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The phonological status of the French Initial Accent and its role in semantic processing: an Event-Related Potentials study

Noémie te Rietmolen[1]*, Radouane El Yagoubi*[2]*, Alain Ghio*[3] *and Corine Astésano*[1]

[1]U.R.I Octogone-Lordat (E.A. 4156), Université de Toulouse, UTM, Toulouse, France
[2]Laboratoire CLLE-LTC (UMR 5263), Université de Toulouse, UTM, Toulouse, France
[3]Laboratoire Parole & Langage (UMR 7309), Aix-Marseille Université, Aix-en-Provence, France
noemie.te-rietmolen@univ-tlse2.fr, yagoubi@univ-tlse2.fr, alain.ghio@lpl-aix.fr, astesano@univ-tlse2.fr

Abstract

French accentuation is held to belong to the level of the phrase. Consequently French is considered 'a language without accent' with speakers that are 'deaf to stress'. Recent ERP-studies investigating the French initial accent (IA) however demonstrate listeners not only discriminate between different stress patterns, but also prefer words to be marked with IA early in the process of speech comprehension. Still, as words were presented in isolation, it remains unclear whether the preference applied to the lexical or to the phrasal level. In the current ERP-study, we address this ambiguity and manipulate IA on words embedded in a sentence. Furthermore, we orthogonally manipulate semantic congruity to investigate the interplay between accentuation and later speech processing stages. Preliminary results on 14 participants reveal a significant interaction effect: the centro-frontally located N400 was larger for words without IA, with a bigger effect for semantically incongruent sentences. This indicates that IA is encoded at a lexical level and facilitates semantic processing. Furthermore, as participants attended to the semantic content of the sentences, the finding underlines the automaticity of stress processing. In sum, we demonstrate accentuation plays an important role in French speech comprehension and call for the traditional view to be reconsidered.

Index Terms: speech perception, prosody, semantic processing, Event-Related Potentials, N400

1. Introduction

While in written form, language is structured by white spaces and punctuation marks, spoken language is organized through intonation, accentuation, and rhythm. Clearly, prosody plays an essential role in speech comprehension. Metrical structures, for instance, have long been considered crucial in the segmentation of speech. With no clear separation between words in the speech signal, the metrical segmentation strategy (MSS) proposes that listeners rely on their languages' metrical pattern to identify word boundaries [1, 2].

Indeed, in stress languages, such as English or Dutch, in which stress is part of the lexical entry, accents provide reliable cues to lexical boundaries. Even in French, a language often described to be syllable-based due to the fairly homogeneous metrical weight on syllables, prosodic structure has been found to guide speech segmentation [3, 4, 5, 6, 7, among others]. However, in these studies, segmentation was not considered lexical but presumed phrasal, i.e. listeners are assumed to adopt a *prosodic segmentation strategy* in which intonational and accentual patterns function to segment *prosodic groups* (level of AP [8]) from the speech signal [9]. This view stems from traditional descriptions of French as 'a boundary language' [10] or 'a language without accent' [11] according to which stress, because it is not lexically distinctive in French and its surface realization is acoustically merged with intonational boundaries, has no clear metrical value.

Di Cristo's metrical model of French, however, posits that lexical words are encoded with (latent) cognitive stress templates underlying their phonological representation [12]. These stress patterns comprise both a primary final accent (FA) on the last syllable of the word and a secondary and optional initial accent (IA) on the word's first syllable. That is, according to Di Cristo's model, words are marked with metrically strong syllables at both left and right lexical boundaries that can readily notify listeners on when to initiate lexical access. The model therefore provides a valuable theoretical context to speech segmentation in French.

In the current ERP-study, we investigate the representation of the French initial accent. Although the initial accent is thought of as an optional secondary accent in French, and mainly recognized for its rhythmic balancing function and role in emphasis placement, studies showing IA to also play an important role in the marking of lexical structure and speech segmentation are accumulating. Indeed, a perception study in which the accoustic parameters of IA had been manipulated, indicated listeners to have a strong phonological preference for IA [13]. In addition, IA has been found to be a more reliable cue to word boundaries than FA and to be perceived as more prominent at both phrasal and lexical levels [14, 15, 16]. These results prompted a recent paper to revisit the secondary and optional nature of IA and suggest IA carries a metrical strength that is equal to that of FA, both accents working together in the marking of the lexical word [17].

