Disentangling perceptual and linguistic factors in parsing

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Abstract

We offer a re-evaluation of the tone-monitoring technique in the study of parsing. Experiment 1 shows that reaction times (RTs) to tones are affected by two factors: a) processing load, resulting in a tendency for RTs to decrease across a sentence, and b) a perceptual effect which adds to this tendency and moreover plays a role in neutralising differences between sentence types. Experiment 2 successfully discriminates these two factors by registering event-related brain potentials during a monitoring task, establishing that the amplitudes of the N1 and P3 components —the first associated with temporal uncertainty, the second with processing load— correlate with RTs. Experiment 3 then behaviourally segregates the two factors by placing the last tone at the end of sentences, activating a wrap-up operation and thereby both disrupting the decreasing tendency and highlighting structural factors.

Keywords: Tone monitoring; Processing load; ERPs; Position effect.

Introduction

Monitoring tasks have long been employed in psycholinguistics, and the end-of-clause effect is possibly the better-known result in the study of parsing. According to Abrams and Bever (1969), the end of a clause exerts a particular cognitive load in the parser: reaction times (RTs) to tones are higher when placed at the end of the first clause of biclausal sentences than in between clauses or at the beginning of the second clause. Other structural effects have been reported in complex sentences with this technique, such as differences in processing load between subject and object relative clauses (Cohen & Mehler, 1996).

In this paper, we track the processing load of parsing monoclausal sentences carefully and show that the issues are rather nuanced. In particular, we show that the RTs of a tone-monitoring task are affected by the additive effects of perceptual and psycholinguistic factors, and this has gone unnoticed until now. Interestingly, perceptual and psycholinguistic factors can be both successfully discriminated by registering event-related brain potentials (ERPs) during a monitoring task and behaviourally segregated by placing the last tone at the end of sentences, where a wrap-up operation presumably takes place. Perceptual factors are rather strong in monitoring tasks and they appear to have been operative in past studies too, which now need to be reconsidered.

Experiment 1

Monoclausal, subject-verb-object Spanish sentences were constructed. Starting from a matrix *proposition*, two different types of sentences were created: *type A* sentences exhibited a complex subject but a simple object, and the reverse was the case for *type B* sentences. By a complex subject or object we mean a noun phrase which is modified by another noun phrase, whilst a simple subject or object is composed of a determiner and a noun only. Three tone positions were determined to probe the processing load of the parser, both within a sentence and between sentence types. The materials of Experiment 1 are shown below, where the | symbol identifies the boundaries under study:

Type A: El candidato | del partido | se preparó | el próximo discurso.
'The party's candidate prepared his next speech'.

Type B: El candidato | ha preparado | un discurso | sobre la sanidad.
'The candidate has prepared a speech about the health service'.

We chose to focus on two central operations of parsing — phrase completion and clausal integration— and hypothesised that a) the *tone position* and *sentence type* factors would each be significant, and b) there would be an interaction between them. This general hypothesis yields a number of more specific predictions. In the first position, the parser has processed the same material in type A and type B sentences, identifying the noun phrase *the candidate* as the subject of the sentence, following the canonical subject-verb-object(s) order in Spanish, and thereby predicting the appearance of the verb. Thus, the cognitive load should be equal and the RTs similar. In the second position, the verb prediction is borne out in type B sentences and the parser successfully completes the subject noun phrase, whereas in type A sentences the parser is processing a longer subject noun phrase and the verb prediction is still active. Moreover, in type B sentences the parser has integrated the verb and the subject noun phrase and now expects an object noun phrase, whilst in type A sentences the parser is yet to conduct any integration. In this case, the processing load should be greater in type A sentences and RTs higher to those of type B sentences, given the central role of the verb in a sentence. Finally, in the third position the parser has integrated subject and verb in type A sentences and now predicts an object noun phrase, whereas in type B sentences the parser has successfully integrated part of the object noun phrase. In this case too type A sentences should involve more processing load and therefore higher RTs at this position.

Method

Participants. 80 psychology students participated for course credit. The mean age was 20 years, and participants had no known hearing impairments.

Materials. Two variants of monoclausal, active, declarative, subject-verb-object Spanish sentences were constructed from 60 matrix *propositions*. Type A sentences exhibited an [NP-[PP-NP]-[VP-NP]] pattern whereas type B sentences manifested a [NP-[VP-NP-[PP-NP]]] form —these are the structural conditions of the experiment. All sentences were unambiguous and composed of high- or very high-frequency words. Three tone positions per sentence were established, the three positional conditions of the experiment (1-2-3). Tones were placed on the vowel of the second syllable following the relevant boundary, had a frequency of 1000 Hz, a duration of 25 ms., and a peak amplitude equal to that of the most intense sound of the materials (80 dBs). Every sentence had one tone only.

