic subject-verb intransitive sentences, so effects cannot be explained by the markedness of the structures either.

The integration-based minimality account also fails to explain our results. According to this account, patient subject interpretations would be preferred because they are more closely tied to the verbs, and hence form a more minimal structure (i.e. without an external argument). Our results show instead that there was a top-down tendency to assign the agent role to the initial ambiguous arguments.

The tendency to assign agency to ambiguous arguments is consistent with a general preference for agents in event cognition. Agents and patients exist as abstract role categories (Dowty et al., 1985; Rissman & Majid, 2019), and viewers extract these roles spontaneously and rapidly when exposed to an event (Hafri et al., 2018). In addition, agents attract more visual attention than the other elements or roles in events (Cohn & Paczynski, 2013; Gerwien & Flecken, 2016). Wilson et al. (2022) review evidence from humans, other primates, and other animals and suggest that agent-based event representations are phylogenetically old and were already present in the ancestors of modern humans. They hypothesised that key aspects of language structure are rooted in cognitive models that privilege agents.

Alternatively, our results can be explained by a further version of the minimality accounts.[3] This account rests on the idea that patients are licenced by a semantic 'cause' notion and that they therefore imply an agent as the causer or abstract cause. Agents, by contrast, do not entail any other referent or abstract notion (Primus, 1999). On this account, an agent reading should be semantically more minimal than a patient reading because it does not require the assumption of an additional causer. Further research is needed to test this theory in comparison with the notion of a general agent preference. It is unclear, for example, to what extent all intransitive patient verbs indeed invoke a cause(r), and whether none of the intransitive agent verbs invoke a second notion.

At a more general level, the causality-based and the agent preference theories are largely compatible, since they are both based on semantic-conceptual notions and posit a top-down mechanism to assign agency to interpret role-ambiguous phrases.

Hence, semantic role is the critical feature in the interpretation of ambiguous arguments. Previous work on incremental sentence processing usually referred to this heuristic as 'subject preference' (e.g. Demiral et al., 2008; Hörberg et al., 2013). Our findings suggest that results in previous studies might also be based on the semantic role interpretations (Bornkessel et al., 2003; Wang et al., 2009). The notion of an agent preference is also more coherent with the grammar of languages like Basque; the subject category was initially posited to describe nominative-accusative languages such as English, but it seems that it does not necessarily generalise to other alignment types (see Dixon, 1994 and Bickel, 2011) for discussion).

An open question is the extent to which the agent preference we find in intransitives is the same mechanism operating in transitive sentences (e.g. Demiral et al., 2008; Erdocia et al., 2009; Hörberg et al., 2013). It is likely that the underlying mechanism guiding sentence processing is essentially the same in both transitive and intransitive scenarios. It could even be hypothesised that the agent preference in intransitives results from a transfer from from transitives structures. This is unlikely though since in Basque intransitive sentences are more frequent (PFBL, Acha et al., 2014) and equally unmarked than transitive sentences. Nonetheless, future research testing both transitive and intransitive sentences together might elucidate the extent to which the agent preference is a shared or distinct mechanism across sentence types.

Another open question regarding the current results relates to the animacy of the subject argument. In the current experiment, all initial subjects referred to humans, mainly due to the selectional restrictions of intransitive verbs. Animacy is known to impact sentence processing (Bornkessel-Schlesewsky & Schlesewsky, 2009b), and therefore human reference might have contributed to agent interpretations. Our results cannot tell whether the same agent preference would apply to inanimate subjects and whether it would be modulated by the degree of animacy involved in the subject. Experiments on Chinese (Wang et al., 2009) and Hindi (Bickel et al., 2015) found that initial arguments were interpreted as agents even when they were inanimate. However, more recent work observed a difference between inanimate and animate arguments: Sauppe et al. (n.d.) conducted an ERP study on Äiwoo, an Oceanic language in which patient-verb-agent ('OVS') is the grammatical default and the most frequent word order. While ambiguous initial arguments showed the characteristic agent preference, i.e. verbs elicited an N400 when disambiguating to patients, this effect was limited to arguments with human reference. When initial arguments were inanimate, the ERP effect was reversed and a preference for patient interpretations emerged. This suggests that the agent preference can be modulated under some conditions, depending on the affordances of individual languages. More research is needed now to probe this also for intransitive subjects.

5. Conclusions

In sum, our findings from the N400 and alpha and beta band desynchronisation show that a preference for agents drives incremental sentence processing. Crucially, we find that this preference is independent of word order and that it cannot be explained by lexical and frequency effects. This suggests that a domain-general cognitive preference for agents exerts a top-down influence on sentence processing, irrespective of the particular language.

Note

1. As we formulate it, the integration-based account is concerned with the semantic relations of a given sentence, and it is not relevant whether the structures tested are involved in any syntactic movement or not.
2. We thank Shayne Sloggett for the discussion of these ideas
3. We thank Ina Bornkessel-Schleswesky for this suggestion.

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Data availability

Raw and processed data, analysis scripts, and models are available from the Open Science Framework at https://osf.io/6gjkz/?view$_o$nly=825cdcbd9b1347c9868cf43426e7761c

Disclosure statement

No potential conflict of interest was reported by the author(s).

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Notes on contributions

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Sebastian Sauppe: Conceptualisation, Methodology, Software, Formal analysis, Writing – Review & Editing, Visualisation, Project administration, Funding acquisition.

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