Activating without Inhibiting: Left-edge Boundary Tones and Syntactic Processing

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Abstract

■ Right-edge boundary tones have earlier been found to restrict syntactic processing by closing a clause for further integration of incoming words. The role of left-edge intonation, however, has received little attention to date. We show that Swedish left-edge boundary tones selectively facilitate the on-line processing of main clauses, the syntactic structure they are associated with. In spoken Swedish, main clauses are produced with a left-edge boundary tone, which is absent in subordinate clauses. Main and subordinate clauses are further distinguished syntactically by word order when containing sentence adverbs. The effects of tone and word order on the processing of embedded main, subordinate, and neutral clauses (lacking sentence adverbs) were measured using ERPs. A posterior P600 in embedded main clauses and a smaller P600 in subordinate clauses indicated that embedded clauses with sentence adverbs were structurally less expected than neutral clauses and thus were reanalyzed. The tone functioned as a cue for main clause word order, selectively reducing the P600 in embedded main clauses, without affecting the processing of subordinate or neutral clauses. Its perception was reflected in a right frontal P200 effect. The left-edge boundary tone thus seems to activate a main clause structure, albeit without suppressing alternative structures. The P600 was also preceded by a short positive effect in cases where a left-edge boundary tone was absent. ■

INTRODUCTION

In the rapid on-line processing of speech, prosodic cues associated with the ends of intonation phrases have repeatedly been observed to constrain the syntactic interpretation of clauses (Kjelgaard & Speer, 1999; Steinhauer, Alter, & Friederici, 1999; Speer, Kjelgaard, & Dobroth, 1996; Warren & Nolan, 1995), even at the earliest processing stages (Eckstein & Friederici, 2006). However, the effects of prosodic cues associated with the beginning of phrases have received less attention to date. Swedish is well suited for investigating the influence of phrase-initial prosody on syntactic processing because a "left-edge boundary tone" is associated with one particular syntactic structure, that is, main clauses (Roll, Horne, & Lindgren, 2009; Roll, 2006). The goal of the present study is to gain further understanding of the prosody–syntax interface by examining the interaction between left-edge intonation and word order in the processing of different clause types in Swedish.

Effects of Right-edge Prosody on Syntactic Processing

Boundary tones, focus, and prefinal lengthening associated with the right edge of intonation phrases can both guide and mislead syntactic processing (Eckstein & Friederici, 2005, 2006; Kjelgaard & Speer, 1999; Steinhauer et al., 1999; Speer et al., 1996; Warren & Nolan, 1995). Steinhauer et al. (1999) tested the effects of prosodic phrasing on temporarily ambiguous sentences in German using ERPs. In a sentence starting with *Peter verspricht Anna*… "Peter promises Anna…," the name *Anna* might be interpreted as an argument of the main clause, referring to the person receiving the promise, as in *Peter verspricht Anna zu arbeiten* "Peter promises Anna to work." However, because objects in German precede nonfinite verbs, *Anna* may also be the object of an upcoming nonfinite clause, as in *Peter verspricht* [*Anna zu entlasten*] "Peter promises to help Anna." A prosodic boundary after *verspricht* "promises" induces closure of the first clause, *Peter verspricht*, constraining the interpretation of *Anna* to being the object of the upcoming verb. If the next verb is *zu arbeiten* "to work," as in **Peter verspricht* ‖ *Anna zu arbeiten*,[1] the immediate interpretation is "Peter promises to work Anna." In the ERPs, *zu arbeiten* "to work" produced an increased N400 followed by a P600 effect when a phrase boundary preceded the name, which Steinhauer et al. argued reflected difficulties in lexical integration of the verb (N400) followed by structural revision (P600). Thus, the presence of cues associated with the right edge of a prosodic phrase in Steinhauer et al. prevented inclusion of the second name (*Anna*) within the first clause.