Recent neuroimaging studies corroborate this idea and underline the role of IA in French word processing. When presenting words with or without IA in an oddball study, Aguilera and colleagues obtained a larger MisMatch Negativity components (MMN) when the oddball had been presented without IA than when the oddball was presented with IA [18]. This not only shows that French listeners heard the accent, and are not deaf to the stress, but also that IA is encoded in long-term memory and part of the expected stress template. Following up on these results, we presented listeners with trisyllabic nouns and pseudowords with or without IA in a lexical decision task [19]. Omitting IA resulted in a processing cost during stress extraction as reflected by a more ample N325 [20] regardless of lexical condition. This demonstrates both the automaticity of stress extraction and an expectation for words to be marked with IA in the pre-lexical stage of speech processing.

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However, in both ERP-studies, words were presented in isolation, with IA always in utterance initial position. Because words had been presented as independent utterances, they may have been processed as individual accentual phrases (AP). Hence, it can not be ruled out that the templates — and the processing cost when IA was omitted— applied to the phrase level instead of the level of the lexical word. In the current study we sought to elucidate this ambiguity and manipulated IA on words positioned within a sentence. Additionally, we manipulated the semantic congruity of the sentences, allowing us to investigate whether IA also affects later processing stages in speech comprehension.

Indeed, in a previous ERP study investigating the relationship between metrical structure and late speech processing in French, metrical violations were found to obstruct semantic processing [21, 22]. In the study, participants listened to sentences in which semantic and/or metrical congruity was manipulated. Semantic congruity was manipulated by presenting sentences in which the last word was incoherent with the semantic context of the sentence, while metrical congruity was manipulated by lengthening the medial syllable of the last word, an illegal stress pattern in French. The metrical violation resulted in an increased N400, even when the sentences were semantically congruent. As the N400 component is thought to reflect a discrepancy to lexico-semantic expectations [23, 24], these results indicate that accentual patterns affect the later stages of speech comprehension, during which access to meaning and semantic integration takes place.

However, as the processing cost resulted from presenting an illegal stress pattern, with metrical weight on the medial syllable, it remains unclear whether semantic processing also suffers when words are presented with metrical structures that deviate from the expected stress pattern. Or put more concretely, if IA is linked to the phonological representation of words and is, along with FA, the expected stress template in French, we anticipate that presenting words without IA also elicits a larger N400.

2. Methods

2.1. Speech stimuli

The same stimuli were used as in [21, 22] and consisted of French carrier sentences ending with either a semantically congruent (+S) or incongruent (−S) trisyllablic target noun (see Figure 1). Congruent and incongruent target words were matched in word frequency, acoustic and phonological characteristics, and word and syllable duration (a more detailed account on the construction of the sentences can be found in [21]).

80 carrier sentences with the most natural IA on the target noun in both semantic conditions were selected. As the fundamental frequency ($f0$) is the phonetic signature of IA [25], we selected only stimuli in the first syllable of the target noun was marked by a $f0$ rise of at least 10% compared to the preceding $f0$ value on the determinant [26, 14].

A customized quadratic algorithm [18] in PRAAT [27] was used to create the accent condition. To remove the natural IA on the target words (−IA condition), the $f0$ value of the first vowel (i.e. IA) was lowered near the $f0$ value of the preceding (unaccented) determinant. The algorithm progressively modified the $f0$ values to reach the $f0$ value at the beginning of the last (accented) vowel. This quadratic transformation allowed for micro-prosodic variations to be maintained, thus keeping the natural sound of the stimuli. The +IA stimuli were forward and back transformed to equalize the speech quality between +IA and −IA stimuli.

The resulting 320 stimuli over the four experimental conditions (+S+IA, −S+IA, +S−IA, and −S−IA) were divided over four lists, such that each participant was presented with 80 unique sentences.

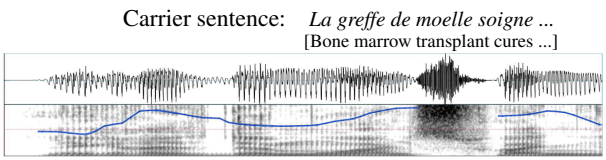
2.2. Participants and procedure

16 French native speakers with foreign language skills at high-school level or less, aged $20 - 47$ (mean age 24.6), originally took part in the study. All subjects were right-handed, with normal hearing abilities and no reported history of neurological or language-related problems. Due to excessive artifacts in the EEG signal, two participants are excluded from analyses.

Each participant was comfortably seated in an electrically shielded and sound attenuated room and presented the stimuli through headphones.

Participants were instructed to judge as quickly and accurately as possible whether a sentence was semantically congruent or incongruent by pressing the left or right arrow key on a standard keyboard (arrow key assignment was counter-balanced across participants). To ensure participants understood the task requirements, the experiment began with a short practice phase, consisting of 10 trials that were similar to the experimental trials, but not included in the analyses.

Each participant listened to all 80 stimuli. Using Latin square designs, the four conditions (+S+IA, −S+IA, +S−IA, and −S−IA) were evenly distributed over two blocks, with block order balanced between participants. Total duration of the experiment, including the set-up of the EEG electrodes, was approximately $1,5$h.



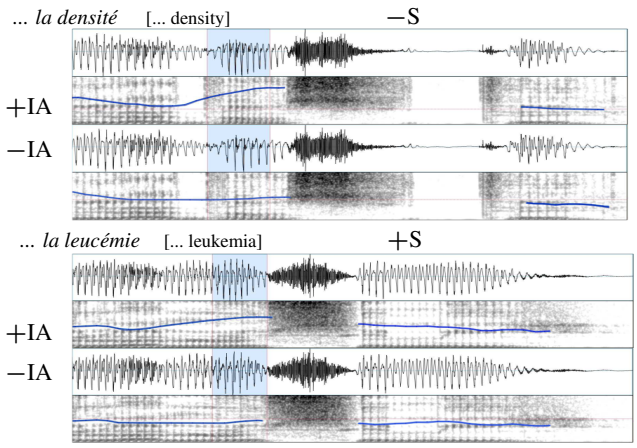


Figure 1: *Example of f 0 resynthesis with (+IA) and without initial accent (IA) on semantically incongruent (S, top two) and semantically congruent (+S, bottom two) sentences with quadratic interpolation from the f 0 value of the preceding determinant to the f 0 value at the beginning of the last stressed syllable for +IA targets (visible in blue).*

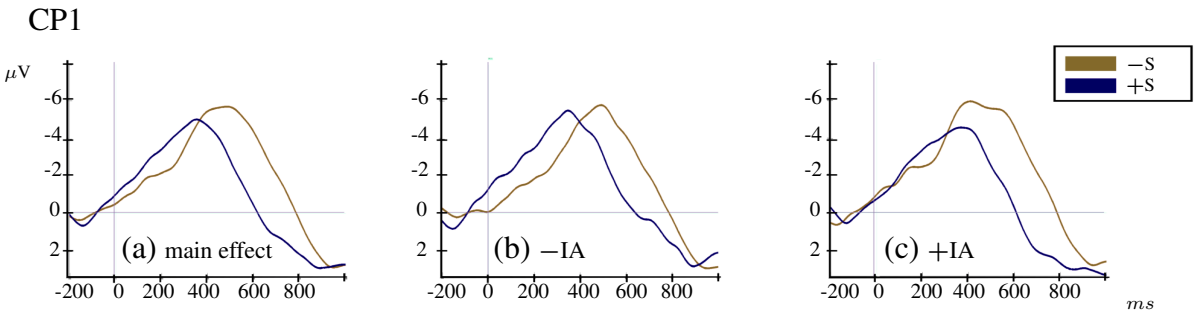


Figure 2: *Grand average N400 in the semantic congruity condition (−S in purple, +S in green), recorded at the CP1 (centro-parietal) electrode for: (a) main effect, (b) −IA, (c) +IA. For ease of presentation, ERP waveforms are filtered at* 10 *Hz.*

2.3. EEG recording and preprocessing

EEG data were recorded with 64 Ag/AgCl-sintered electrodes mounted on an elastic cap and located at standard left and right hemisphere positions over frontal, central, parietal, occipital and temporal areas (International 10/20 System; Jasper, 1958). The EEG signal was amplified by BioSemi amplifiers (ActiveTwo System) and digitized at 2048 Hz.

The data were preprocessed using the EEGLAB package [28] in Matlab [29]. Each electrode was re-referenced offline to the algebraic average of the left and right mastoids. The data were band-pass filtered between $0.01 - 30$ Hz and resampled at 256 Hz. Following a visual inspection, signal containing EMG or other artifacts not related to eye-movements or blinks was manually removed. Independent Components Analysis (ICA) was performed on the remaining data in order to identify and subtract components containing oculomotor artifacts. Finally, data were epoched from -0.2 to 1 seconds surrounding the onset of the target word and averaged within and across participants to obtain the grand-averages for each of the four conditions.

2.4. EEG analysis

The method of EEG is well known for its temporal precision and thus aptly suited to track down online processes. However, the high temporal resolution comes at the cost of many comparisons when ERP amplitude values for each individual electrode, at each recorded time-point, are tested independently, using standard parametric statistics (e.g. ANOVA or t-test). Because EEG measures are not independent, but instead temporally and spatially correlated, we use a non-parametric $t_{\max}$ permutation test to analyze the data [30, 31].

Since N400 amplitude modulations resulting from semantic incongruities are typically maximal in the centro-parietal region of the brain [24, 23], we selected the central and parietal electrodes to test for an effect on semantic processing. The effect of metrical expectancy violations on speech comprehension is typically found in temporal, central and frontal brain areas [20, 19]. Therefore, the effect of metrical expectancy was tested on the temporal and centro-frontal electrodes. To further reduce the number of comparisons and maximize statistical power, a time-window of $350 - 550$ ms surrounding the N400 was selected and data were down-sampled to 128 Hz.

3. Results

Behavioral data (error rates and reaction times) were analyzed with paired two-tailed t-tests in R [32]. Overall, performance on the semantic congruency task revealed high accuracy ($< 5\%$ errors) with no differences between conditions. Reaction times showed a main effect of semantic congruity ($t = -3.09$, $p < 0.05$); congruent sentences were responded to faster than incongruent sentences. Presence of IA had no effect on response latencies ($p = 0.8$, ns).

ERP data show a main effect of semantic congruity (critical t-score: ± 4.6322, $p < 0.05$; Figure 2a): semantically incongruent sentences elicited a larger N400 at 500 ms after the onset of the target word than semantically congruent sentences in the left centro-parietal region (CP1). This difference in N400 amplitude was also significant within the condition without IA (critical t-score: ± 3.575, $p < 0.05$; Figure 2b) and marginally significant within the condition with IA (critical t-score: ± 3.575, $p = 0.056$; Figure 2c).

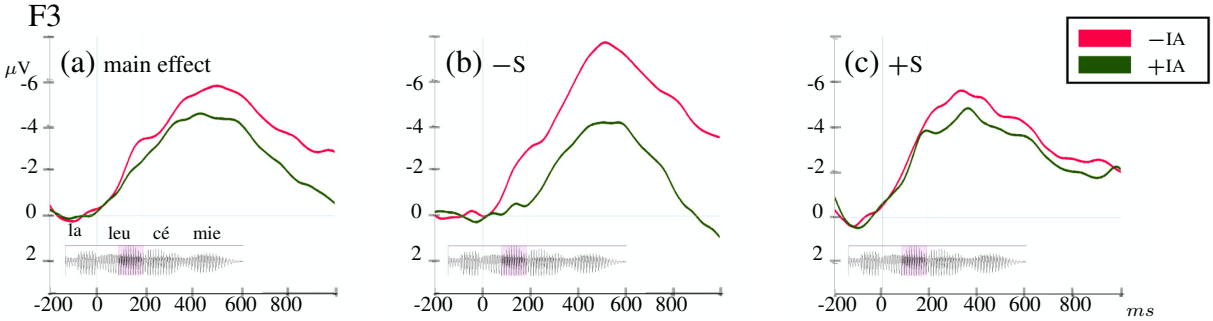


Figure 3: *Grand average N400 in the IA condition (−IA in blue, +IA in pink), recorded at the F3 (fronto-central) electrode for: (a) main effect, (b) incongruent sentences, (c) congruent sentences. For ease of presentation, ERP waveforms are filtered at* 10 *Hz.*

Furthermore, visual inspection suggested a difference in N400 onset latency between semantically congruent and incongruent sentences, but only in the −IA condition. Because this visual effect is important for the discussion of the additional semantic processing cost when words are presented −IA, we computed a t-test specifically focused on differences in peak latencies at CP1. Results show that the N400 onset was significantly delayed when sentences were incongruent compared to when they were congruent ($t = -3.09$, $p < 0.05$).

Finally, while the main effect of ± IA did not reach significance ($p = 0.24$, ns; Figure 3a), we did find a significant interaction effect between semantic congruity and ±IA in the left frontocentral regions (F3): the N400 was significantly bigger in −IA condition than in the +IA condition for semantically incongruent sentences 429 ms after target word onset (critical t-score: ± 4.1932, $p < 0.05$; Figure 3b). The difference between ±IA was considerably smaller, and not significant ($p = 0.26$, ns; Figure 3c), when sentences were semantically congruent.

4. Discussion

In the present study, we examined the phonological status of the French initial accent and its role in semantic processing. We were particularly interested in modulations of the N400 ERP component, a component typically observed subsequent to violations in lexico-semantic expectations [24]. Below, we will discuss each of our results in turn: in (4.1) we inspect whether metrical expectancy affected lexico-semantic processing, in (4.2) we discuss the effect of metrical expectation on speech processing and in (4.3) we revisit the role of IA as secondary boundary marker of the AP.

4.1. Semantic congruity effect

As expected, we found a main effect of semantic congruity in centro-parietal regions (*cf.* Figure 2): semantically incongruent sentences elicited a more ample N400 than did semantically congruent sentences. This effect was also significant within the −IA condition and marginally significant within the +IA condition. Interestingly, close inspection of the ERP waveforms revealed an additional delay in N400 onset latency when semantically incongruent words had been presented without initial accent. This indicates an interaction effect such that when words are presented without IA, semantic conflict resolution starts later. Furthermore, because there was no delay in semantic resolution processes when words were presented +IA, but only an amplitude difference typical to the semantic N400, listeners appeared to expect words to be marked with IA, i.e. IA is phonologically natural.

4.2. Metrical expectancy effect

Our results in the fronto-central brain area partially confirm the phonological status of IA (*cf.* Figure 3): When sentences were semantically incongruent, words −IA elicited a larger N400 than did words +IA. Surprisingly, however, ± IA did not affect speech processing when sentences were semantically congruent. It is possible listeners only appealed to their preferred stress patterns when facing difficulties in the later stages of speech processing, however we consider it more probable the effect did not surface due to low statistical power.

The results presented here are preliminary, because, to this date, we collected data on only 14 participants, each answering to 20 sentences per condition. Moreover, we used a conservative permutation statistic that maximally avoids false discoveries, but may have instead given rise to an effect remaining undetected.

Another indication our statistics may have lacked in sensitivity is demonstrated by the marginally significant effect between semantically congruent and incongruent sentences when words were presented with initial accent. As previously stated, semantic congruency is abundantly found to influence N400 amplitudes, and in fact did so in our study when words were presented −IA. Arguably, the double processing cost when both semantic and metrical information was unexpected led to an effect that was big enough to be detected by our analysis, while the effect was less apparent when only was of the two conditions was unexpected. The N400 modulations resulting from our ± IA conditions confirm this theory. Whereas the effect was highly significant when sentences were semantically incongruent (and thus unexpected), when the sentences were congruent, the difference was much smaller. Still finding a significant interaction between stress patterns and lexico-semantic processing demonstrates that French accentuation is involved in this later stage of speech comprehension.

4.3. The initial accent as a lexical boundary marker

The interactions reported above have another important implication. As discussed in the introduction, previous ERP studies investigating the phonological status of IA, while demonstrating a phonological expectancy for IA, had not been able to distinguish between lexical and phrasal processing. In the current study IA was not utterance initial but embedded in a sentence. Also, we manipulated the semantic congruency of the sentences, allowing us to investigate whether stress patterns affect lexico-semantic processes as reflected by the N400. We found metrical expectancy to modulate the N400 both in the centro-parial and in the centro-frontal brain regions. That is, when asking listeners to judge the semantic congruity of sentences that differed only in ± IA, lexico-semantic processing (as reflected by the N400) was still affected. This result not only indicates IA to play a valuable role in lexico-semantic processes, but also demonstrates that French speech comprehension *naturally* and *automatically* engages lexical stress processing.

5. Conclusions

In this study, we investigated the status of the French initial accent and its function in lexico-semantic processing. While our ERP results at the centro-parietal sites are still somewhat ambiguous, the data obtained at the frontal regions more clearly show an interaction between metrical and lexico-semantic processing. Previous studies had shown a disruption in pre-lexical stress processing when IA had been omitted. As pre-lexical stress templates serve to access the mental lexicon, presenting words without IA in turn hinders lexical access and cascades up the process of speech comprehension to affect lexico-semantic processing. In sum, the study demonstrates that French listeners expect words to be marked with the initial accent, and actively, though automatically, make use of the accent throughout the process of speech comprehension.

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