Procedure. The design of the experiment was a 2 (sentence type factor) by 3 (tone position factor) within-subjects, within-items factorial, and therefore six lists of the task were created. The sentences were presented over the headphones binaurally and participants were instructed to hold a keypad with their dominant hand in order to press a button as soon as they heard the tone. They were told to be as quick as possible, but to avoid guessing. Once a sentence had finished, the next sentence would be presented upon pressing the space bar, giving subjects control over the rate of presentation.

Results

Reaction times were collected and trimmed with the DMDX programme. A response that occurred before the tone or 3 seconds after the tone was not recorded at all, while responses deviating 2.0 SDs above or below the mean of each participant were eliminated (this affected 4.3% of the data). Table 1 collates the RTs per condition.

Table 1: Experiment 1. RTs per tone position per sentence.

	Tone Position		
Sentence Type	1	2	3
A	257.22	222.51	206.78
B	252.40	217.33	205.26

As shown in Table 1, RTs are greater in Position 1 and decrease thereon for each sentence type. A repeated-measures analysis of variance showed that the *tone position factor* was significant for both the subjects and items analyses ($F_1(2,158) = 144$, $p < .001$, $n_p^2 = 0.647$; $F_2(2,118) = 295$, $p < .001$, $n_p^2 = 0.834$), while the *sentence type factor* was only significant for the subjects analysis ($F_1(1,79) = 4.66$, $p < .05$, $n_p^2 = 0.056$; $F_2(1,59) = 2.48$, n.s.). There was no interaction between the two experimental factors (all $Fs < 1$). Pair comparisons between the three positions of the *tone position factor* show that the differences in RTs among the three positions were significant (all $ps < .01$).

Discussion

The results show a clear decreasing tendency in RTs, and whilst the two experimental factors were significant in the subjects analysis, this was not the case in the items analysis, where only the *tone position factor* was significant. Moreover, there was no interaction between the two factors. Thus, not all of our predictions were confirmed. The decreasing progression is rather robust, and the high significance of the (tone) position factor is further confirmation. This would be in line with the general expectation that processing load decreases as a sentence is presented, which follows from the incremental nature of parsing; in this case, the least linguistic material to process, the easier it will be to respond to the tone. However, the fact that there was no interaction between the two factors is surprising, as tone monitoring was expected to be sensitive to structural features. Each tone was placed in a different segment in each sentence type, and thus the parser, except for the first tone position, cannot be computing the same predictions at each position —i.e., the processing load cannot be the same. This ought to be especially significant when it comes to integrating nouns and verbs during the course of a sentence, but as the data show the earlier or later appearance of the verb and whether noun phrases were simple or complex do not appear to have had an effect. It is worth restating that tones were placed a syllable after the main boundary, but this very short sound (/de/ or /a/, in one case) would not be enough to predict the precise nature of the new phrase in the absence of further material (prepositional, verb, etc.), as various continuations are possible; this extra syllable would only indicate that the previous phrase had finished and needs to be completed, which is precisely what we were aiming to track in the experiment.

The decreasing tendency can be observed in Abrams and Bever (1969) too (and in other past studies). These authors established three positions in sentences such as *since she was free that* | *day* | *her* | *friends asked her to come* (i.e., *before* the main clause break, *in* the clause break, and right *after* the clause break, all marked with |), and the RTs they obtained certainly exhibit a decrease: 243 ms., 230 and 216. Relatedly, Cutler and Norris (1979) report that monitoring tasks in general exhibit a tendency of RTs to decrease across a sentence, and this needs to be taken into consideration. Crucially, the results reported in Abrams and Bever (1969) cannot be wholly explained in terms of processing load as they used biclausal, complex sentences and the course of incremental parsing in that study ought to have been different to what we obtained here.

Thus, we postulate that there is a perceptual factor at play in monitoring tasks; roughly stated, the later the tone appears, the more prepared the participants are to respond to it. If this is the case, there would be two types of uncertainties to track in monitoring tasks: one linguistic, stemming from incrementality (viz., what linguistic material is it left to process?), and the other perceptual (viz., when will the tone appear?), which we shall call the *position* effect. As such, the results of our experiment —a decrease in RTs and no interaction between factors— would be the product of the additive effects of perceptual and psycholinguistic factors. If this conjecture is correct, then the greater RTs in the first tone position in Abrams and Bever (1969) may not have been due to an end-of-clause effect, but the result of the combination of perceptual and psycholinguistic factors. Indeed, given that past studies did not consider this perceptual factor and thus did not control for tone position, we are unsure as to whether the end-of-clause effect is well supported. That being so, the results reported in Cohen and Mehler (1996) are at first sight structural rather than perceptual, and as such tone monitoring must be sensitive to both factors (our own results yielded clear structural factors too). In order to delve deeper into this issue, we can combine tone monitoring with the recording of ERPs, which will allow us to track two different ERP components, one related to processing load (and linguistic uncertainty), the other to the position effect (and temporal uncertainty). If there is a correlation between these ERP waves and RTs, our analysis would be confirmed.

Experiment 2

Only type A sentences from the previous experiment were employed, as there was no need to use both sentence types; the tone positions, however, remained the same. We concentrated on two ERP components, yielding two broad predictions. It was hypothesised that the N1 wave, a component associated with temporal uncertainty (Näätänen & Picton, 1987), would correlate with the RTs, and thus its amplitude would be highest at the first tone position, the perceptual uncertainty of the participants being greatest at that point, and decrease thereon. This part of the experiment aimed to evaluate the significance of the position effect, and the N1 is a pertinent component for such a task, given that it tracks perceptual processes rather than (higher) cognitive ones.

The second component is the P3, a component whose amplitude to a secondary task has been shown to be affected by the difficulty of the primary task in dual-task settings such as ours. Past results with dual-task experiments (e.g., Wickens, Kramer, Vanasse, & Donchin, 1983) indicate that the P3 associated with a secondary task (in this case, reacting to the tone) will have a low amplitude if the primary task (here, parsing the sentence) is of considerable difficulty. In other words, there ought to be a correlation between the fluctuations in difficulty in a primary task and the amplitude of the P3 to a secondary task. In our experiment, as the primary task decreases in difficulty (as manifested by the linear decrease in RTs from the first to the third position), the amplitude of the P3 was predicted to increase from position 1 onwards.

Crucially for our purposes, the biphasic pattern we are hypothesising is well established in the dual tasks literature. Wickens et al. (1983) report an N1-P3 pattern when an auditory probe is employed, and this is precisely what we are after: an N1 wave tracking perceptual processes and a P3 component tracking cognitive processes. In particular, we expect to obtain an N1 wave with a frontal distribution and a P3 with a more posterior-paretial distribution, thus singling out two independent components and confirming the processes that interest us. If these two waves turn out to be present in the data, and their amplitudes go in the direction we are postulating, we would have clear evidence for the two factors we have postulated. To our knowledge, moreover, this is the first time that the P3 is employed in a study of parsing as a metric of processing load, and we hope our results constitute evidence for its general usefulness. Naturally, these two hypotheses hold if and only if the pattern in RTs obtained in the previous experiment does not vary, and we hypothesised that this would be the case indeed.

Method

Participants. 18 psychology students participated in the experiment. The mean age was 22 years, and subjects had no known hearing impairments.

Materials. The same as type A sentences from the previous experiment, but these now numbered 120 items.

Procedure. Participants were exposed to a total of 120 items, presented in three blocks. Apart from the electroencephalography (EEG) measures that were undertaken and the greater number of items, the task remained the same as in the previous experiment. The EEG was recorded continuously by 19 Ag/AgCl electrodes which were fixed on the scalp by means of an elastic cap (Electrocap International, USA) positioned in accordance with the 10-20 International system. ERPs were algebraically re-referenced to linked earlobes offline. Electrode impedances were kept below 5 $k\Omega$. All EEG and EOG channels were amplified using a NuAmps Amplifier (Neuroscan Inc., USA) and recorded continuously with a bandpass from 0.01 to 30 Hz and digitised with a 2 ms. resolution. The EEG was refiltered off-line with a 25-Hz, low-pass, zero-phase shift digital filter. Automatic and manual rejections were carried out to exclude periods containing movement or technical artefacts (the automatic EOG rejection criterion was $\pm 50\ \mu$V).

Results

Behavioural Data

The reaction times of the 18 participants were collected and trimmed with the DMDX programme. As before, responses deviating 2.0 SDs above or below the mean of each participant were eliminated, which in this case affected 3.6% of the data. The data are presented in Table 2.

As expected, the RTs manifest the exact same pattern as in Experiment 1: reaction times decrease from the first position onwards. A repeated-measures analysis of variance showed that the *tone position factor* was significant for both the subjects and items analyses ($F_1(2,34) = 39$, $p < .001$, $n_p^2 = 0.698$; $F_2(2,238) = 93$, $p < .001$, $n_p^2 = 0.441$). Regarding pair comparisons between the different tone positions (1

Table 2: RTs per tone position.

Tone Position		
1	2	3
325.05	266.53	247.60

vs. 2, etc.), the analyses showed that all comparisons were significant (all *ps* $< .01$).

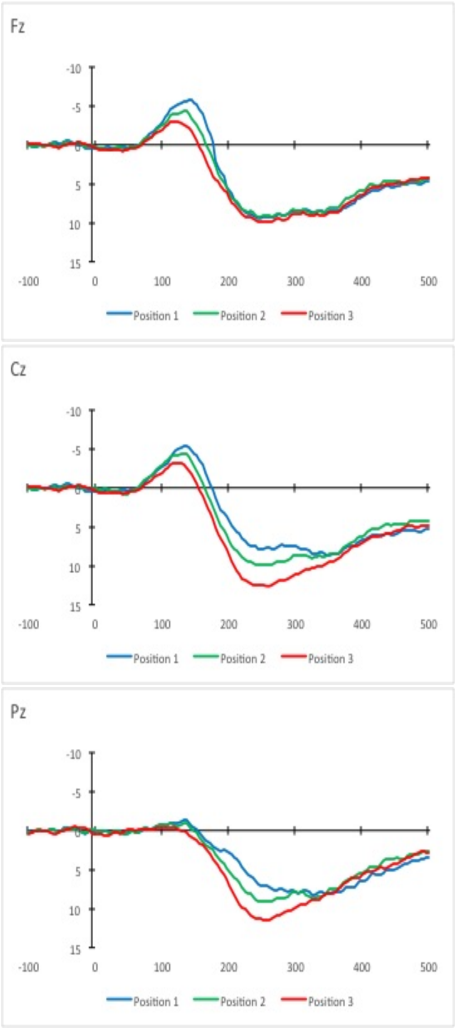
Electrophysiological data

The data were processed using BrainVision Analyzer 2 (Brain Products, Gilching, Germany). Average ERPs were calculated per condition and per participant from -100 to 500 ms. relative to the onset of the tone, and before grand-averages were computed over all participants. A 100 ms. pre-tone period was used as the baseline. Only trials without muscle artefact or eye movement/blink activity were included in the averaging process. The analyses were based on 15 channels divided into five separate parasagittal columns along the anteroposterior axis of the head. The columnar approach to analysing the ERP data provides both an anterior-to-posterior as well as a left/right comparison of ERP effects. The electrodes in each of two pairs of lateral columns (Inner Column: F3/F4, C3/C4, P3/P4; Outer column: F7/F8, T3/T4, T5/T6) and on the Midline Column (Fz, Cz, Pz) were analysed with three separate ANOVAs. The analysis of the midline column included the position factor (position 1 vs. position 2 vs. position 3) and the location factor with three levels (Fz vs. Cz vs. Pz). The analyses of the two pairs of lateral columns involved repeated measures ANOVAs with within-participants factors Position (position 1 vs. position 2 vs. position 3) and Location (anterior, central, and posterior). Omnibus ANOVAS were followed up with pairwise comparisons intended to discern whether there were differences among the three tone positions. All post-hoc analyses were Bonferroni corrected. Based on prior reports, two time windows were selected for analysis of the mean amplitudes of the components of interest: the N1 component was analysed from 120 ms. to 200 ms., and the P300 component was evaluated from 230 ms. to 400 ms. In order to not clutter the presentation of our results, we only report the main effect of the Tone Position factor and the significant interaction effects.

Fig. 1 depicts brain potential variations in the three midline electrodes included in the analyses. As can be observed, the three tone positions exhibit a clear biphasic pattern, with a first modulation in the N1 time window in frontal and central electrodes, followed by a second modulation in the P300 time window in the central and posterior electrodes.

N1 epoch (120-200 ms). During the N1 epoch, there was a main effect of Position in the Midline, Inner, and Outer columns. Bonferroni corrected pairwise comparisons showed that all three positions differ from each other significantly in the three columns (all *ps* $< .05$), reflecting a more negative-going amplitude for position 1 relative to position 2, and a more negative-going amplitude for position 2 relative to position 3. There was also a significant interaction between Position and Location in the Midline, Inner, and Outer columns (all *ps* $< .05$). In the Midline and Inner columns, post-hoc comparisons revealed that whereas in frontal and central electrodes position 1 was more negative relative to position 2, and position 2 more negative relative to position 3 (all *ps* $< .05$), there were no differences in the posterior electrodes (all *ps* $> .20$). In the Outer column, post-hoc comparisons revealed that whereas in frontal electrodes position 1 was more negative than position 2, and position 2 more negative than position 3 (all *ps* $< .05$), there were no differences in central and posterior electrodes (all *ps* $> .52$).

Figure 1: ERP waveforms for the three tone positions shown from a 100 ms. before tone presentation to a 500 ms. post-tone presentation. The waveforms depict brain potential variations in the three midline electrodes included in the analyses. Negative voltage is plotted up.



P300 epoch (230-400 ms). During the P300 epoch, there was a main effect of Position in the Midline, Inner, and Outer Columns. Bonferroni corrected pairwise comparisons in the three columns showed all three positions to differ from each other significantly (all $ps < .05$), reflecting a more positive-going amplitude for position 3 relative to position 2, and a more positive-going amplitude for position 2 relative to position 1. There was also a significant interaction between Position and Location in the Midline, Inner, and Outer columns (all $ps < .05$). In all three columns, post-hoc comparisons revealed that whereas in central and posterior electrodes position 3 was more positive relative to position 2, and position 2 more positive relative to position 1 (all $ps < .05$), there were no differences in the frontal electrode (all $ps > .11$).

Discussion

As the behavioural data show, the prediction regarding the RTs pattern was confirmed; that is, RTs to the first tone are slowest, and then become faster thereon. This allows us to discuss the ERP data in the terms we had devised. The ERP data confirm the hypothesised topographical distributions and amplitudes for the N1 and P3 waves we expected. The N1 pattern indicates that participants are indeed uncertain as to when the tone is going to appear, and their uncertainty decreases as the sentence unfolds. We stated in the previous section that the linear decrease in RTs must be due to a combination of two factors and the N1 data confirm that there is indeed a purely perceptual factor at play, what we called earlier the position effect. Regarding the P3, its pattern can be explained in terms of processing load. As the amplitude of the P3 increases from position 1 onwards, and there is furthermore a negative correlation between RTs and the amplitude of the P3, this confirms that as the sentence is being processed the parser's unfulfilled predictions decrease, and thereby more resources can be allocated to monitoring the tone.

The biphasic pattern we have recorded confirms our analysis. First, the correlation between the amplitude of the N1 wave and tone position confirms that there is a strong perceptual factor and that it has an effect on performance. Second, the correlation between the amplitude of the P3 and tone position confirms two interrelated points: a) that tone monitoring is a dual task in which sentence processing is the primary task and tone monitoring the secondary; and, consequently, b) that the fluctuations in processing load are in part due to the decreasing uncertainty the parser experiences, thus dismissing alternative explanations in terms of response strategies, guessing the position of the tone, etc. All in all, we have succeeded in discriminating —that is, recording— the two factors we had posited. In the next experiment we shall show how they can in addition be behaviourally segregated.

Experiment 3

In the previous experiments we did not examine the end-of-clause effect directly, as we used monoclausal instead of biclausal sentences and moreover none of the tones were placed at the end of the sentences. In this experiment, we change the tone positions of type B sentences from Experiment 1 to probe if by placing a tone at the end of a sentence the strong tendency for RTs to decrease is disrupted. The end of sentences is the locus of a wrap-up operation, which need not be the same as an end-of-clause effect; the wrap-up would involve operations that would not apply at the end of clauses (e.g., closing off *all* syntactic phrases, completing the sentence's semantic representation, etc.). We only used type B sentences because a) no across-sentence-type comparisons were relevant, and b) type B sentences exhibit a complex noun phrase in the object position, and this is a better configuration for our purposes.

Three tone positions are maintained, but their locations were changed: one at the beginning of the sentence and two within the verb's complex object, shown in the next section. It was hypothesised that the wrap-up effect would be indeed applicable at the end of a sentence and therefore that the pattern in RTs should be different from the pattern observed in the previous experiments. In particular, we expected a V-shape pattern in which RTs to the first position were highest, descending significantly for the second position, but then raising for the third and last position, the postulated locus of the wrap-up.

Method

Participants. 37 psychology students participated in the experiment for course credit. The mean age was 22 years, and none of the subjects had any known hearing impairments.

Materials. Type B sentences from Experiment 1 were employed. The tone positions were modified to evaluate the wrap-up effect, as shown in the sentence below (where | marks tone position). 60 fillers were also employed. In all other respects, the task did not change.

(1) El candi|dato ha preparado un di|scurso sobre la sani|dad.

Procedure. The same as in Experiment 1.

Results

The reaction times of the 37 participants were collected and trimmed with the DMDX programme. Responses deviating 2.0 SDs from the mean of each participant were eliminated, affecting 3.8% of the data. Table 3 presents the final data.

Table 3: RTs per tone position.

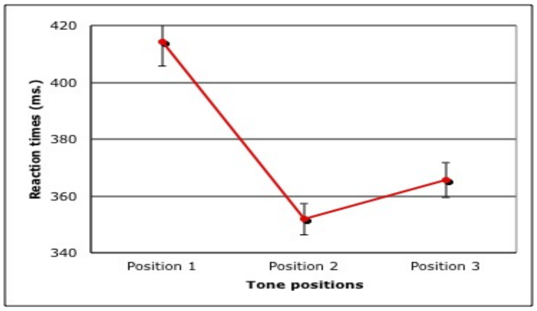
Tone Position		
1	2	3
414.16	351.88	365.45

In this experiment, RTs were greatest in the first position, and there was a slight increase from the second to the third position. A repeated-measures analysis of variance showed that the *tone position factor* was significant for both the subjects and items analyses ($F_1(2,72) = 98$, $p < .001$; $F_2(2,118) = 110$, $p < .001$). All post-hoc pairwise comparisons proved to be significant (all $ps < .001$).

Discussion

As predicted, the wrap-up effect was detectable with the tone-monitoring task, thereby disrupting the linear decrease in RTs, as can be seen in Fig. 2.

Figure 2: RTs progression in Experiment 3



Indeed, even though RTs to the first position were greatest and there was a noticeable decrease from the first to the second position, the processing load associated with the wrap-up effect resulted in an increase in RTs from the second to the third position, in clear contrast with what was obtained in the previous experiments, and resulting in the V-shape pattern observed in Fig. 2. This would seem to indicate that tone monitoring is not entirely hostage to perceptual factors such as the position effect; a design can be found so that structural properties are brought out more clearly, resulting in the clear segregation of the two factors that have animated the whole discussion. This is behavioural confirmation of what was observed on the ERP record, vindicating the usefulness of tone monitoring as a psycholinguistic technique.

Whether the wrap-up operation can be related to the end-of-clause effect apparently unearthed in previous studies is not so clear. In those studies, and as already stated, the end of a clause was in fact the end of a subordinate clause within complex, biclausal sentences, and that introduces a specific level of complication. Moreover, the end-of-clause position was also the first tone position in those studies, pointing to the probable impact of the position effect.

Conclusion

We have here reported three main results with the tone-monitoring technique: a) a pronounced decrease in RTs for each sentence type (Experiments 1 and 2), which suggests that the parser's processing load decreases as the sentence is presented, thus releasing more cognitive resources to monitor the tone in so doing, in accordance with well-known properties of parsing (viz., incrementality); b) no interaction between the *tone position* and *sentence type* factors (Experiment 1), the potential result, in part, of what we have called here the position effect; and c) perceptual and psycholinguistic factors can be separately observed in an ERP recording (Experiment 2) and behaviourally segregated in a carefully designed experiment (Experiment 3).

The position effect, in particular, seems to have gone entirely unnoticed in all previous tone-monitoring studies. Abrams and Bever (1969) explained their data solely in terms of what they called the end-of-clause effect, but the two factors we have analysed here seem to be operative in their study too, and that muddies their data significantly. That is, even though these scholars placed a tone at the end of a clause, this tone position constituted the first of a decreasing tendency in a series of three tones, and thus the higher RTs to this (first) position may not have been the sole result of structural factors. There is, therefore, a very possible confusion and conflation between perceptual and psycholinguistic factors in their data, and this merits a closer look.

The two main factors we have identified here —the position effect and processing load— conspire to yield the RTs that can be obtained with the tone monitoring technique, and as a result future experiments employing this technique, we advise, will need to take this contingency into consideration. In our study we have shown that the two factors can be certainly separated, especially when one sets out to do so, but the combination of these factors may hide or obscure structural effects in tone monitoring tasks, requiring a more focused design if structural effects constitute the focus point.

Acknowledgments

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