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Research Report

The prediction potential indexes the meaning and communicative function of upcoming utterances

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ABSTRACT

Prediction has a fundamental role in language processing. However, predictions can be made at different levels, and it is not always clear whether speech sounds, morphemes, words, meanings, or communicative functions are anticipated during dialogues. Previous studies reported specific brain signatures of communicative pragmatic function, in particular enhanced brain responses immediately ***after*** encountering an utterance used to request an object from a partner, but relatively smaller ones when the same utterance was used for naming the object. The present experiment now investigates whether similar neuropragmatic signatures emerge in recipients ***before*** the onset of upcoming utterances carrying different predictable communicative functions. Trials started with a context question and object pictures displayed on the screen, raising the participant's expectation that words from a specific semantic category (food or tool) would subsequently be used to either name or request one of the objects. Already 600 msec before utterance onset, a larger prediction potential was observed when a request was anticipated relative to naming expectation. As this result is congruent with the neurophysiological difference previously observed right after the critical utterance, the anticipatory brain activity may index predictions about the social-communicative function of upcoming utterances. In addition, we also found that the predictable semantic category of the upcoming word was likewise reflected in the anticipatory brain potential. Thus, the neurophysiological characteristics of the prediction potential can capture different types of upcoming linguistic information, including semantic and pragmatic aspects of an upcoming utterance and communicative action.

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1. Introduction

In daily life, when we engage in social interactions, we constantly make predictions about what the other person is going to do and say. These predictions are based on previous language use, mimic, gestural and other social cues, environmental information and common knowledge. Predictive mechanisms have been shown to play a crucial role in dialogue processing at various linguistic (e.g., semantic, lexical, phonological) and communication-related levels, as supported by a growing body of research (Holler, 2022; Holler & Levinson, 2019; Huettig, 2015; Levinson, 2016; Pickering & Gambi, 2018; Pickering & Garrod, 2013; Żygis & Fuchs, 2023).

Recent studies have documented neurophysiological correlates of predictive processes building up prior to expected stimuli which are highly predictable from prior contexts. These studies consistently report a slow negative potential emerging hundreds of milliseconds before the presentation of the strongly expected stimulus (Barthel et al., 2024; Grisoni et al., 2016, 2017; Grisoni et al., 2024a; Huang et al., 2023; León-Cabrera et al., 2017, 2019). This potential, known as the predictions potential (PP), serves as a direct measure of semantic predictions (for review, see Pulvermüller & Grisoni, 2020). These findings hold even when participants are instructed to ignore the auditory stimuli and direct their attention away from them, for example towards a visual input irrelevant to the language experiment (Grisoni et al., 2017, 2019, 2021,Grisoni et al., 2024b). Notably, source localization of the PP suggest that specific semantic features of the predicted words and utterances[1] are reflected (Grisoni, 2022). Specifically, Grisoni et al. (2021) reported relatively stronger activation of visual brain areas when subjects expected animal- (as compared to tool-) related words and stronger activation of prefrontal and motor areas when they anticipated tool- (as compared to animal-) related words (see also Grisoni et al., 2017, 2024a). This cortical dissociation of semantic categories is consistent with semantic rating studies showing that tools are related to the experience of actions and physical manipulations, while animals tend to be more strongly associated with visual information, such as perceived motion and visual complexity (Binder et al., 2016; Carota et al., 2012). Therefore, this double dissociation reflects semantic grounding of concepts at the neural level, within sensory and motor brain systems (Constant et al., 2023; Kiefer & Pulvermüller, 2012; Martin et al., 1996; Pulvermüller, 2013; Tomasello et al., 2017). Overall, the PP, whose amplitude and topography are modulated by the semantic characteristics of the predicted utterance, provides valuable insights into the predictive processing of semantic information during language comprehension.

Although the PP has been observed at semantic (Grisoni et al., 2017), phonological (Grisoni & Pulvermüller, 2022), and discourse levels (Barthel et al., 2024) and across different modalities (Grisoni et al., 2024a), it is yet to be determined whether similar anticipatory mechanisms are also manifest at the pragmatic level of communicative action processing during dialogues. It is well known that the same linguistic units can carry very different communicative functions depending on the dialogue contexts in which they are used. Take, for example, the case of the word “glass”, which can be used to simply name an object, or, alternatively, to request this object from a partner. Several studies have reported brain activity reflecting communicative functions (as, for example, naming and requesting), which emerged with short latency (100–200 msec) after the critical utterances could first be recognized (Egorova et al., 2013, 2014; Tomasello et al., 2019, 2022; Gisladottir et al., 2015; for a review see Tomasello, 2023). For instance, Egorova et al. (2013; 2014) showed enhanced early negative-going event-related potentials response when processing the same single word for requesting an object as compared to naming it. Similar instantaneous brain response differences were also found during the processing of the communicative functions of naming and requesting conveyed by hand gestures (Tomasello et al., 2019) as well as for other communicative functions (statement compared to questions) signalled by speech prosody (Tomasello et al., 2022). These results suggest that communicative function is processed immediately when an utterance is perceived. However, these studies could not address the issue of predictive processing, as they focused on brain activity following the critical stimuli. Therefore, it is crucial to investigate whether the communicative function of a predictable dialogic action becomes physiologically manifest even before the critical utterance appears.

First insights into the physiological indexes of predictive processing of communicative function have been reported in the language production domain. A study investigated social interactions between two individuals, where one person utters words to name and request various objects from the other in different social contexts (i.e., requesting an object in a shopping role play and naming an object in a language-test role play; Boux et al., 2021). Intriguingly, the authors found a greater negative-going prediction potential starting 600 msec before requests as compared to naming actions, a pattern similar to the one found immediately after the critical communicative actions (see Egorova et al., 2013 and related work). The predictive brain activity here found for communicative functions resembled that previously documented for different semantic categories (Grisoni et al., 2019, 2021). Therefore, consistent semantic prediction potentials indicating aspects of the semantic meaning of an upcoming utterance may possibly be distinguishable from pragmatic ones addressing communicative function.

In this study, we investigate whether a prediction potential indexing the communicative function of predictable dialogue contributions can be observed in individuals perceiving naming and request actions. In addition, we explore whether any brain indexes of pragmatic predictions related to communicative functions (naming and requesting) co-exist with semantic prediction potentials. Previous research has identified different scalp topographies and neural generators for the processing of specific semantic word categories and for different pragmatic types of communicative actions (Binder et al., 2016; Carota et al., 2012; Egorova et al., 2013, 2014, 2016; Glenberg and Gallese, 2012; Martin, 2007; Pulvermüller, 2013; Pulvermüller & Fadiga, 2010; van Ackeren et al., 2012,

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[1] By ‘utterance’, we mean any spoken or written word or word sequence but refer to the written single target words in the context of this experiment.

2016; Tomasello et al., 2022). For instance, as mentioned above, animal-related words showed greater involvement of visual areas, whereas tool-related words exhibited increased engagement of frontocentral sensorimotor areas, and at the pragmatic level, significant activations in the hand motor cortex, specifically preceding requests. Similar topographical and source related differences were also found in the semantic PP recorded in language production and comprehension (Grisoni et al., 2021, 2024a) and in the pragmatic PP recorded before speech act production (Boux et al., 2021), but not before comprehension of a predictable communicative act.

The present EEG experiment now investigates the putative anticipatory brain responses underlying communicative function understanding and their interplay with semantic prediction potentials, carrying referential information. To this end, participants had to watch schematically illustrated interactions between two communication partners. Each episode started with four objects from the same category (all depicting either food or tools) being displayed on the screen and a context question asked by interlocutor A inviting partner B to either name an object or request it from A. This setting is similar to previous studies (Boux et al., 2021) and allows to raise the expectation that a word from a specific semantic category will subsequently be used to either name or request one of the objects. We expected that, in addition to a semantic modulation of the prediction potential indexing the semantic category from which the upcoming word had to be selected, a pragmatic modulation of the prediction potential reflecting the predictable communicative function determined by the context question will be observed.

2. Methods

2.1. Participants

The experiment was approved by the Ethics Committee of the Charité Universitätsmedizin, Campus Benjamin Franklin (Berlin, Germany) and was in agreement with the Declaration of Helsinki. A total of 29 volunteers (15 female participants) with normal hearing and normal or corrected-to-normal vision were recruited to take part in the experiment. All participants were monolingual native speakers of German and had no record of neurological or psychiatric disorders. They all gave their written informed consent prior to the start of the experiment and were paid for their participation. Data from four participants were excluded from the analysis because more than 20% of the trials were rejected. Therefore, the EEG analysis was carried out on the data from 25 participants (mean age 26.6 ± 5.6 SD; 13 female participants). All of them were right-handed, as assessed by the Edinburgh Handedness Inventory (Oldfield, 1971; mean laterality quotient 82.2 ± 15.9 SD).

2.2. Stimuli and procedure

In order for critical word usage to be understood as speech acts by participants, two pragmatic scenarios were created. Different question sentences were chosen as context of interactions introducing predictable naming or request actions performed by uttering a single word (e.g., “hammer”). One of three different context question sentences (e.g., “Which one can you name?”) called for, and thus biased understanding of the subsequent answers towards, naming actions. A second set of three different questions (e.g., “Which one do you want?”) was used to introduced, and bias understanding of the critical word, towards requests. In the naming trials, participants were presented with one of the following context questions: “Wie nennt man das?” (What do you call it?), “Kannst du eins benennen?” (What can you name?) and “Welches kannst du benennen?” (Which one can you name?). In the request trials, participants were shown one of the following questions: “Was darf es sein?” (What do you want?), “Was kann ich dir geben?” (What can I get you?) and “Welches möchtest du haben?” (Which one do you want?). Thus, the word “hammer” used after the sentence “Which one can you name?” is considered a naming speech act, but with a request when preceded by “Which one do you want?”. The context questions were matched in length-number of words (request: $M = 4.33$, $SD = .58$; naming: $M = 4.00$, $SD = 0$; $F(1, 4) = 4.303$, $p = .423$) and number of syllables (request: $M = 6.00$, $SD = 1.00$; naming: $M = 5.67$, $SD = 1.53$; $F(1, 4) = 3.182$, $p = .770$). And they were presented above a set of four objects. A total of 104 pictures of familiar objects was used as the set of experimental pictorial stimuli, including 52 food and 52 tools objects. The critical words of the experiment were the nouns used to label the depicted objects (see Fig. 1). All images of objects were obtained from the internet, were copyright-free, and part of the public domain. The background was removed from each image, so that objects of interest appeared on a grey background.

During the experiment, four images of objects from the same semantic category were displayed together below the context question. The objects were arranged in two rows of two objects. For each semantic category, each of the 52 objects was presented once in each of the four positions, resulting in 52 sets of four objects. Each set was a unique combination of four objects (see Fig. 1). This counterbalancing avoids sensory habituation and prompts a renewed response (Järvilehto et al., 1978).

Then, food and tool nouns were used in different pragmatic and sentential contexts to convey their respective functions as tools for either naming or requesting. Written nouns were presented individually, in the middle of the screen, as an answer to the previous question. The 104 German nouns were taken from a previous experiment that investigated the multimodal processing of language and gestures conveying different speech acts (Tomasello et al., 2019). Among the 104 nouns, 52 belonged to the semantic category of food items and 52 to that of tools. The classification of words into semantic categories was based on previous rating studies (see Carota et al., 2012; Dreyer et al., 2015) which also revealed the items' semantic links to mouth and hand actions. Semantic ratings were confirmed by 20 German speakers who were not involved in the present study (for more details see Tomasello et al., 2019). All the selected nouns from the two semantic categories were matched for different lexical and sub-lexical psycholinguistic variables retrieved from the DLEX corpus (Heister et al., 2011). Psycholinguistic variables

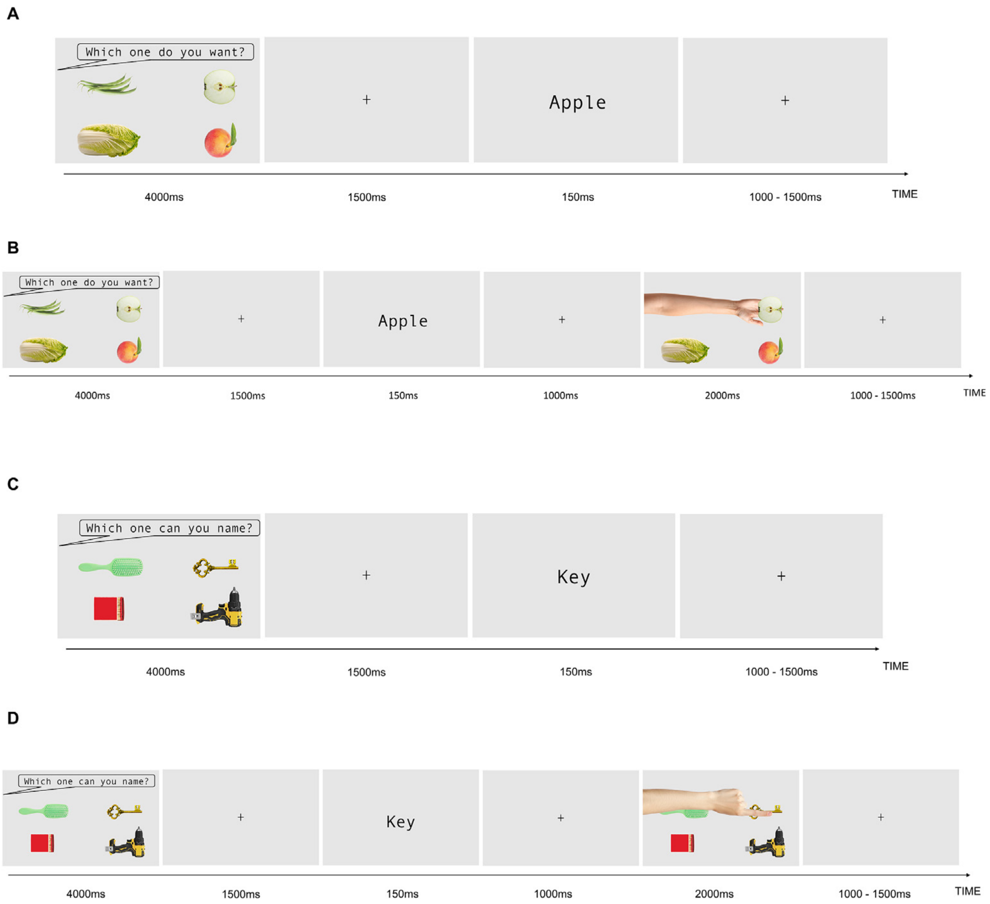

Fig. 1 – Schematic illustration of the experimental design. (A, C) A trial always started with the presentation of four objects from the same category with a context question at the top of the screen, in a speech bubble pointing to the left, for 4000 msec. Then, the critical word was shown in the centre of the screen for 150 msec. Note that the context question biased the understanding of the critical word towards either naming or request. The speech bubble and position of the utterances (together with the instructions) indicated that context questions and critical words were used by different communication partners. The inter trial interval randomly varied between 1000 and 1500 msec. (B, D) One tenths of the trials were "action trials", where the critical utterance was followed by a picture of the hand gesture symbolizing an action following the critical speech acts, either pointing to an object after naming or handing it over after a request. In addition, the gesture symbols highlighting the object previously mentioned. (A, B) Examples of request using food items and (C, D) naming trials using tools.

included: word length (food: $M = 5.88$, $SE = .23$; tool: $M = 5.94$, $SE = .20$), number of syllables (food: $M = 1.81$, $SE = .03$; tool: $M = 1.90$, $SE = .04$), normalized lemma frequency (food: $M = 6.38$, $SE = 1.46$; tool: $M = 6.11$, $SE = .91$), cumulated character-bigram frequency (food: $M = 209{,}463$, $SE = 17{,}833$; tool: $M = 254{,}403$, $SE = 19{,}861$), cumulated character-trigram frequency (food: $M = 117{,}739$, $SE = 117{,}739$; tool: $M = 139{,}712$, $SE = 13{,}272$), as well as the number (food: $M = 6.28$, $SE = 1.09$; tool: $M = 7.13$, $SE = .80$) and cumulated corpus frequencies of orthographic neighbours (food: $M = 82.74$, $SE = 60.19$; tool: $M = 53.74$, $SE = 16.15$). F-Tests on these variables did not indicate any significant differences between semantic categories (see Tomasello et al., 2019). The emotionality of the two semantic categories were comparable, as indicated by the matched related semantic ratings of a largely overlapping sets of words used by Dreyer and Pulvermüller (2018) and Dreyer et al. (2020). Both food and tool categories scored low on the variable 'arousal', which gives the degree of emotion-relatedness, with no significant difference observed between these categories (Dreyer & Pulvermüller, 2018; Dreyer et al., 2020; see Fig. 1 in both paper).

In rare 'action trials', images of a hand gesture, either a pointing or a give-me gesture on top of the object pictures, was shown after the communicative verbal utterances. Action trials were displayed once every ten trials. The gesture was directed toward the relevant object: the pointing or the give-me gesture was oriented toward the object whose name had been presented before (Fig. 1B and 1D). These displays were added to symbolize a typical partner response – the handing-over of the object to requests or a pointing gesture toward it for naming – and thereby to make the interaction more similar to everyday communication. Indeed, in natural dialogue, a specific communicative activity is characterized by the sequences of communicative actions in which this activity is typically embedded (see Austin, 1975; Fritz, 2005; Searle and Searle, 1969). A request for an object is a goal-directed communicative activity and is typically followed by the object being handed over, whereas a naming act in the context of testing may be followed or accompanied by the mentioned object being pointed at (for discussion, see, for example, Egorova et al., 2013).

The experiment was carried out in the soundproof and electrically shielded chamber of the Brain Language Laboratory at the Freie Universität Berlin. The EEG session lasted about 45 min. Inside the EEG chamber, a button was available to participants in case they needed to communicate with the experimenter in the control room outside. Participants were seated at a desk, 80 cm from a 66.4 × 37.4 cm monitor on which the stimuli were visually displayed using E-prime 2.0 (Psychology Software Tools, Pittsburgh, PA). Before the beginning of the experiment, instructions were presented on the screen and explained to participants. Participants were asked to imagine that they were following an interaction between two communication partners, which was symbolized by visual stimuli. One of the communication partners would invite the other to either name or make requests about objects displayed on the screen. The other partner would answer using only one word: a category term designating the target object. Participants were instructed to carefully watch these interactive scenes on the screen, but they were not given a specific behavioural task to complete during the experiment. To further motivate participants to pay attention to the experimental stimuli they were told that they should constantly attend to the experimental stimuli and that they will be tested regarding the experiment content at the end. They were not specifically told to primarily attend to the critical words or the pictures or any other specific aspect of the experiment. Following the experiment, a memory test was conducted in which participants had to identify 26 critical words from a list of 40 words. Participants' performances were evaluated based on both the percentage of correct responses and their d-prime values. D-prime is a bias-free measure of the correctness of responses also taking into account both misses and false positive errors. In the present study, d-prime calculations were based on discriminating between words that appeared in the experiment (target words) and those that did not appear in the experiment (fillers).

The experiment started with a practice block composed of six trials to allow participants to familiarize themselves with the experimental setting, the stimuli used in this practice block were not presented in the main experiment. The experiment was divided into three blocks of similar length whose order was counterbalanced across participants. It included two self-paced breaks in-between blocks to allow participants to rest. A trial started with a context question in a speech bubble presented for 4000 msec at the top of a grey screen together with four objects from the same semantic category (i.e., either food or tool objects). In half of the trials the question introduced a naming speech act, and a request speech act in the other half. This setting allowed raising the expectation that a word from a specific semantic category (food or tool) would subsequently be used to either name or request one of the displayed objects. This context of interaction was followed by a fixation cross on a grey background for 1500 msec (see Fig. 1). This was considered the period of interest for EEG analysis as it was expected that participants would make predictions about the following utterance. As mentioned, previous studies reported anticipatory activity starting up to 600 msec before the apparition of a predictable critical word (Boux et al., 2021; Grisoni et al., 2017, 2021). To minimize the potential overlap between context processing and anticipatory activity, we introduced this break (i.e., the 1500 msec between the pictures and the subsequent critical word), similar to the strategy used in previous studies on the PP, at both the phonological (Grisoni, 2022) and semantic levels (Grisoni et al., 2017, 2021). Then, the critical written stimulus word followed, which was the preferred label of one of the four depicted objects from the food or tool category; it was presented in the middle of the screen for 150 msec on a grey background and followed by an interstimulus interval (ISI) randomly varying between 1000 and 1500 msec during which a fixation cross was centred on the grey screen. The location of the image related to the critical word presented at the end of the trial varied randomly from trial to trial, so that it was unpredictable which object would subsequently be requested or named or where the to-be-referred-to object would appear in the following trial. During the experiment, the 104 words from the two semantic categories appeared twice, once to name the object and once to request the object. Therefore, participants watched a total of 208 trials divided into three blocks.

Trials appeared in a pseudo-randomized order, with the constraint that every ten trials the pointing or give-me gesture would follow the critical speech act. In these "action trials", after the speech act a fixation cross appeared for 1000 msec, the following image was presented for 2000 msec and consisted of the relevant hand gesture (i.e., pointing or give-me gesture in naming and request condition, respectively) directed toward the relevant object (Fig. 1B and 1D).

2.3. *EEG recording*

The EEG signal was recorded through 128 active electrodes embedded in a fabric cap (ActiCAP 128CH Standard-2, Brain Products GmbH, Munich, Germany). The electrodes were conventionally placed according to the international 10-5 system, with the following modifications: the reference electrode was moved from FCz position to the tip of the participants' nose, the electrode assigned to the posterior I2 position was moved to the empty FCz position, and the electrode assigned to the posterior I1 position was placed under the participants' right eye. All electrodes were re-referenced to the reference electrode placed on the tip of the nose.

EEG data were amplified and recorded using the Brain Vision Recorder (Brain Products GmbH Munich, Germany) with a passband of .1–250 Hz and a sampling rate of 1000 Hz. Impedances of all active electrodes were kept below 10 kΩ.

2.4. *EEG data preprocessing*

The EEG data were first preprocessed using EEGlab toolbox (Delorme & Makeig, 2004) for Matlab (2014, the MathWorks Inc). After visual inspection, EEG channels with noisy signals or substantial artefacts were removed and interpolated using adjacent channels. The EEG signal was filtered using a high pass filter at .1 Hz. Independent component analysis (ICA) was performed using the standard algorithm included in the EEGlab toolbox (‘runica’; Bell & Sejnowski, 1995). Principal Component Analysis (PCA) was applied before ICA to reduce dimensionality and obtain 32 Independent Component (IC). An IC was considered as artifactual if its topography showed peak activity at the horizontal or vertical eye electrodes and if it showed a smoothly decreasing power spectrum, which is typical for eye movements (Delorme & Makeig, 2004). After artifactual ICA-components were selected, they were removed from the EEG data using the standard function implemented in EEGlab. On average, 2.4 components per participant were removed, whereby, for most subjects, two to four ICA components were rejected. Only for two subjects, none and one ICA component were rejected. After exclusion of these participants' data from statistical analyses, the overall results remained unchanged (see Supplementary materials).

Further off-line analysis was performed using BrainVision Analyzer (Brain Products GmbH, Munich, Germany). In order to better isolate post-ICA artifacts, bipolar EOG channels were created. The vertical EOG (vEOG) was calculated as the difference between the lower eye and the Fp2 electrodes; while the horizontal EOG (hEOG) was calculate by subtracting the activity recorded at the F10 from the F9 electrodes. The EEG signal was then filtered using a zero-phase shift Butterworth filter with a low cutoff of .1 Hz, a high cutoff of 20 Hz, and a notch filter of 50 Hz (24 dB/oct), which are typical settings for slow brain potentials (Luck & Kappenman, 2011; see previous work following similar procedure Grisoni et al., 2021). The filtered EEG data were then segmented into epochs. The data of the first 400 msec of the fixation cross presentation after the context questions and images were excluded from analysis as it could have captured noise resulting from the transition from the context question with the objects to the fixation cross (e.g., eye movements), as well as perceptual responses. In previous studies on semantic and pragmatic predictive processing, anticipatory activity emerged up to 600 msec before the apparition of a predictable critical word (see Boux et al., 2021; Grisoni et al., 2017, 2021). Therefore, EEG data were segmented into epochs starting 1100 msec before critical word onset and ending 900 msec after word onset. Baseline correction was applied by subtracting from the data the average voltage of the 200 msec time window from −1100 msec to −900 msec before critical word onset. At all channel locations except eye electrodes (vEOG and hEOG), epochs with an EEG signal exceeding −100 or 100 μV were excluded from further analysis, and participants' data with a trial rejection rate greater than 20% were excluded from further analysis. For vEOG and hEOG channels, thresholds were defined at −70 and 70 μV. Overall, 3.33% of trials were rejected in the evaluated dataset. After these artifact rejection steps, the datasets of three participants were rejected, leaving datasets from 25 participants for the main analyses.

2.5. *EEG data analysis*

2.5.1. *Pre-stimulus activity*

The study aimed to examine the brain's anticipatory activity before word onset, known as the prediction potential (PP). Based on previous research, strong predictive activity was expected approximately 600 msec before word onset (Boux et al., 2021; Grisoni et al., 2017, 2021). Therefore, to explore the temporal and spatial dynamics of the anticipatory activity in the present study, a repeated-measures analysis of variance (ANOVA) was conducted in the last 600 msec before stimulus presentation. Before performing the ANOVA, a lognormality Kolmogorov–Smirnov test was performed on the overall data for the time-widow between −600 msec and stimulus onset, which was consistent with a normal distribution of data points ($D(24) = .10005$, $p > .100$). In addition, we divided the interval from −600 msec to stimulus onset into three equally spaced 200 msec time windows and conducted lognormality Kolmogorov–Smirnov tests on the data for each time window separately. The results were compatible with normal distribution for the −600 to −400 msec ($D(24) = .1656$, $p = .075$) and −400 to −200 msec ($D(24) = .1084$, $p > .100$) time windows, but suggested lack of normality for the time window from −200 msec to stimulus onset ($D(24) = .1862$, $p = .025$). Note however that, after correcting for multiple comparisons using Bonferroni logic, this significance got lost (critical $p = .0167$). Nevertheless, given the possible lack of normal distribution in the time window closest to stimulus onset, one may argue that the ANOVA results from this interval need to be interpreted with care. For this reason, we added, and refer readers to, the results of the non-parametric cluster-based permutation tests for this entire time window (i.e., last 600 msec before stimulus onset).

To assess brain activity differences between topographies, 27 electrodes were grouped in nine pools of electrodes (Fig. 2D): left anterior (F7, F5, F3), midline anterior (F1, Fz, F2), right anterior (F4, F6, F8), left central (T7, C5, C3), midline central (C1, Cz, C2), right central (C4, C6, T8), left posterior (P7, P5, P3), midline posterior (P1, Pz, P2), and right posterior (P4, P6, P8). Moreover, the amplitude (in microvolts) at the 27 electrodes was averaged in three 200 msec time windows: the last 200 msec before critical word onset (TW1), from 400 msec before to 200 msec before critical word onset (TW2), and from 600 msec before to 400 msec before critical word onset (TW3). Thus, a 5-way ANOVA was performed with the following within-subject factors: Pragmatics (two levels: naming and request), Semantics (two levels: food and tool items), Gradient (three levels: anterior, central, and posterior), Laterality (three levels: left, midline, and right) and Time window (three levels: TW1, TW2 and TW3). Greenhouse–Geisser correction (Greenhouse & Geisser, 1959) was applied to degrees of freedom whenever violation of the sphericity assumption occurred. In this case, corrected p-values, along with epsilon (ε) values are reported for each statistical analysis. A measure of effect size, partial eta-square (η_p^2) values, are also stated (.01–.06: small; .06–.14: medium; >.14: large effect sizes; Cohen, 1988). Post-hoc analyses were conducted using the Fisher Least Significant Difference (LSD) test, followed by Bonferroni correction to account for multiple comparisons. The Bonferroni correction involved multiplying the uncorrected p-value by the number of relevant comparisons. Therefore, all reported p-values labelled as “Bonferroni corrected” have been corrected for multiple comparisons. Cohen's d are reported as a measure of effect size for post-hoc tests (.2: small; .5: medium; .8: large).

Furthermore, since every tenth trial of the experiment was an ‘action trial’, we conducted an additional ANOVA excluding these trials from the dataset to check whether these trials

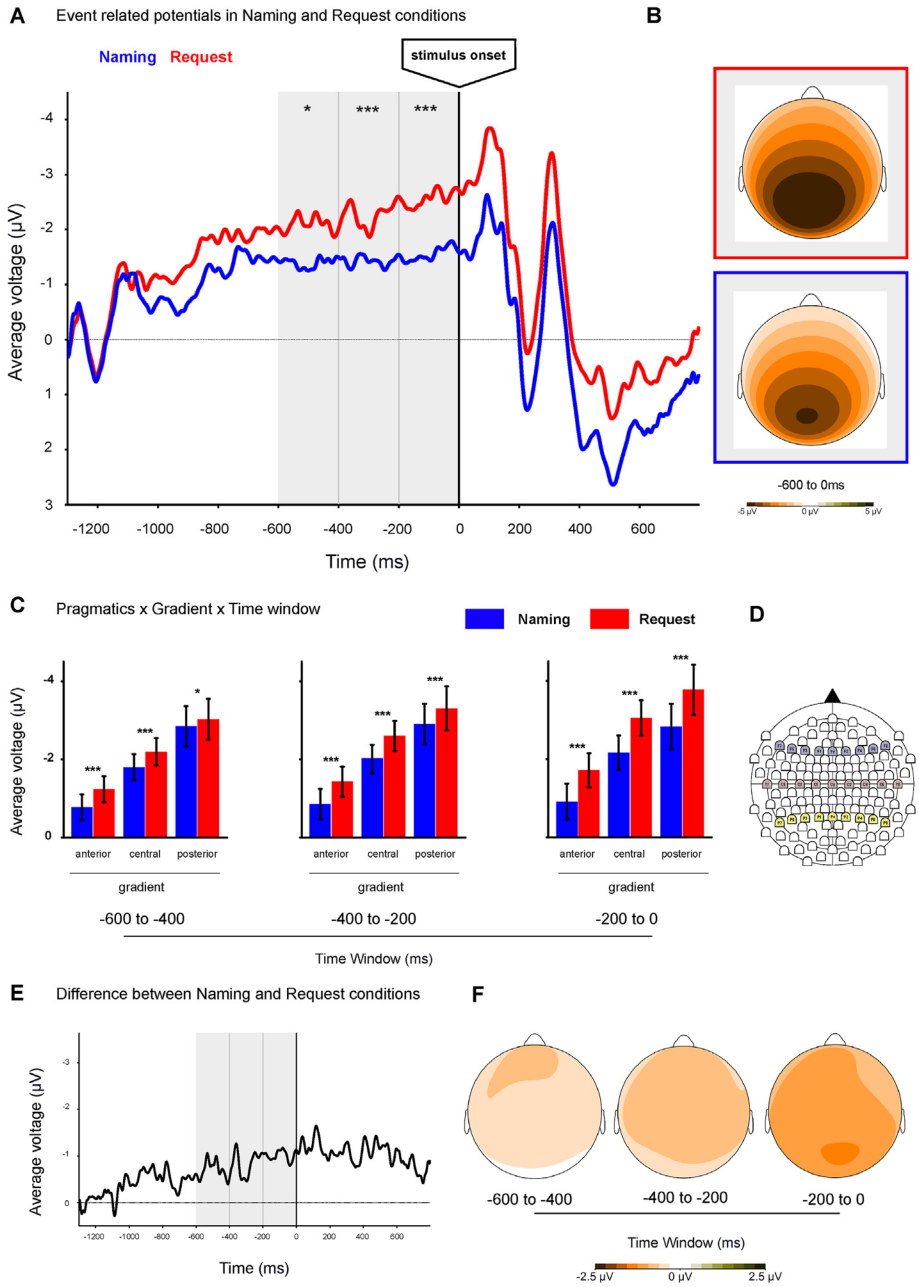

Fig. 2 – | Summary of the main Pragmatics results before stimulus word onset. (A) Grand average event-related potentials (ERP) measured before the onset of critical word presentation in naming (blue) and request (red) conditions. Recordings are from mid-frontal electrodes F1, Fz and F2. The X axis represents time in milliseconds, msec, before and after critical word presentation onset; the Y axis represents the ERP amplitude in micro-Volt (μV). The areas in grey indicate the time windows when differences between naming and request conditions were significant (after Bonferroni correction for 3 comparisons) with their respective significance levels. (B) ERP topographies for naming and request conditions from −600 msec to stimulus presentation onset. The maps display the average potentials of the 600 msec time window. Each map shows the head and recording array from above, with the nose pointing upward. (C) Bar graphs illustrating the significant results of the Pragmatics, Gradient and Time window interaction. The error bars represent Standard Error of the Mean, the asterisk indicate significant differences between the conditions in pairwise comparisons (*$p \leq .05$; **$p \leq .01$; ***$p \leq .001$). (D) Electrodes used in the ANOVA. The three coloured lines represent the three levels of the gradient factor: anterior, central, and posterior. (E) Difference of grand average EPRs between request and naming conditions. Recordings are from mid-frontal electrodes F1, Fz and F2. (F) Topographies of the difference between request and naming conditions from −600 msec to stimulus presentation onset. Each map displays the average potentials in time windows of 200 msec.

influenced the obtained results. The same 5-way ANOVA as described above was performed. The results of this additional analysis confirmed the results obtained with the entire dataset, thus showing that the observed prediction potential results were not affected by the presence of these predictable action trials. For detailed information about these results, please refer to the Supplementary materials.

Finally, in order to examine the reliability of the neurophysiological manifestations of Pragmatic and Semantic differences using non-parametric, cluster-based permutation tests were performed as implemented in the FieldTrip toolbox in Matlab (Maris & Oostenveld, 2007; Sassenhagen & Draschkow, 2019; Shibasaki & Hallett, 2006). At the pragmatic level, the prediction potential has been shown to appear hundreds of milliseconds before stimulus onset at frontal, central and posterior electrodes. Thus, we performed the analysis on the time period from −600 msec to stimulus onset, and followed the selection of electrodes from a previous study (Boux et al., 2021) and included 45 electrodes (Frontal: F7, F5, F3, F1, Fz, F2, F4, F6, F8, FC5, FC3, FC1, FCz, FC2, FC4, FC6; Central: T7, C5, C3, C1, Cz, C2, C4, C6, T8, CP5, CP3, CP1, CPz, CP2, CP4, CP6; and Posterior: P7, P5, P3, P1, Pz, P2, P4, P6, P8, PO7, POz, PO8). The permutation distribution was approximated by a Monte Carlo method of 10,000 randomizations of the data of the two experimental conditions. We performed a one-tail test as we had the a priori hypothesis that the amplitude would be more negative in the request condition compared to the naming condition, as observed in previous studies (Boux et al., 2021; Egorova et al., 2013; Tomasello et al., 2019). Furthermore, we conducted an additional permutation test in a narrower time-window, from −400 msec to stimulus onset, as previous research has shown that the prediction potential tends to show stronger negativity closer to the predicted stimulus onset. Clusters were considered significant if the permutation *p*-value was below 5% (critical alpha level). A separate two-tailed non-parametric cluster-based permutation test was performed to compare semantic conditions.

2.5.2. *Post-stimulus activity*

In order to compare the processing of naming and request speech acts following stimulus presentation, segmented epochs were baseline-corrected using a canonical baseline going from −100 msec to word onset. In previous work, Egorova et al. (2013) found early processing of pragmatic and semantic information during speech acts comprehension. We examined the post-stimulus onset activity to investigate whether previous findings of enhanced activity at fronto-central regions in request (relative to naming) contexts could be replicated (Egorova et al., 2013, see, particularly their Figs. 3 and 4D; see also Boux et al., 2021, Fig. 2C). Given that Egorova et al. (2013) observed the most significant differences in ERPs between request and naming conditions, this motivated hypothesis-driven focussing on fronto-central electrodes. In addition, we conducted a comprehensive analysis of electrodes across a broader pool of electrodes. Although this approach could potentially reveal interactions between topography and pragmatics, such interactions were not evident, possibly due to a relatively low signal-to-noise ratio. In summary, our examination of fronto-central ERP recordings post stimulus onset was motivated by previous findings and can therefore be interpreted.

As mentioned above, previous studies in pragmatics, specifically comparing brain activity immediately following naming and request speech acts performed with words from different semantic type (Egorova et al., 2013; Tomasello et al., 2019) revealed significant differences between these categories at fronto-central electrodes and in fronto-central cortical areas. To investigate these early post-stimulus differentiations, we selected time-window latencies closely aligned with Egorova et al. (2013)'s study. Recorded brain activity was averaged in four time-windows following word presentation: 95–135 msec, 165–205 msec, 290–330 msec, and 400–500 msec. Furthermore, to investigate brain activity differences in topography, 18 electrodes were grouped into anterior (F7, F5, F3, F1, Fz, F2, F4, F6, F8), and central (T7, C5, C3,

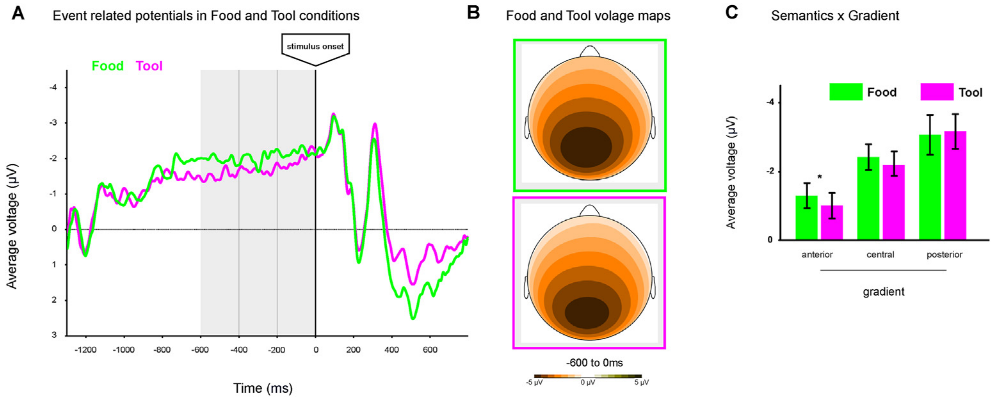

Fig. 3 – | Summary of the main Semantics results before stimulus word onset. (A) Grand average event-related potentials (ERP) measured before the onset of critical word presentation in food (green) and tool (pink) conditions. Recordings are from mid-frontal electrodes F1, Fz and F2. The X axis represents time in milliseconds (ms), before and after critical word presentation onset; the Y axis represents the ERP amplitude in micro-Volt (µV). (B) ERP topographies for food and tool trials from −600 msec to stimulus word presentation onset. The maps display the average potentials of the 600 msec time window. Each map shows the head and recording array from above, with the nose pointing upward. (C) Bar graph illustrating the significant results of the Semantics and Gradient interaction. The error bars represent Standard Error of the Mean, the asterisk indicates significant differences ($p < .05$) between the conditions in pairwise comparisons.

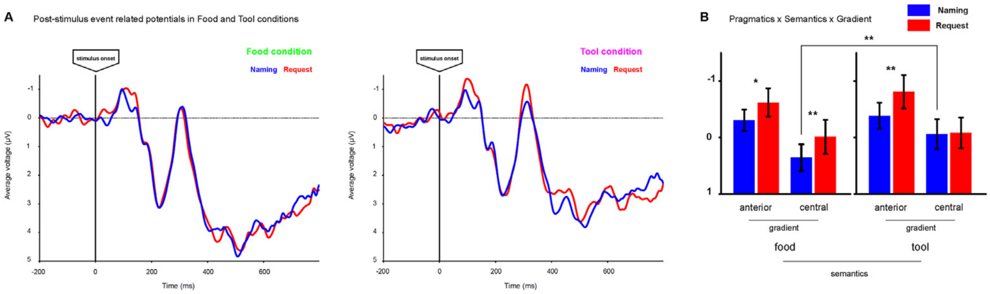

Fig. 4 – | Summary of the main results after stimulus word presentation. (A) Grand average event-related potentials (ERP) measured after the onset of critical word presentation in naming (blue) and request (red) conditions, in trials during which food images were presented (left) or tool images (right). Recordings are from mid-frontal electrodes F1, Fz and F2. The X axis represents time in seconds, before and after critical word presentation onset; the Y axis represents the ERP amplitude in micro-Volt (μV). (B) Bar graph illustrating the significant results of the Pragmatics, Semantics and Gradient interaction. The error bars represent Standard Error of the Mean, the asterisks indicate significant differences between the conditions in pairwise comparisons (*$p \le .05$; **$p \le .01$; ***$p \le .001$).

C1, Cz, C2, C4, C6, T8), pools of electrodes. Before performing the ANOVA, a lognormality Kolmogorov–Smirnov test was performed on the four above-mentioned time windows. The data were found to be compatible with the normality assumption in the first three time windows of Egorova ($D(24) = .095$, $p > .100$), ($D(24) = .139$, $p > .100$) and ($D(24) = .152$, $p > .100$), respectively, but not in the latest one ($D(24) = .222$, $p = .002$). Consequently, we refrain from interpreting the results observed in the fourth time window, from 400 to 500 msec. The ANOVA tests were conducted in each time windows and included three factors: Pragmatics (two levels: naming and request), Semantics (two levels: food and tool items), and Gradient (two levels: anterior, central).

We also conducted a supplementary analysis including posterior pool of electrodes. Thus, 27 electrodes were grouped into anterior (F7, F5, F3, F1, Fz, F2, F4, F6, F8), central (T7, C5, C3, C1, Cz, C2, C4, C6, T8), and posterior (P7, P5, P3, P1, Pz, P2, P4, P6, P8) pools of electrodes. A second set of ANOVA tests with Pragmatics (two levels: naming and request), Semantics (two levels: food and tool items), and Gradient (three levels: anterior, central, and posterior) was conducted in the same four time-windows. It is important to note that no definitive conclusions can be drawn from these results due to the absence of source analysis.

Similar to the pre-stimulus analysis, Greenhouse–Geisser correction was applied to degrees of freedom in case of sphericity assumption violation. Partial eta-square (η_p^2) values are also reported, and post-hoc analyses were conducted using the Fisher Least Significant Difference (LSD) test, followed by Bonferroni correction to account for multiple comparisons.

3. Results

3.1. *Questionnaire*

To assess participants' attention to and memory for the experimental stimuli, a questionnaire was administered at the end of the experiment. Among a list of 40 tool and food words participants had to mark the one which were presented during the experiment. It included 26 critical words, and 14 filler words from the same semantic categories. On average, participants obtained a score of 36.76 out of 40 possible correct answers (i.e., hits and correct rejections included; SD = 3.7), thus demonstrating that there paid attention to and successfully recalled the critical words presented on the computer screen during the experiment. All participants achieved above-chance performance, with all giving more than 30 correct answers. Participants' performance was further evaluated using their d-prime values. For all participants, d-prime values were high (mean: 3.43, range: 1.68–4.48), thus indicating effective recognition of stimulus items and attention to the experiment.

To explore the potential correlation between prediction potential (PP) and memory performance, Pearson correlation tests were conducted. These tests aimed to assess the relationship between participants' PPs -the mean amplitude calculated across time windows and across pools of electrodes – and the same subjects' scores on the questionnaire. However, the results did not reveal any significant correlation between participants' questionnaire scores and their prediction potentials ($r(23) = -.2067$, $p = .3215$) calculated across the entire 600 msec window (−600 msec to 0 msec), nor for PPs observed in specific 200 msec time windows: −200 msec to stimulus onset ($r(23) = -.2730$, $p = .1868$), −400 msec to −200 msec ($r(23) = -.1905$, $p = .3618$), and −600 msec to −400 msec ($r(23) = -.1170$, $p = .5774$). Additionally, Pearson correlation tests were conducted between participants' PPs and their d-prime values. Similarly, no significant correlation was found between participants' overall prediction potentials and their d-prime scores ($r(23) = -.1318$, $p = .5297$), nor for PPs observed in specific time windows: −200 msec to stimulus onset ($r(23) = -.2085$, $p = .3171$), −400 msec to −200 msec ($r(23) = -.1263$, $p = .5475$), and −600 msec to −400 msec ($r(23) = -.0253$, $p = .9044$). These findings fail to support a relationship between participants' working memory performance, as assessed by the questionnaire administered at the end of the experiment, and the sizes of their individual PPs.

3.2. Pre-stimulus results, prediction potential

To investigate any differences in pre-stimulus activation between conditions, a repeated measures 5-way ANOVA was performed (Pragmatics × Semantics × Gradient × Laterality × Time Window) in the 600 msec preceding stimulus presentation.

The ANOVA revealed a significant interaction between Pragmatics and Time window (F(2, 48) = 5.515, adjusted $p = .015$, $\varepsilon = .717$, $\eta_p{}^2 = .187$; see Fig. 2A). The significant interaction was confirmed by post-hoc *t*-tests (Bonferroni corrected for 3 comparisons), showing that the prestimulus negativity was significantly larger in the request condition compared to the naming condition in TW1 ($p < .001$; d = .221), TW2 ($p < .001$; d = .132) and TW3 ($p = .011$; d = .086). This difference of PPs between different expected communicative acts found here in comprehension is similar to the negative-going anticipatory potential previously observed in production, which resembled the readiness potential, but nevertheless reflected communicative function (Boux et al., 2021).

The analysis also revealed a significant interaction between Pragmatics, Gradient and Time window for the entire 600 msec pre-word time window (F(4, 96) = 3.496, adjusted $p = .048$, $\varepsilon = .417$, $\eta_p{}^2 = .127$; see Fig. 2C). Post-hoc *t*-tests (Bonferroni corrected for 9 comparisons) showed that, during TW1, prestimulus negativity was significantly larger in request compared to naming conditions at anterior, central and posterior pools of electrodes ($p < .001$ at the three gradient levels; d = .196, d = .232, d = .217, respectively), which was also true in TW2 ($p < .001$ at the three gradient levels d = .149, d = .153, d = .095, respectively). In the same way, during TW3, request conditions led to relatively greater negativity than naming at anterior ($p < .001$; d = .112), central ($p < .001$; d = .100) and posterior ($p = .025$; d = .043) pools of electrodes.

Finally, a significant interaction was revealed between Semantics and Gradient (F(2, 48) = 4.830, adjusted $p = .025$, $\varepsilon = .691$, $\eta_p{}^2 = .167$, see Fig. 3). Post-hoc *t*-test (Bonferroni corrected for 3 comparisons) showed that the food condition led to greater negativity compared to tool at the anterior pool of electrodes specifically ($p = .011$; d = .073; see Fig. 3C). The coexistence of the effects of Semantics and Pragmatics shows that, in the time range where the upcoming verbal utterance was expected, the ERP reflected both semantic and pragmatic information processing.

It may be argued that some persistent activity differentiating between speech act conditions may have been present all along the interval from picture to word presentation. However, the grand average ERP curves of naming and request conditions clearly speak against this possibility, as there was no clear divergence between them after picture onset until around 600 msec before word onset. To ascertain this, additional statistical analyses were performed for 200 msec wide time windows between −1000 and −800 msec and −800 to −600 msec. Neither ANOVAs (Pragmatics × Semantics × Gradient × Laterality; F(1, 24) = .3952 and F(1, 24) = 3.8308, respectively; $p > .05$) nor non-parametric cluster based permutation tests (performed on both time-windows and the whole interval) revealed significant differences between conditions. The earliest neurophysiological dissociation between communicative functions of the verbal utterances was seen from −600 to −400 msec before word onset, as reported above.

To re-investigate any differences between naming and request conditions using a non-parametric test, a cluster-based permutation test was performed on the time window from −600 msec to stimulus onset on the date from 45 electrodes. The test revealed a significant positive cluster discriminating between request and naming conditions, which extended from −300 msec to −160 msec ($p = .047$). Consistent with findings from previous studies and the above reported ANOVA results, more negative-going ERPs preceded request than naming actions. Similarly, an additional cluster-based permutation test performed on the time window between −400 msec to word onset revealed two significant positive clusters for the difference between request and naming conditions ($p = .032$ and $p = .042$). These differences were most clearly manifest in the time windows between −300 msec and −140 msec and again from −140 msec to stimulus onset. The same analyses were also run on the horizontal and vertical EOG recordings to investigate any putative differences between conditions in eye movement behaviour. The tests did not reveal significant clusters in the time windows of interest, neither during the last 600 msec before word onset, nor during the last 400 msec before word onset.

To examine differences between semantic conditions, another two-tailed non-parametric cluster-based permutation test was conducted on the time window from −600 msec to stimulus onset. However, this test did not yield any significant clusters. As upon visual inspection of the event-related potentials (ERPs), a greater frontal negativity was obvious in the food compared to the tool condition early-on, we conducted an exploratory one-tailed non-parametric cluster-based permutation test on an earlier time window, spanning from −700 to −400 msec, focussing on the frontal pool of electrodes (AFF5h, AFF1h, AFF6h, AFF2h, F3, F1, Fz, F2, F4). This analysis revealed a cluster of electrodes where the difference between semantic conditions was significant ($p = .048$). However, due to the restrictive nature of this latter analysis, we do not interpret this result on its own. In contrast, the pragmatic effects reflected by the PP were equally manifest in the results of both parametric and non-parametric statistical analyses.

3.3. Post-stimulus results

To investigate any differences post-word presentation, two sets of repeated measures ANOVA were performed with 3 factors (Pragmatic × Semantic × Gradient) on the neurophysiological brain responses recorded post word presentation in four time-windows: 95–135 msec, 165–205 msec, 290–330 msec and 400–500 msec. We selected time-window latencies closely aligned with those used in prior studies on early speech act processing (Egorova et al., 2013) where they found significant effects of pragmatic and semantic factors on neurophysiological activity post stimulus onset.

In the first time-window (95–135 msec), the ANOVA with a 2-levels Gradient factor (anterior and central) revealed a significant Pragmatics, Semantics and Gradient interaction (F(1,

24) = 4.997, $p = .035$, $\eta_p^2 = .172$; see Fig. 4). Pairwise comparisons (Bonferroni corrected for 4 comparisons) revealed that in the food condition, requests led to a greater negativity compared to naming, both at the anterior ($p = .019$; d = .283) and central ($p = .005$; d = .273) pools of electrodes. Similarly, in the tool condition a greater negative-going activity was observed after requests compared to a naming at the anterior pool of electrodes ($p = .001$; d = .320). The ANOVA with a 3-levels Gradient factor (anterior, central, posterior) revealed a near-significant interaction between Pragmatics, Semantics and Gradient (F(2, 48) = 3.191, $p = .05$, $\eta_p^2 = .117$) which did not survive correction for violation of the sphericity assumption (adjusted $p = .083$, $\varepsilon = .283$).

In the second time-window (165–205 msec), the ANOVA with a 2-levels Gradient factor revealed a significant Semantics and Gradient interaction (F(1, 24) = 5.066, $p = .034$, $\eta_p^2 = .175$). Pairwise comparisons (Bonferroni corrected for 2 comparisons) revealed greater positive activity in the food condition compared to the tool condition at central pool of electrode ($p = .026$; d = .011). The ANOVA with a 3-levels Gradient factor did not reveal any significant differences.

In the third time-window (290–330 msec), both ANOVAs failed to reveal any significant differences.

In the fourth time-window (400–500 msec), the ANOVA with a 3-levels Gradient factor revealed a near-significant interaction between Pragmatics and Gradient (F(2, 48) = 3.538, $p = .037$, $\eta_p^2 = .128$) which did not survive correction for violation of the sphericity assumption (adjusted $p = .058$, $\varepsilon = .659$).

4. Discussion

The present study investigated event-related brain potentials, ERPs, in participants perceiving request and naming interactions where both the communicative function of upcoming linguistic-pragmatic actions and their categorial semantic content were predictable. Surprisingly, these brain potentials reflected both communicative function and semantic content of upcoming linguistic actions before the words carrying these functions and meanings actually appeared. Both naming and request conditions showed a negative going anticipatory potential, with a larger negativity for request as compared to naming conditions starting already 600 msec before the onset of the critical word. Brain correlates of the semantic category of the upcoming word were also observed starting 600 msec before critical word onset. The observed pragmatic difference in predictive ERPs – larger negativities for requests than naming actions – is similar to that seen immediately after the critical utterance, as reported by several studies in the literature (Egorova et al., 2013, 2014, 2016; Tomasello et al., 2019). Furthermore, the difference in prediction potentials between communicative actions and its time course, here observed during language understanding, aligns with earlier findings in speech production (Boux et al., 2021). This congruency suggests that this anticipatory brain activity reflects predictions about the socio-communicative function of upcoming utterances independent of the modality of language use (i.e., in production and comprehension).

4.1. *Predictive neurophysiological indexes of communicative function and semantic content*

The key finding of the present study is that, when participants expected a request, they showed greater prediction potentials, or PPs, than when they expected a simple naming action. This result was consistently manifest in significant effects across parametric and non-parametric statistical analyses and aligns well with a previous study in which subjects had to produce words to either ask a partner to hand-over a given object or to correctly name an object (Boux et al., 2021). In both experiments, the related PPs were larger for request than for naming actions. Although this congruency suggests that brain indicators of pragmatic prediction, and possibly even the related brain-internal mechanisms, are similar across comprehension and production modalities, more work is needed to back these suggestions. Here, we just present an analysis of ERP amplitudes and topographies. To further analyse commonalities and differences between brain mechanisms, source localisation and possibly more sophisticated analyses of brain activity would be necessary (e.g., multiple dipole analyses, minimum norm estimates or beamformers to infer the underlying sources), along with studies using other neuroimaging and neurophysiological methods. Our results on predictive brain activity reflecting different communicative functions also align well with the aforementioned post-stimulus ERPs elicited by these same communicative actions, for which results from a range of studies using different imaging methods along with source results are available (Egorova et al., 2013, 2014, 2016; Tomasello et al., 2019; van Ackeren et al., 2012, 2016; for a review see Tomasello, 2023). Moreover, the post-stimulus activity changes between semantically different utterances and between pragmatically different communicative actions could also be replicated in the present study. If brain generators reflecting differences between communicative functions are found to be the same in production and comprehension, and in anticipation of and following critical stimuli, this would provide important support for so-called integration models of language and communication. These models argue that production and comprehension of language are closely linked, sharing similar cognitive and brain mechanisms (e.g., Pickering & Garrod, 2013; Pulvermüller & Fadiga, 2010; Strijkers & Costa, 2016). In contrast, several stream models propose that language production and comprehension are controlled by at least partly separate modules, suggesting the involvement of distinct cortical mechanisms in language use and understanding (e.g., Hickok & Poeppel, 2000, 2004, 2007; Indefrey & Levelt, 2004).

Already 600 msec before critical word presentation, different ERP topographies emerged for the predictable semantic categories from which the upcoming critical words were chosen (i.e., food *vs* tool items). The anticipatory semantic effects were shown by parametric analyses and could also be confirmed by non-parametric testing when focussing on anterior electrodes. This anticipatory activity can be linked to the semantic Prediction Potential preceding predictable words whose precise identity was determined by the context (Grisoni et al., 2017, 2019, 2021; Pulvermüller & Grisoni, 2020). However, strictly speaking, in contrast to the earlier results, the present experimental design left it open until critical word onset which word form and which precise semantic features would characterize the upcoming item. What was predictable in the present study was the semantic *category* to which the critical word belonged. More precisely, it was predictable that one of the four visually displayed objects from the same semantic category would be followed by the preferred verbal label of one of these alternatives. This opens a range of different possibilities for interpreting the semantically related topographical differences observed in the pre-stimulus slow negative shift. It could be (i) that subjects just predicted one of the four alternatives (with $p = .25$), (ii) that they predicted more than one of the displayed items or all four of them, or (iii) that the entire semantic category was predicted. And it is even possible that the slow wave reflected memory processes for the object pictures that had previously been visible on screen. Due to these multiple ways in which the semantic modulation of the slow negative-going potential can be interpreted, we prefer avoiding speculatively focussing on just one of these possibilities. However, we note that the observed differences in brain signatures for different semantic categories appeared before the onset of the critical word, when it was not yet clear which of the four alternative pictures would be referred to. One may suggest that the slow potential shift may well reflect the subject's expectation -not of the upcoming word, as this was only predictable with $p = .25$, but- of the semantic category of the upcoming word. This pre-stimulus difference is in agreement with but also extends previous research indicating that, if the identity of the upcoming utterance is precisely predictable, the PP reflects between-category differences (see Grisoni et al., 2021). More research is necessary to fully understand these pre- and post-stimulus responses and their relationships to pictorial stimuli, semantic categories, semantic features, and word forms.

4.2. *The prediction potential and current linguistic debates*

Predictions in language can be defined as the integration of both the linguistic context of the conversation (i.e., linguistic representations of the speaker's utterance) and the non-linguistic context (e.g., shared background knowledge, shared visual information), which preactivates predictable linguistic concepts and their features before they appear (Amos & Pickering, 2020; Gambi & Pickering, 2017; Huettig, 2015; ; Lelonkiewicz et al., 2021; Pickering & Gambi, 2018; Pulvermüller & Grisoni, 2020). During a conversation, interlocutors continually make predictions about the other person's current and next utterance, intended meanings and communicative goals, and update them as the conversation progresses, as evidenced, for example, by single words identified by listeners before their ends (Altmann & Kamide, 1999; Marslen-Wilson, 1987; Sacks et al., 1974). In an EEG study, Magyari et al. (2014) showed that already 1250 msec before the end of an utterance, the interlocutor predicted the end of a turn, as indicated by a beta frequency desynchronization in the anterior cingulate cortex and the inferior parietal lobule. These and many other studies demonstrate how quickly language is processed and make it plausible that predictions, at different levels, play a crucial role in rapid comprehension. To better understand the related predictive mechanisms, it is essential to have available a direct measure of the physiological correlates of predictions as they emerge in real time. Previous studies on predictions have primarily focused on prediction error, as reflected, for example, by the N400 (see Kutas & Federmeier, 2011; Ito et al., 2016; Otten et al., 2007; Rabovsky & McRae, 2014), thus studying processing consequences of predictions. Recent studies have identified a brain potential building up prior to a meaningful predicted utterance, at the lexico-semantic (Grisoni et al., 2016, 2017, 2019, 2021; León-Cabrera et al., 2017, 2019), phonological (Grisoni, 2022), discourse (Barthel et al., 2024) and pragmatic levels (Boux et al., 2021; present study). This predictive brain activity, which in parallel reflects features of the upcoming stimulus at different levels (phonemes, word forms, semantics, pragmatics), was thus called the prediction potential (PP).

4.3. *Pragmatic processing pre- and post-stimulus*

To address the early time course of pragmatic processing, researchers have investigated the neurophysiological processing of different communicative actions or speech acts by presenting the same propositional content in different communicative contexts. For instance, using the word “glass” to request or name an object. Some studies measured participants' brain's responses to short clips of two people interacting, thus putting the participant in a third-person perspective just observing a dialogue and found an early dissociation between speech act types (Egorova et al., 2013) with the earliest differentiation measured at 50–90 msec and clear dissociations between 100 and 200 msec (Egorova et al., 2014). Interestingly, similar early processing of different communicative functions was also observed when the speech acts were directed towards participants, placing them in a second-person perspective (Tomasello et al., 2019). In these different experimental settings, the early differentiation was characterized by stronger brain responses for request speech acts than naming speech acts. Specifically, when investigating the processing of speech act functions by gesture-word combinations, this speech act differentiation was observed around 150 msec (Tomasello et al., 2019). However, when gestures were presented alone, without semantic-referential information, significantly later differentiations were observed, thus showing the importance of different levels of linguistic information being available during communication. As discussed earlier, a recent study (Boux et al., 2021) with an experimental setting approximating real-life interactions, where participants addressed speech acts to a confederate present in the room, thus maintaining a first-person perspective, found that 600 msec prior to production, anticipatory brain activity was greater for request compared to naming. Thus, the present study adds to the existing research on pragmatic processing of communicative functions by showing that anticipatory brain responses during comprehension reflects communicative function of predicted speech acts. In line with Boux and colleagues' findings (2021), the prediction of request speech acts elicited significantly greater anticipatory activity compared to naming speech acts, evident 600 ms before word onset, a temporal neurophysiological differentiation similar to that observed in production.

Similar to Egorova et al. (2013), the current study revealed stronger post-stimulus ERP responses to request action as compared to naming performed with the counterbalanced utterances. In addition, the interaction between the pragmatics, semantics and gradient factors in the 95–135 msec time window was similar to previous findings, with larger negative-going ERPs in the request than in the naming condition (see Fig. 4A). Our analysis here focused on frontocentral activity based on findings by previous literature showing increased brain activity in motor areas when processing request compared to naming speech acts (Egorova et al., 2013; Tomasello et al., 2019). Therefore, our data suggest that the pragmatic function of predictable communicative actions is reflected in neurophysiological activity both before and shortly after utterance onset.

It is important to note that the results of the non-parametric cluster-based permutation tests indicated earlier semantic processing compared to pragmatic processing. However, this temporal distinction could be attributed to the experimental design. Semantic information (i.e., the semantic category of the relevant object) was available from the beginning of the trial. Likewise, pragmatic information about the communicative action to follow was introduced by the ‘context sentences’, which appears together with the set of four pictures. In both cases, aspects – either semantic or pragmatic ones – of the upcoming utterance could be predicted but in the semantic domain, this information was about an entire category, whereas the predictable pragmatic aspect, communicative function, was pre-defined by the context sentence as either naming or requesting. Therefore, the greater uncertainty associated with the categorial semantic prediction and the definitiveness of the unique pragmatic expectation (either of a request or a naming action) may have contributed to the differences in the temporal dynamics of the pre-word semantic and pragmatic effects revealed by non-parametric statistics. However, we note that ANOVAs indicated the simultaneous emergence of semantic and pragmatic effects throughout the 600 msec of the pre-word interval (see Figs. 2 and 3).

5. Limitations and future directions

As already mentioned above, no source localization was conducted in the present study. Thus, similarities with previously reported PP need to be further investigated. Grisoni et al. (2021) found a significant activation of the inferior prefrontal cortex during predictions as well as a pre-activation of semantic features of the predicted utterance with greater involvement of visual areas for animal-related words and frontocentral sensorimotor areas for tool-related words. Similarly, when investigating cortical sources of the pragmatic PP, Boux et al. (2021) found significant activations in the hand motor cortex before requests but not naming. It would therefore be interesting to determine whether pre-activations of both semantic and pragmatic features can be observed in the present design with topographical dissociations when predicting tool or food words, and naming or request speech acts.

The present experiment did not systematically investigate the possible role of heart rate changes on the slow potentials recorded. In theory, it might be possible that conditions of different pragmatic or semantic type could lead to different types of heart rate changes, which, in turn, could affect slow potential shifts (Schmidt et al., 2022). Future research is necessary to assess whether such a hypothetical change in heart rate may have affected the reported results.

Although our present experiment emphasised the differences in brain signatures of predictions related to communicative function and semantics, we note that the pre-stimulus-word differences reported here still leave it open whether the PP indicates prediction per se. To show this, unpredictable control conditions would be necessary. However, a range of previous experiments used one or more such unpredictable control conditions (e.g., Grisoni et al., 2017, 2021; León-Cabrera et al., 2017, 2019) and showed the specificity of PP elicitation to predictable conditions and its absence (or substantial reduction) in unpredictable ones. Still, it would be useful to perform experiments similar to the present one in future where one condition is characterized by lack of predictability of the pragmatic function of the upcoming communicative action.

It is important to note that since the present study did not systematically evaluate emotional-affective aspects of the pictorial stimuli, including the properties of arousal and valence (Lang et al., 1993), it is possible, for example, that emotional attitudes towards (e.g., craving for or avoidance of specific) food-related images might influence any pre- and post-stimulus ERP effects that potentially differentiate between the two semantic categories. Thus, future research should aim to clarify whether the emotional features of the depicted objects contribute to any ERP differences between categories or whether their origin is entirely semantic-conceptual.

Moreover, this potential could, in principle, also reflect memory of the context – which implies subsequent either naming or request actions. However, we believe that this interpretation is not very plausible, because the PP did not persist from context sentence to critical word presentation, but only emerged around half a second before the critical word. Thus, the temporal dynamics of the ERP is more supportive of a genuine prediction-related physiological index than with a memory-related one. Or, to adopt a terminology from Fuster's famous studies on the physiological basis of working memory: our ERP signatures are more consistent with a role in “memory for the future” than with “memory for the past” (Fuster, 2001).

As for any experiment, one may argue that subjects engaged in other activities not required or suggested by the instruction and experimental paradigm and that such additional silent activity may have been the source of any measured difference. For example, one may argue that silent responses to questions may have preceded word presentations or that subjects may have intensively imagined, that is mentally visualized, one or more target objects during the period of PP emergence. While we cannot exclude the possibility that such hypotheses may be correct for the entire set of our participants, we would however expect that the presence of such task-unrelated mental activities would vary greatly across the population of experimental subjects, and, if present at all, would have differed substantially between individuals. Therefore, these task-unrelated processes do not, in our view, represent likely causes of prediction potential emergence. And, given some of the subjects might have engaged in different such activities (e.g., one silently articulating, one mentalizing visually, auditorily, olfactorily etc.), the question emerges whether a consistent ERP signature might have resulted in the grand average ERP.

Previous studies on communication and social interaction mimicked such interactions at different levels or realism. For example, the study by Boux et al. (2021) had two interacting partners in the lab, whereas in the present study, a relatively abstract and well-controlled setup was implemented. Clearly, both strategies –maximizing the naturalness of dialogues and strict control of experimental variables– have their respective advantages. Considering the present study, the constrained design of the experiment may not capture the richness of the environment of related real-world social interactions. When engaging in everyday-life dialogues, one does not only process linguistic representations of the utterances, but also auditory features of speech sounds, speakers' gestures, and the social environment in which the conversation takes place (Garrod & Pickering, 2004; ; Pickering & Garrod, 2013). However, it is important to note that even in such a controlled laboratory environment, this study was able to find similar results to those obtained in the production domain during a face-to-face interaction (Boux et al., 2021). Laboratory-constrained experiments have some limitations, including the risk of observing unusual brain processes that would not otherwise occur in natural settings. Specifically, in prediction studies, the slow presentation rates of stimuli raise the concern of observing predictive brain mechanisms facilitated by these long time-periods between a context and its predictable ending. Pickering and Gambi (2018) explained that these prediction periods might allow listeners to extensively engage their production system, which might not be the case when language is processed at a natural faster rate. While a break in-between context sentences and predicted words allows to avoid noise in the baseline before perceiving or performing communicative action (as in the present study, Boux et al., 2021; Grisoni et al., 2017; 2021; Ito et al., 2016 León-Cabrera et al., 2017; 2019), its drawback is that it created a somewhat artificial interaction in which frequent breaks may interfere with the flow of communicative information exchange. Therefore, it is important to point to the parallelism of ERP results in studies with naturally spoken continuous sentences and with breaks before the predictable word (León-Cabrera et al., 2017, 2019). Still, future research should focus on the time-course of semantic and pragmatic predictions in communication in a more life-like setting without pre-stimulus breaks.

6. Conclusion

In conclusion, when following a conversation, an anticipatory brain potential can be observed before a meaningful predictable utterance. This potential reflects the expectation of both the communicative function of the predicted utterance and of information about the semantic category of upcoming language stimuli. We found that the prediction potential (PP) reflected the understanding of the pragmatic communicative function of language use in interaction; the pragmatic PP was larger in request contexts compared to naming contexts, thus indexing pragmatic predictions. Potential topography was also modulated by the expectation of either food or tool words, thus, also indexing aspects of semantics. In light of the results of Boux et al. (2021), our results suggest that predictive communicative function of an upcoming utterance modulates anticipatory brain activity in a similar way across comprehension and production modalities. This finding is consistent with the idea that shared predictive mechanisms are at work in language and communication processing in both comprehension and production, a claim for which recent evidence has been reported within the semantic domain (Grisoni et al., 2024a). By allowing faster processing of the predicted utterance -at multiple levels of linguistic representations-, anticipatory and predictive processing of communicative and semantic function may facilitate and speed the partners' contributions to dialogues (Holler & Levinson, 2019; Huettig, 2015; Kuperberg & Jaeger, 2016; Levinson, 2016; Pickering & Gambi, 2018; Pickering and Garrod, 2007, 2013). Future studies should explore the PP in more depth, as it may shed light on how the brain computes predictions about different types of information relevant for cognition. Moreover, future research should take into account the conversational aspect of language by engaging participants in dialogue, which can be achieved for example by using EEG hyperscanning.

Open practices

The study in this article has earned Open Materials badge for transparent practices. The materials studies are available at: https://osf.io/eqhdv/.

CRediT authorship contribution statement

Salomé Antoine: Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Luigi Grisoni:** Writing – review & editing, Visualization, Validation, Supervision, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Rosario Tomasello:** Writing – review & editing, Methodology, Conceptualization. **Friedemann Pulvermüller:** Writing – review & editing, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization.

Declaration of competing interest

The authors declare no conflicts of interests.

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Supplementary data

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REFERENCES

Altmann, G. T., & Kamide, Y. (1999). Incremental interpretation at verbs: Restricting the domain of subsequent reference. *Cognition, 73*(3), 247–264.

Amos, R. M., & Pickering, M. J. (2020). A theory of prediction in simultaneous interpreting. *Bilingualism: Language and Cognition, 23*(4), 706–715.

Austin, J. L. (1975). *How to do things with words*. Oxford: Clarendon Press.

Barthel, M., Tomasello, R., & Liu, M. (2024). Conditionals in context: Brain signatures of prediction in discourse processing. *Cognition, 242*, Article 105635.

Bell, A. J., & Sejnowski, T. J. (1995). An information-maximization approach to blind separation and blind deconvolution. *Neural Computation, 7*(6), 1129–1159.

Binder, J. R., Conant, L. L., Humphries, C. J., Fernandino, L., Simons, S. B., Aguilar, M., & Desai, R. H. (2016). Toward a brain-based componential semantic representation. *Cognitive Neuropsychology, 33*(3–4), 130–174.

Boux, I., Tomasello, R., Grisoni, L., & Pulvermüller, F. (2021). Brain signatures predict communicative function of speech production in interaction. *Cortex; a Journal Devoted To the Study of the Nervous System and Behavior, 135*, 127–145.

Carota, F., Moseley, R., & Pulvermüller, F. (2012). Body-part-specific representations of semantic noun categories. *Journal of Cognitive Neuroscience, 24*(6), 1492–1509.

Constant, M., Pulvermüller, F., & Tomasello, R. (2023). Brain-constrained neural modeling explains fast mapping of words to meaning. *Cerebral Cortex, 33*(11), 6872–6890.

Cohen, J. Statistical power analysis for the behavioral sciences. Statistical power analysis for the behavioral sciences (rev. ed.). 2nd, (Erlbaum, 1988)

Delorme, A., & Makeig, S. (2004). EEGLAB: an open source toolbox for analysis of single-trial EEG dynamics including independent component analysis. *Journal of Neuroscience Methods, 134*(1), 9–21.

Dreyer, F. R., Frey, D., Arana, S., Saldern, S. V., Picht, T., Vajkoczy, P., & Pulvermüller, F. (2015). Is the motor system necessary for processing action and abstract emotion words? Evidence from focal brain lesions. *Frontiers in Psychology, 6*, 166.

Dreyer, F. R., Picht, T., Frey, D., Vajkoczy, P., & Pulvermueller, F. (2020). The functional relevance of dorsal motor systems for processing tool nouns–evidence from patients with focal lesions. *Neuropsychologia, 141*, Article 107384.

Dreyer, F. R., & Pulvermüller, F. (2018). Abstract semantics in the motor system? – An event-related fMRI study on passive reading of semantic word categories carrying abstract emotional and mental meaning. *Cortex; a Journal Devoted To the Study of the Nervous System and Behavior, 100*, 52–70.

Egorova, N., Pulvermüller, F., & Shtyrov, Y. (2014). Neural dynamics of speech act comprehension: An MEG study of naming and requesting. *Brain Topography, 27*(3), 375–392.

Egorova, N., Shtyrov, Y., & Pulvermüller, F. (2013). Early and parallel processing of pragmatic and semantic information in speech acts: Neurophysiological evidence. *Frontiers in Human Neuroscience, 7*, 86.

Egorova, N., Shtyrov, Y., & Pulvermüller, F. (2016). Brain basis of communicative actions in language. *NeuroImage, 125*, 857–867.

Fritz, G. (2005). On answering accusations in controversies. *Studies in Communication Sciences, 5*, 151–162.

Fuster, J. M. (2001). The prefrontal cortex — An update: Time is of the essence. *Neuron, 30*(2), 319–333.

Gambi, C., & Pickering, M. J. (2017). Models linking production and comprehension. *The Handbook of Psycholinguistics*, 157–182.

Garrod, S., & Pickering, M. J. (2004). Why is conversation so easy? *Trends in Cognitive Sciences, 8*(1), 8–11.

Gisladottir, R. S., Chwilla, D. J., & Levinson, S. C. (2015). Conversation electrified: ERP correlates of speech act recognition in underspecified utterances. *Plos One, 10*(3), Article e0120068.

Glenberg, A. M., & Gallese, V. (2012). Action-based language: A theory of language acquisition, comprehension, and production. *Cortex; a Journal Devoted To the Study of the Nervous System and Behavior, 48*(7), 905–922.

Greenhouse, S. W., & Geisser, S. (1959). On methods in the analysis of profile data. *Psychometrika, 24*(2), 95–112.

Grisoni, L. (2022). Predictions built upon belongings. *Frontiers in Psychology, 13*.

Grisoni, L., Boux, I. P., & Pulvermüller, F. (2024a). Predictive brain activity shows congruent semantic specificity in language comprehension and production. *Journal of Neuroscience, 44*(12).

Grisoni, L., Dreyer, F. R., & Pulvermüller, F. (2016). Somatotopic semantic priming and prediction in the motor system. *Cerebral Cortex, 26*(5), 2353–2366.

Grisoni, L., Miller, T. M., & Pulvermüller, F. (2017). Neural correlates of semantic prediction and resolution in sentence processing. *Journal of Neuroscience, 37*(18), 4848–4858.

Grisoni, L., Mohr, B., & Pulvermüller, F. (2019). Prediction mechanisms in motor and auditory areas and their role in sound perception and language understanding. *NeuroImage, 199*, 206–216.

Grisoni, L., Piperno, G., Moreau, Q., Molinari, M., Scivoletto, G., & Aglioti, S. M. (2024b). Predicting and coding sound into action translation in spinal cord injured people. *European Journal of Neuroscience, 59*(5), 1029–1046.

Grisoni, L., & Pulvermüller, F. (2022). Predictive and perceptual phonemic processing in articulatory motor areas: A prediction potential & mismatch negativity study. *Cortex; a Journal Devoted To the Study of the Nervous System and Behavior, 155*, 357–372.

Grisoni, L., Tomasello, R., & Pulvermüller, F. (2021). Correlated brain indexes of semantic prediction and prediction error: Brain localization and category specificity. *Cerebral Cortex, 31*(3), 1553–1568.

Heister, J., Würzner, K. M., Bubenzer, J., Pohl, E., Hanneforth, T., Geyken, A., & Kliegl, R. (2011). dlexDB–eine lexikalische Datenbank für die psychologische und linguistische Forschung. *Psychologische Rundschau*.

Hickok, G., & Poeppel, D. (2000). Towards a functional neuroanatomy of speech perception. *Trends in Cognitive Sciences, 4*(4), 131–138.

Hickok, G., & Poeppel, D. (2004). Dorsal and ventral streams: A framework for understanding aspects of the functional anatomy of language. *Cognition, 92*(1–2), 67–99.

Hickok, G., & Poeppel, D. (2007). The cortical organization of speech processing. *Nature Reviews Neuroscience, 8*(5), 393–402.

Holler, J. (2022). Visual bodily signals as core devices for coordinating minds in interaction. *Philosophical Transactions of the Royal Society B, 377*(1859), Article 20210094.

Holler, J., & Levinson, S. C. (2019). Multimodal language processing in human communication. *Trends in Cognitive Sciences, 23*(8), 639–652.

Huang, Z., Feng, C., & Qu, Q. (2023). Predicting coarse-grained semantic features in language comprehension: Evidence from ERP representational similarity analysis and Chinese classifier. *Cerebral Cortex*, Article bhad116.

Huettig, F. (2015). Four central questions about prediction in language processing. *Brain Research, 1626*, 118–135.

Indefrey, P., & Levelt, W. J. (2004). The spatial and temporal signatures of word production components. *Cognition, 92*(1–2), 101–144.

Ito, A., Corley, M., Pickering, M. J., Martin, A. E., & Nieuwland, M. S. (2016). Predicting form and meaning: Evidence from brain potentials. *Journal of Memory and Language, 86*, 157–171.

Järvilehto, T., Hari, R., & Sams, M. (1978). Effect of stimulus repetition on negative sustained potentials elicited by auditory and visual stimuli in the human EEG. *Biological Psychology, 7*(1–2), 1–12.

Kiefer, M., & Pulvermüller, F. (2012). Conceptual representations in mind and brain: Theoretical developments, current evidence and future directions. *Cortex; a Journal Devoted To the Study of the Nervous System and Behavior, 48*(7), 805–825.

Kuperberg, G. R., & Jaeger, T. F. (2016). What do we mean by prediction in language comprehension? *Language, Cognition and Neuroscience, 31*(1), 32–59.

Kutas, M., & Federmeier, K. D. (2011). Thirty years and counting: Finding meaning in the N400 component of the event related brain potential (ERP). *Annual Review of Psychology, 62*, 621.

Lang, P. J., Greenwald, M. K., Bradley, M. M., & Hamm, A. O. (1993). Looking at pictures: Affective, facial, visceral, and behavioral reactions. *Psychophysiology, 30*(3), 261–273.

León-Cabrera, P., Flores, A., Rodríguez-Fornells, A., & Morís, J. (2019). Ahead of time: Early sentence slow cortical modulations associated to semantic prediction. *NeuroImage, 189*, 192–201.

León-Cabrera, P., Rodríguez-Fornells, A., & Morís, J. (2017). Electrophysiological correlates of semantic anticipation during speech comprehension. *Neuropsychologia, 99*, 326–334.

Lelonkiewicz, J. R., Rabagliati, H., & Pickering, M. J. (2021). The role of language production in making predictions during comprehension. *Quarterly Journal of Experimental Psychology, 74*(12), 2193–2209.

Levinson, S. C. (2016). Turn-taking in human communication–origins and implications for language processing. *Trends in Cognitive Sciences, 20*(1), 6–14.

Luck, S. J., & Kappenman, E. S. (Eds.). (2011). *The Oxford handbook of event-related potential components*. Oxford University Press.

Magyari, L., Bastiaansen, M. C., De Ruiter, J. P., & Levinson, S. C. (2014). Early anticipation lies behind the speed of response in conversation. *Journal of Cognitive Neuroscience, 26*(11), 2530–2539.

Maris, E., & Oostenveld, R. (2007). Nonparametric statistical testing of EEG-and MEG-data. *Journal of Neuroscience Methods, 164*(1), 177–190.

Marslen-Wilson, W. D. (1987). Functional parallelism in spoken word-recognition. *Cognition, 25*(1–2), 71–102.

Martin, A. (2007). The representation of object concepts in the brain. *Annual Review of Psychology, 58*, 25–45.

Martin, A., Wiggs, C. L., Ungerleider, L. G., & Haxby, J. V. (1996). Neural correlates of category-specific knowledge. *Nature, 379*, 649–652.

Oldfield, R. C. (1971). The assessment and analysis of handedness: the Edinburgh inventory. *Neuropsychologia, 9*(1), 97–113.

Otten, M., Nieuwland, M. S., & Van Berkum, J. J. (2007). Great expectations: Specific lexical anticipation influences the processing of spoken language. *BMC Neuroscience, 8*(1), 1–9.

Pickering, M. J., & Gambi, C. (2018). Predicting while comprehending language: A theory and review. *Psychological Bulletin, 144*(10), 1002.

Pickering, M. J., & Garrod, S. (2007). Do people use language production to make predictions during comprehension? *Trends in Cognitive Sciences, 11*(3), 105–110.

Pickering, M. J., & Garrod, S. (2013). An integrated theory of language production and comprehension. *Behavioral and Brain Sciences, 36*(4), 329–347.

Pulvermüller, F. (2013). How neurons make meaning: Brain mechanisms for embodied and abstract-symbolic semantics. *Trends in Cognitive Sciences, 17*(9), 458–470.

Pulvermüller, F., & Fadiga, L. (2010). Active perception: Sensorimotor circuits as a cortical basis for language. *Nature Reviews Neuroscience, 11*(5), 351–360.

Pulvermüller, F., & Grisoni, L. (2020). Semantic prediction in brain and mind. *Trends in Cognitive Sciences, 24*(10), 781–784.

Rabovsky, M., & McRae, K. (2014). Simulating the N400 ERP component as semantic network error: Insights from a feature-based connectionist attractor model of word meaning. *Cognition, 132*(1), 68–89.

Sacks, H., Schegloff, E. A., & Jefferson, G. (1974). A simplest systematics for the organization of turn-taking for conversation. *Language, 50*, 696–735.

Sassenhagen, J., & Draschkow, D. (2019). Cluster-based permutation tests of MEG/EEG data do not establish significance of effect latency or location. *Psychophysiology, 56*(6), Article e13335.

Schmidt, F., Danböck, S. K., Trinka, E., Demarchi, G., & Weisz, N. (2022). Age-related changes in “cortical” 1/f dynamics are linked to cardiac activity. *bioRxiv*, 2022-11.

Searle, J. R., & Searle, J. R. (1969). *Speech acts: An essay in the philosophy of language* (Vol. 626). Cambridge University Press.

Shibasaki, H., & Hallett, M. (2006). What is the Bereitschaftspotential? *Clinical Neurophysiology, 117*(11), 2341–2356.

Strijkers, K., & Costa, A. (2016). The cortical dynamics of speaking: Present shortcomings and future avenues. *Language, Cognition and Neuroscience, 31*(4), 484–503.

Tomasello, R. (2023). Linguistic signs in action: The neuropragmatics of speech acts. *Brain and Language, 236*, Article 105203.

Tomasello, R., Garagnani, M., Wennekers, T., & Pulvermüller, F. (2017). Brain connections of words, perceptions and actions: A neurobiological model of spatio-temporal semantic activation in the human cortex. *Neuropsychologia, 98*, 111–129.

Tomasello, R., Grisoni, L., Boux, I., Sammler, D., & Pulvermüller, F. (2022). Instantaneous neural processing of communicative functions conveyed by speech prosody. *Cerebral Cortex, 32*(21), 4885–4901.

Tomasello, R., Kim, C., Dreyer, F. R., Grisoni, L., & Pulvermüller, F. (2019). Neurophysiological evidence for rapid processing of verbal and gestural information in understanding communicative actions. *Scientific Reports, 9*(1), 1–17.

van Ackeren, M. J., Casasanto, D., Bekkering, H., Hagoort, P., & Rueschemeyer, S. A. (2012). Pragmatics in action: Indirect requests engage theory of mind areas and the cortical motor network. *Journal of Cognitive Neuroscience, 24*(11), 2237–2247.

van Ackeren, M. J., Smaragdi, A., & Rueschemeyer, S. A. (2016). Neuronal interactions between mentalising and action systems during indirect request processing. *Social Cognitive and Affective Neuroscience, 11*(9), 1402–1410.

Żygis, M., & Fuchs, S. (2023). Communicative constraints affect oro-facial gestures and acoustics: Whispered vs normal speech. *The Journal of the Acoustical Society of America, 153*(1), 613–626.