The P600 is a positive deflection in the ERPs peaking around 600 msec after the onset of syntactically unexpected stimuli (Hagoort, Brown, & Groothusen, 1993; Osterhout & Holcomb, 1992, 1993; Neville, Nicol, Barss, Foster, & Garrett, 1991). P600 effects have been found for noncanonical

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word order in both Swedish and German (Roll, Horne, & Lindgren, 2007; Bornkessel, Schlesewsky, & Friederici, 2002b; Rösler, Pechmann, Streb, Röder, & Hennighausen, 1998). The positive deflection has usually been assumed to reflect syntactic integration cost or reanalysis of the syntactic structure. However, late positive effects have also been attributed to nonsyntactic factors such as unexpected thematic role assignment (van Herten, Kolk, & Chwilla, 2005; Hoeks, Stowe, & Doedens, 2004; Bornkessel, Schlesewsky, & Friederici, 2002a) and even prosodic features incongruent with the expected syntactic structure (Eckstein & Friederici, 2005, 2006). Eckstein and Friederici (2005) found a P600 effect in the absence of right-edge boundary tones and prefinal lengthening associated with the last word of sentences. Likewise, Astésano, Besson, and Alter (2004) reported a posterior positivity similar to the P600, peaking at 800 msec following the point where question intonation had been cross-spliced with statement intonation and vice versa. In view of the variety of information that may produce late positivity, Bornkessel and Schlesewsky (2006, 2008) suggested that it might reflect difficulties in "generalized mapping," the confluence of information from different sources contributing to pragmatic interpretation, as well as subsequent evaluation of the degree of well-formedness and reanalysis of the utterance.

Swedish Left-edge Intonation and Clause Structure

In Swedish, not only is the end of clauses signaled by prosodic means but also the *beginning* of main clauses. More specifically, a high (H) "left-edge boundary tone" is associated with the last syllable of the first prosodic word of main clauses (Horne, Hansson, Bruce, & Frid, 2001; Horne, 1994) but not subordinate clauses (Roll, 2006). Swedish subordinate clauses differ from main clauses with respect to their word order. Main clauses have postverbal sentence adverbs, as in *Vandalerna* ***intog inte*** *Gallien* "(literally) The Vandals conquered not Gaul," where the sentence adverb *inte* "not" follows the verb *intog* "conquered." In subordinate clauses, conversely, sentence adverbs must be preverbal, as in … *att vandalerna* ***inte intog*** *Gallien* "(lit.) that the Vandals not conquered Gaul."

In spoken language, embedded main clauses with postverbal sentence adverbs, like *inte* "not" in *Jag sa att [vandalerna* ***intog inte*** *Gallien]* "(lit.) I said that the Vandals conquered not Gaul" are often used instead of subordinate clauses to express speech acts such as assertions, which are realized as main clauses (Jörgensen, 1978; Andersson, 1975). Like ordinary main clauses, embedded main clauses are associated with left-edge boundary tones. Figure 1 shows the waveform and the F0 contour of a sentence containing an embedded main clause. An H tone is associated with the last syllable of the first word of the sentence, *berättaren* "the storyteller," as well as the first word of the embedded main clause, *vandalerna* "the Vandals." The rise to the H starts in the last syllable of the first word and peaks in the first syllable of the following word. The dotted line shows the intonation contour of an embedded main clause lacking a left-edge boundary tone, obtained by cross-splicing with the corresponding subordinate clause.

Using sentences similar to those in Figure 1, but where the intonation difference was obtained by F0 editing, Roll et al. (2009) found two significant effects in the processing of sentences with only embedded main clauses. Firstly, there was an anterior positive deflection between 200 and 250 msec after the onset of the tone. The positivity was interpreted as an effect on the P200 component, showing the perception of the acoustic features of the pitch change, as earlier found for phrase-initial pitch accents in German (Heim & Alter, 2006). Secondly, there was a biphasic positive effect at the sentence adverb in embedded main clauses when not preceded by a left-edge boundary tone. The biphasic positivity was interpreted as a P345–P600 effect (Friederici, Mecklinger, Spencer, Steinhauer, & Donchin, 2001), reflecting the detection and subsequent reanalysis of a main clause structure, which was unexpected in the absence of a left-edge boundary tone.

Because Roll et al. (2009) compared only embedded main clauses, it has remained unclear whether H left-edge

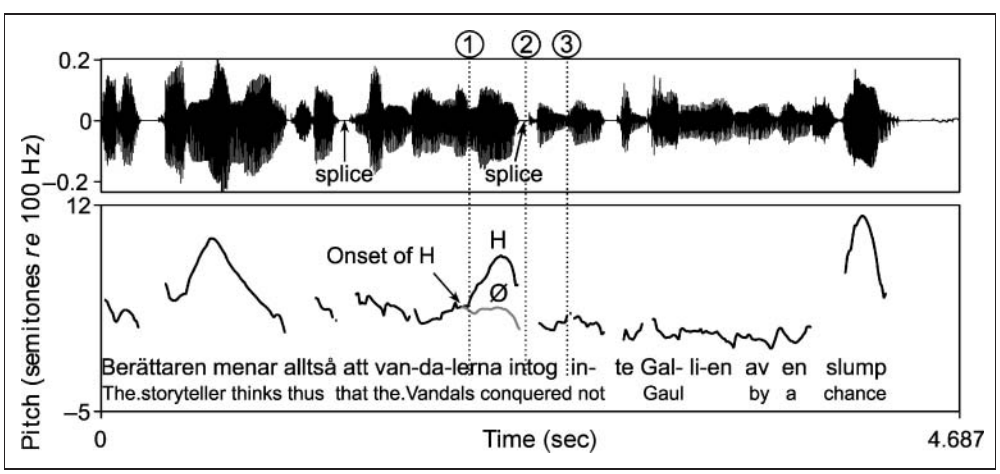

Figure 1. Waveform and intonation contour exemplifying the stimuli EMC H and EMC Ø illustrated in Example Sentences 1 and 2. EMC H has an H left-edge boundary tone associated with the last syllable of the first word of the embedded clause, that is, *vandalerna* "the Vandals" (black line). The tone is absent in EMC Ø (gray line). The analysis reference points are indicated in the circles at the top of the figure.

boundary tones selectively increase the expectation of main clause word order or more generally facilitate syntactic processing. A second open question is whether left-edge tones are as constraining as right-edge boundary tones, which may induce a misanalysis of the syntactic structure. If they are, their presence would be thought to decrease the expectation for the competing subordinate clause structure. Thirdly, it is not clear what the first positivity in the P345–P600 effect obtained for prosody–syntax mismatch reflects. Thus, embedded main clauses that were unexpected because of the semantic bias of the embedding verb yielded a continuous P600 effect between 350 and 700 msec (Roll et al., 2009). To investigate these questions, it is necessary to test how different word orders are processed in embedded clauses with or without left-edge boundary tones.

The Present Study

The present study investigates the influence of left-edge boundary tones and word order on the syntactic processing of embedded clauses. The conditions are presented in Examples 1–6. EMC stands for embedded main clause, SC for subordinate clause, and NC for structurally neutral clause. H represents the presence of a high left-edge boundary tone in the embedded clause, and Ø is the absence of a tone. The onset of the H will be referred to as "Reference Point 1." The embedded clauses are resolved as regards word order only when the second syllable of the second word is heard, a point hereby referred to as "Reference Point 2." The first syllable of that word is always *in-*. After the second syllable, the listener will have heard, either the preverbal sentence adverb *inte* "not," which cues subordinate clause word order, as in the conditions SC H and SC Ø illustrated by Examples 3 and 4, or the verb *intog*, which cues main or neutral clause word order. This is the case in the conditions EMC H and EMC Ø in Examples 1 and 2, where the sentence adverb *inte* "not" follows the verb, or in the baseline conditions NC H and NC Ø in Examples 5 and 6, where the adjective *hela* "all of" occurs instead of a sentence adverb in the postverbal position. The point of distinction between *inte* in EMC and *hela* in NC will be referred to as "Reference Point 3."

(1) *EMC H* Berättaren menar alltså att vandalerna^{H} intog inte Gallien av en slump

The storyteller thinks thus that the Vandals conquered not Gaul by a chance
"The storyteller thus thinks that the Vandals didn't conquer Gaul by accident"

(2) *EMC Ø* Berättaren menar alltså att vandalerna^{Ø} intog inte Gallien av en slump

The storyteller thinks thus that the Vandals conquered not Gaul by a chance

(3) *SC H* Berättaren menar alltså att vandalerna^{H} inte intog Gallien av en slump

The storyteller thinks thus that the Vandals not conquered Gaul by a chance

(4) *SC Ø* Berättaren menar alltså att vandalerna^{Ø} inte intog Gallien av en slump

The storyteller thinks thus that the Vandals not conquered Gaul by a chance

(5) *NC H* Berättaren menar alltså att vandalerna^{H} intog hela Gallien av en slump

The storyteller thinks thus that the Vandals conquered all of Gaul by a chance

(6) *NC Ø* