The Neural Processing of Cross-categorial Innovations in Language

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Abstract

Cross-categorial innovations, such as nouns used as verbs, are a productive source of polysemy in language. Although such innovative forms are typically interpreted with ease, little is known about their neural processing. This study investigates the neural correlates of innovative denominal verbs during naturalistic sentence reading. Using concurrent eye-tracking and EEG, we compared innovative denominal verbs with their base nouns and with conventionalized verbs, allowing innovation-related effects to be distinguished from general noun–verb differences. EEG signals were time-locked to the first fixation on the critical word. Innovative denominal verbs elicited a reliable left-anterior negative-going effect in the 300–500 ms time window relative to both control conditions, which extended into the 500–800 ms interval. No evidence was found for an ELAN or P600. We argue that the observed sustained negativity reflects increased demands on semantic-pragmatic integration and context-dependent meaning construction, rather than morphosyntactic anomaly processing.

Keywords: polysemy; denominal verbs; cross-categorial innovation; ERPs; reading; semantic-pragmatic integration

Introduction

Polysemy is a linguistic phenomenon in which a single form has multiple related senses. These meanings may occur within the same syntactic category, such as with the noun *paper,* which can refer both to the physical material, and to the academic work currently being read (amongst other senses). Polysemy can also be cross-categorial. That is to say, related senses can surface with different syntactic categories, such as nouns, verbs, and adjectives (e.g., *to run, the run*).

In English, this change of syntactic category does not require overt derivational morphology; as a result, the surface forms of nouns and verbs can be identical. This process is productive, leading to innovative uses of nouns as verbs (denominalization, e.g. to *porch* the newspaper; Clark & Clark, 1979). In such cases, the verbal sense must be pragmatically inferred based on the existing nominal sense in combination with the syntactic environment, discourse context, and world knowledge (Carston, 2022). As multiple potential interpretations may arise, the reader or listener may need to select the pragmatically most appropriate one. In contrast, conventionalized forms such as *run* (both as a noun and as a verb) may not require a pragmatic inference, as they are stored in and retrieved from the mental lexicon.

Importantly, although cross-categorial innovations are, by definition, novel and require a pragmatic inference, listeners and readers are generally able to assign them a coherent interpretation. This interpretation is typically related to the meaning of the existing base form via a polysemous relation (Kelly, 1998; Vogelzang et al., 2026) rather than a homophonous one, in which the two forms have unrelated meanings. For example, the novel denominal *cocktail* in (1) was taken to mean ‘to provide cocktails’ (a clearly related and thus polysemous sense) by 78% of participants in Vogelzang et al. (2026). Nevertheless, from a cognitive perspective, this process of meaning assignment appears to require additional processing resources. Evidence for this comes from reading-time studies showing that novel denominal verbs are read slower than both existing verbs (Kaschak & Glenberg, 2000) and than their base nouns (Vogelzang et al., 2025, 2026).

(1) Linda and Robert throw great dinner parties and always *cocktail* their guests liberally beforehand.

Past neuroimaging studies investigating denominalization have mainly focussed on conventionalized forms. Findings show that polysemous forms are associated with increased response times (Lukic et al., 2023) and increased neural activity in brain regions involved in morphological processing, such as the left inferior frontal gyrus (Pliatsikas et al., 2014) compared to non-polysemous, unambiguous forms.

A notable exception is Thierry et al. (2008), who examined cross-categorial innovations as used by Shakespeare (denominalizations as in (2) as well as other category shifts, e.g. verb → noun) with event-related potentials (ERPs). They found that category shifts elicited a left anterior negativity (LAN) as well as a P600 effect. These components are typically associated with grammatical violations, suggesting that category shifts may be processed as morphosyntactic anomalies.

(2) you would *companion* me

However, late ERP components like the P600 are not uniquely associated with morphosyntactic anomalies. Research on polysemy and compositional meaning has demonstrated that later processing stages may also index semantic reinterpretation in context. Schumacher (2013), for example, distinguishes between cases in which an appropriate meaning can be selected from a set of closely related alternatives and cases in which interpretation requires a revision of the discourse representation. Reinterpretations

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of the latter type have been consistently associated with late positive-going ERP effects in the 500–800 ms time window. In addition, integration difficulty during discourse interpretation has been associated with sustained anterior negativities (Van Berkum et al., 2003, 2007).

Importantly, the study by Thierry et al. (2008) has several methodological limitations. First, it is unclear whether selected the forms and senses constituted genuine innovations either at the time of writing or at the time of testing (e.g., 'to *friend* someone' is now conventionalized or in the process of being conventionalized). If these items were truly novel, the absence of any semantic surprisal or pragmatic integration effects such as an N400 would be highly unexpected. Second, Thierry and colleagues used a word-by-word reading paradigm, which is arguably a less natural way to read. Finally, the experiment tested a variety of category shifts, not only denominals, and it is unclear whether this affected their results.

At the same time, interpreting differences between denominal verbs and their base nouns is complicated by potential noun-verb confounds. Vigliocco et al. (2011) review evidence that noun-verb contrasts are often difficult to attribute to grammatical category alone, because category is frequently confounded with semantic distinctions (e.g., object- vs. event/action-related meaning) and with differences in processing demands that emerge especially during sentence integration. As a result, any differences between innovative denominal verbs and their base nouns could reflect general differences in the processing of objects and events rather than mechanisms specific to innovation-driven meaning construction.

We therefore conducted an EEG/ERP study examining the neural processing of innovative category shifts in a more naturalistic way, controlling for both the type of shift (denominal verbs only) and the novelty of the verb form. By including a comparison with conventionalized verbs, the present design allows effects attributable to grammatical category/semantic type to be distinguished from those associated with innovation. We predict that the pragmatic inference required to derive the meaning of the novel denominal verbs will be reflected in semantic processing effects, in addition to any morphosyntactic effects.

Hypotheses

The study and its hypotheses were preregistered prior to data collection on the open science framework (OSF)[1]. The preregistered hypotheses regarding the processing of innovative denominal verbs compared to their base nouns are:

H1: A pronounced N400 effect
H2: A pronounced P600 effect
H3: A possible left anterior negativity (ELAN) effect

Note that after further review of the literature post-preregistration, we might additionally expect a LAN effect to accompany the P600 effect (in line with Thierry et al., 2008), as well as a late positive-going effect in the 500-800 ms time window (in line with Schumacher, 2013). In line with Van Berkum (2003; 2007), we might also consider the possibility that denominal verbs can elicit extended integration-related activity, potentially without a robust late positivity.

Methods

Participants

26 monolingual English-speaking participants from the UK participated in the study[2] (18 female; 7 male; 1 other; mean age 20.8; age range 19-25). Participants were recruited through social media and mailing lists of undergraduate and postgraduate students at the University of Cambridge. All participants were native speakers of English, did not grow up speaking any other language than English until the age of 7, were right-handed, had normal or corrected-to-normal vision, were not color blind, and had no record of neurological/psychiatric disorders or reading deficits.

Written informed consent was obtained from all participants prior to the experiment. Participants were paid £10/hr for their time. Ethical approval for the study was obtained from the Faculty of Modern and Medieval Languages and Linguistics Research Ethics Committee at the University of Cambridge.

Design

Participants were asked to complete a sentence reading task. The task used a within-subjects design, which included 34 sentences with attested nouns (3a), 34 sentences with the same forms used as unconventional, cross-categorial verbs (3b), 34 sentences with unrelated conventionalized verbs (3c), and 34 non-sensical fillers. Thus, the task contained 136 trials (34 trials in each of the 4 conditions) for each participant. The nonsensical fillers were added to distract participants while conventionalized verbs were included to isolate effects related to grammatical category/semantic type rather than innovation. Participants were shown both the sentences with the denominal verbs and their base nouns, but never in the same block (i.e. one was before a mid-task break, one after). Two pseudorandomized lists were created.

The denominal verbs were taken from Vogelzang et al. (2026). The frequency of the denominal verbs was always

[1] Preregistration (February 2022): https://osf.io/xn7sh. As the preregistration was aimed at a more extensive journal article, we additionally made some predictions about the influence of cognitive abilities on the neural processing of cross-categorial innovations. These data will not be presented here and were not part of the pre-registered core hypotheses.

[2] This was slightly lower than the preregistered sample size aim of 28. Four additional participants participated in the study. One participant was excluded prior to analyses because they indicated having spoken Urdu at home from a young age and had a cochlear implant. Three participants were excluded based on the quality of their EEG data (see Section on EEG pre-processing).

lower than their frequency as a noun based on the SUBTLEX-UK corpus (Van Heuven et al., 2014).[3]

(3a) He eats with *chopsticks* for fun.
[noun condition]

(3b) The waiters *chopsticked* the noodle bowls.
[innovative denominal verb condition]

(3c) The gardener *planted* the tulip bulbs in the garden.
[conventionalized verb condition]

We used a concurrent eye-tracking and EEG paradigm to enable the presentation of full sentences during naturalistic reading (cf. Thierry et al., 2008).

Procedure

Participants were tested individually in a lab. They first filled out demographic questionnaires, then performed some cognitive tasks, and finally performed the main denominal task. Only the denominal task is reported in the present paper. This task was implemented in Experiment Builder (SR Research).

During the task, participants silently read sentences while electroencephalogram (EEG) recordings were taken. Eye movements were recorded using an Eyelink 1000 eye-tracker and chin rest with a sampling rate of 1000 Hz. The eye-tracker was calibrated to the right eye of each participant at the beginning of the experiment using a 9-point calibration and was recalibrated after the mid-task break and as required.

Each trial started with a series of exclamation marks (!!!) on the screen for 3000 ms to allow participants to blink. After a delay of 200 ms, a drift correction point was presented at the location of the first word in the upcoming sentence. Each sentence was presented for 5000 ms. After each sentence, participants were asked to respond to a question, e.g., whether the sentence made sense or whether the sentence contained an action by pressing 'F' (for 'yes') or 'J' (for 'no') on a keyboard – these questions were included to engage the participant and will not be analyzed. Participants got 4000 ms to answer the question before moving on to the next trial. 5 practice trials preceded the main testing blocks.

The task took approximately 40 minutes to complete, with a short break in the middle. The complete test battery, including questionnaires, cognitive tasks, and EEG setup took approximately 2 hours.

EEG recordings

EEG recordings were taken from 64 Ag/AgCl electrodes mounted on a head cap (arranged according to the extended 10–20 International system) using an actiCHamp and BrainVision Recorder. Data were recorded using a central reference electrode placed between Cz and Fz and a ground electrode positioned in front of AFz. We recorded electro-oculograms (EOGs) using electrodes positioned above and below the left eye to monitor vertical eye movements, with a passive electrode on the earlobe. Signals were digitized at a sampling rate of 500 Hz. Digital codes (TTL links) were sent from the stimulus presentation computer to mark the onset and condition of each trial. These triggers were subsequently time-locked to the onset of reading the critical word based on the gaze data.

In order to do this, we followed Eyelink's default identification of fixations. Areas of interest (AOIs) on the critical words were defined through Experiment Builder. Using this, the eye-tracking data signaled the exact time participants moved their gaze to the critical word in each sentence, i.e. the first fixation to the AOI. Each trial's trigger in the EEG signal was then moved to the onset of the first fixation to the critical word in Matlab (version R2024b). Trials with missing eye-tracking data (i.e. no fixations on the critical word) were excluded; this led to 4.75% data loss.

EEG pre-processing

The data (pre-)processing minimally deviated from the preregistration due to a software-license issue. Instead of using Brain Vision Analyzer, (pre-)processing of the EEG data was performed with the Matlab-based packages EEGlab and ERPlab (Delorme & Makeig, 2004; Lopez-Calderon & Luck, 2014). Very similar (pre-)processing steps as in the preregistration (based on the Krigolson lab; www.krigolsonlab.com/data-analysis.html) were followed. This included 1) re-referencing the data to electrodes TP9 and TP10 (mastoids); 2) resampling the data to 250 Hz; 3) filtering the data with a 0.1 Hz high-pass filter, a 40 Hz low-pass filter, and a 50 Hz Notch filter; 4) manually removing the time before and after the critical stimuli as well as the break; 5) removing bad channels; 6) running an independent components analysis (ICA); 7) rejecting components based on the ICA (with the help of the ICLabel and ADJUST plug-ins, Mognon et al., 2011; Pion-Tonachini et al., 2019); and 8) interpolating missing channels. For an additional 3 participants not reported on in the participants section, the data were too noisy, and no sensical independent components could be identified in the ICA; these were excluded from further analyses. Across the remaining 26 participants, 46 channels were interpolated (fewer than 2 channels on average per participant). Subsequently, 1) bin-based epochs were extracted per participant in the [-350; 1500] time window with a baseline window of [-200; 0]; and 2) artifact detection was performed with simple voltage thresholds (voltage limits [-100 100] μV), and moving window peak-to-peak threshold (100 μV) in the full time window and in [-200 200] ms for the vertical EOG channel. This artifact rejection led to a further 4.87% of data exclusion; an average of 122.4 out of 136 trials per participant remained[4]. Averaged ERPs were calculated per participant per condition, time-locked to the

[3] A full list of stimuli can be found on the paper's OSF repository: https://osf.io/3x9ru/overview?view_only=c09b49df1f7d4c46a9daf9fb083740c2

[4] The preregistration indicated that participants with more than 25% missing data would be excluded. This held true for 1 participant but was due to difficulties with their gaze data. As this individual seemed to have reliable EEG data, they were retained.

first fixation on the critical word, after which the data were exported.

Analyses

All statistical analyses[5] were performed in the R software (version 4.4.1; R Core Team, 2024). For statistical analysis, the midline electrodes were divided into three groups: frontal (AFz & Fz), central (Cz & CPz), and posterior (Pz & POz). Twelve groups of lateral electrodes were created (frontal: left (F1, F3 & F5), right (F2, F4 & F6); fronto-central: left (FC1, FC3 & FC5), right (FC2, FC4 & FC6); central: left (C1, C3 & C5), right (C2, C4 & C6); centroparietal: left (CP1, CP3 & CP5), right (CP2, CP4 & CP6); parietal: left (P1, P3 & P5), right (P2, P4 & P6), occipital: left (PO3, PO7 & O1), right (PO4, PO8 & O3)). Group values were calculated as an average of the included electrodes.

The ERPs were analyzed using a Generalized Additive Mixed Model (GAMM; Wood, 2006), a type of modeling that allows for analyses of time series data in a nonlinear fashion. This way, all pre-defined analysis windows (N400, P600, ELAN) can be investigated in the same analysis and no averaging of data over time is required. The analysis windows were pre-defined as 100-200 ms (ELAN), 300-500 ms (N400/LAN), and 500-800 ms (P600).

The analysis included condition (noun, denominal verb, and conventionalized verb) and location (midline groups: frontal, central, posterior; lateral groups: frontal, fronto-central, central, centroparietal, parietal, occipital left & right) as an interacting predictor (see Van Rij et al., 2016). As statistically significant differences between the nouns and the denominal verb were found, the conventionalized verb condition was used to check whether these effects were not due to the difference in word class (noun vs. verb), but indeed due to the unconventional nature of the cross-categorial verbs. This led to the following model specification:

*Voltage ~ ConditionLocationInteraction + s(Time, by = ConditionLocationInteraction, k = round(0.01 * 1850), bs = "cr") + s(Participant, bs = "re").*

The AR1 correlation parameter (rho) was set to .99. Because the analysis of a large dataset over time and the large number of channel groups increase the risk of Type 1 errors, we interpreted our results with caution by setting the confidence intervals of the model fit plots to 99% instead of the commonly used 95% (i.e. z-score set to 2.58).

Results

The grand average ERP data including the pre-defined analysis windows are shown in Figure 1[6]. The model's output indicated that the non-linear pattern of time significantly contributes to activation in each condition-location combination. It should be noted, however, that GAMM significance values lack straightforward interpretability. Rather, the differences between conditions over time per channel group can best be interpreted when presented visually, as in Figures 2 and 4. Figure 2 shows the differences in neural activation, based on the model fits, between the noun (3a) and the innovative denominal verb (3b) conditions, over time. Scalp plots for the difference between denominal verb and noun processing at four time points of interest are shown in Figure 3.

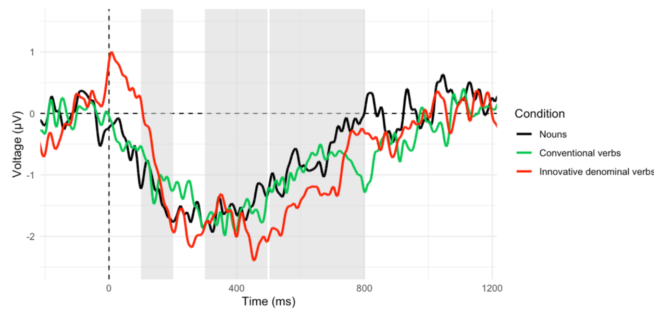

Figure 1. Grand average ERP data for the three conditions. Time is aligned to the onset of the first fixation on the critical word. Grey shading indicates the pre-defined analysis windows (100-200 ms, 300-500 ms and 500-800 ms).

In the first analysis window (100-200 ms), there is no evidence of a negative effect of the denominal verb condition compared to the noun condition in any channel group. Rather, a (very) early positivity emerged at central and parietal locations (CC, LCP, RCP, LP, PC, RP, LPO, and RPO; see Figure 2 and Figure 3, 152 ms plot).

In the second analysis window (300-500 ms), negative effects were found at FC, LF, LC and LFC (left and frontal regions), consistent with an N400. However, these effects seem more in line with a LAN, as they are stronger in left anterior regions (see Figure 3, 400 ms plot), rather than the N400 which is typically stronger in centro-parietal regions.

Finally, in the third analysis window (500-800 ms), the data show no evidence of a positive effect (see Figure 2 and Figure 3, 600 and 800 ms plots). Rather, several channel groups (broadly distributed, though mainly frontal and central, e.g., CC, FC, LF, LFC) show negative (rather than positive) effects of denominal verbs: This suggests a sustained negativity rather than a P600.

We argued that any activity differences between the noun and denominal verb conditions could only be ascribed to the innovative cross-categorial nature of the denominal verbs if they also differed from conventionalized verbs in the same time window; otherwise, effects could be ascribed to a difference in the processing of nouns vs. verbs, without an influence of novelty. To investigate whether the differences

[5] We stuck closely to the preregistered analysis plan and refrained from running additional exploratory analyses.

[6] Data, analysis code, and Supplementary Materials containing a figure with the ERP data for the three conditions per channel group as well as a table with the full GAMM output can be found in the on the paper's OSF repository: https://osf.io/3x9ru/overview?view_only=c09b49df1f7d4c46a9daf9fb083740c2.

in Figure 2 are also found between the denominal verb condition (3b) and the conventionalized verb condition (3c), we present these difference smooths in Figure 4. Like Figure 2, this figure provides no evidence of an early negative activity (such as an ELAN), rather a (very) early positive effect at central and parietal locations.

Also like Figure 2, Figure 4 shows negative effects of denominal verbs in the N400 window (300-500 ms). In the comparison between the two verb conditions, these effects are all frontal and restricted to the LF, FC, and LFC channel groups. Finally, there is no evidence of a P600, rather there of a sustained negativity effect of denominal verbs (in FC and LF). These results suggest that the negative effect in the 300-500 ms time window as well as the late negativity and early positivity are not merely due to the word class of the denominal verbs, but at least in part due to their innovative nature.

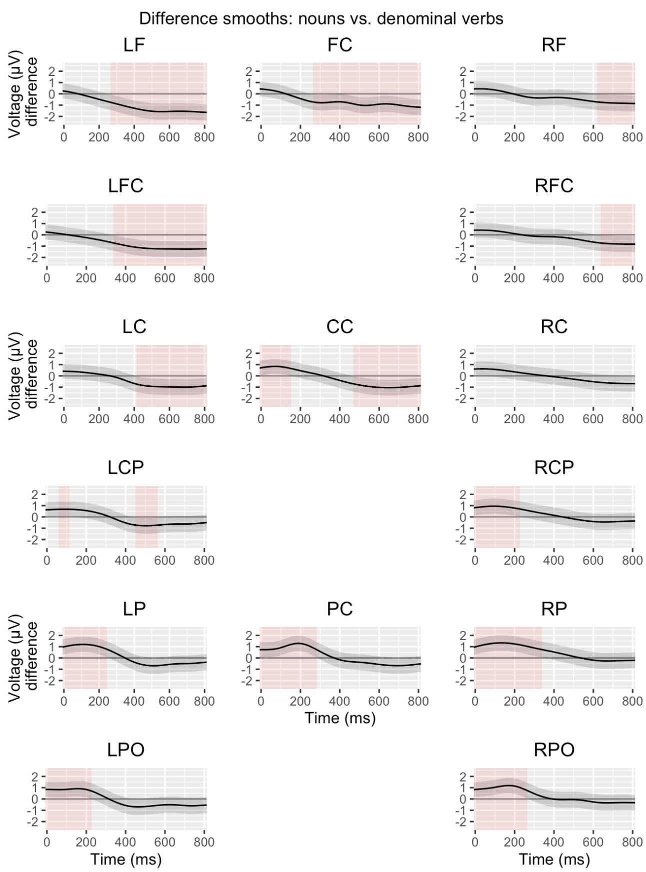

Figure 2. Difference smooths between neural responses to the noun and innovative denominal verb conditions from the GAMM per channel group (frontal at the top, occipital at the bottom; L = left; R = right; F = frontal; C = central; P = posterior; O = occipital). We interpret a difference as meaningful when the difference smooth, including its 99% confidence interval, does not cross 0; these time points are shaded in red. Note that we will only interpret effects that occur in our pre-defined analysis windows (100-200 ms, 300-500 ms and 500-800 ms corresponding to the ELAN, N400 and P600, respectively).

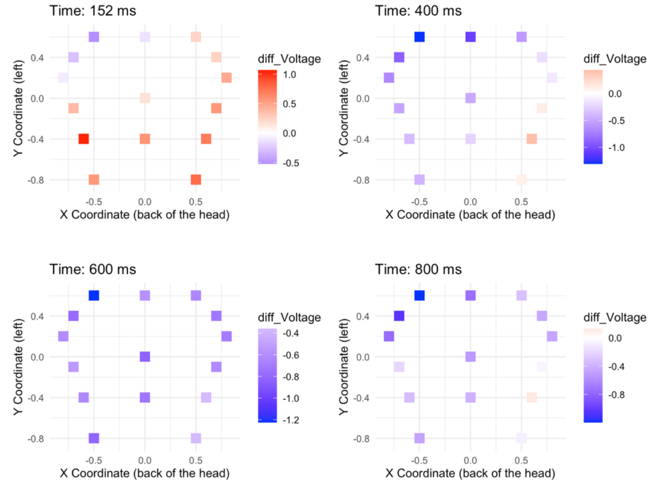

Figure 3. Scalp plot of the difference between the neural responses to the denominal verbs versus the noun condition. Times shown are 152 ms (ELAN window), 400 ms (N400/LAN window), 600 ms (P600 window), 800 ms (end of the P600 window).

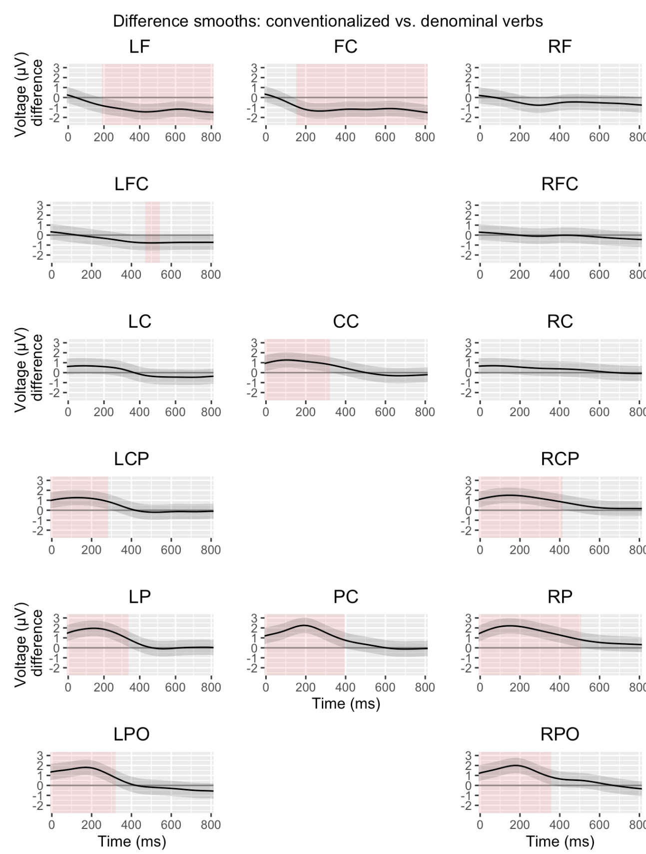

Figure 4. Difference smooths between neural responses to conventionalized and innovative denominal verbs from the GAMM per channel group (frontal at the top, occipital at the bottom; L = left; R = right; F = frontal; C = central; P = posterior; O = occipital). We interpret the difference as

meaningful when the difference smooth, including its 99% confidence interval, does not cross 0; these time points are shaded in red. Note that we will only interpret effects that occur in our pre-defined analysis windows (100-200 ms, 300-500 ms and 500-800 ms corresponding to the ELAN, N400 and P600, respectively).

Discussion

This study set out to investigate the neural processing of innovative category shifts in language. Based on previous research (Thierry et al., 2008), we controlled for shift type and verb-form novelty by comparing innovative denominal verbs to their base nouns and to conventionalized verbs, thereby reducing noun-verb confounds and isolating innovation-related costs more directly.

Across analyses, innovative denominal verbs elicited reliable processing differences relative to both comparison conditions. In the 300–500 ms time window, denominal verbs produced a negative-going effect relative to both base nouns and conventionalized verbs, with a predominantly left anterior distribution. Although this time window overlaps with the canonical N400 (in line with H1), the observed topography differs from the typical centro-parietal distribution associated with lexical-semantic access. We therefore interpret the left-anterior negativity as reflecting increased demands on interpretation-level integration and meaning construction, including construing a nominal base as an event-denoting predicate and selecting a pragmatically appropriate interpretation among plausible candidates in context (Carston, 2022). This interpretation is consistent with ERP evidence that discourse-level interpretation and integration difficulty can elicit anteriorly distributed, sustained negativities when competing candidates must be resolved in context (Van Berkum et al., 2003; 2007).

Contrary to H2, we found no evidence for a positive-going P600 effect in the 500-800 ms window. Instead, the negativity observed in the earlier interval continued into this window, yielding a predominantly left anterior (though broadly distributed), sustained negative-going pattern rather than a late positivity. This differs from Thierry et al. (2008), who reported LAN-P600 components for Shakespearean cross-categorial innovations and interpreted these in terms of morphosyntactic anomaly processing and reanalysis. In our materials, the absence of a P600 suggests that innovative denominal verbs did not reliably trigger repair-like reanalysis; rather, the dominant cost appears to lie in prolonged semantic-pragmatic integration and meaning construction. This interpretation is consistent with Schumacher's (2013) proposal that late positivities are most likely when comprehension requires updating or revising the discourse representation, whereas selection among contextually supported interpretations may be resolved without a robust late positivity.

Nonetheless, if the P600 is taken to reflect reanalysis or late-stage discourse revision more generally (e.g., Aurnhammer et al., 2021), its absence here suggests that such processes were not strongly engaged in this sentence-level reading task. Importantly, this does not preclude extended semantic-pragmatic integration, which is instead reflected in the sustained negativity observed across the 300-800 ms window.

We also found no evidence in support of H3. Rather than an early left anterior negativity, a (very) early positivity emerged at central and parietal sites, which does not align with canonical ELAN patterns. Although the left anterior distribution of the 300–500 ms effect could invite a LAN-like interpretation (Friederici et al., 1993), it was not clearly dissociable from the broader N400-range negativity, cautioning against a strongly syntactic account.

One alternative interpretation is that the very early positivity reflects fixation-locked perceptual or attentional processes, given that epochs were time-locked to the first fixation on the critical word. Neural responses in the 100-200 ms window have been shown to be sensitive to early visual and attentional processing during reading, as well as to form-based expectations associated with predicted syntactic categories (Dikker et al., 2010; Dimigen et al., 2011; Farmer et al., 2006).

From this perspective, the early positivity observed for denominal verbs may reflect increased perceptual or attentional demands arising from a mismatch between the predicted syntactic category (e.g., a verb) and a surface form that is statistically more typical of nouns. Although denominal verbs are fully licensed verbal predicates, their noun-derived form may constitute a less prototypical realization of the expected verb category, requiring early adjustment of form-based expectations during incremental processing. However, the present design does not allow us to determine why such an effect emerged selectively for denominal items. In particular, form typicality and category predictability were not systematically manipulated across conditions, and future work will be needed to establish whether comparable early positivities arise for other cases of reduced form–category typicality.

In addition, the present design attempted to distinguish between effects related to grammatical category/semantic type vs. innovation through the inclusion of conventionalized verbs. An optimal design would also test for innovative uses, albeit related to existing ones, of the base nouns to see whether there are measurable differences in neural responses to innovative cross-categorial polysemy and innovative intra-categorial polysemy. Finally, Schumacher (p.c.) suggested an analysis of the possible positive trend for denominals compared to conventionalized verbs in Figure 1 in a later time window (800-900 ms), but we restricted our analyses here to the pre-registered time windows. Future work could examine this extended interval.

In sum, we interpret the observed sustained negativity spanning 300-800 ms to indicate that innovation-related processing involves an extended semantic-pragmatic integration operation. Interpreting innovative denominal verbs appears to require context-sensitive meaning construction and selection in order to converge on a pragmatically appropriate interpretation.

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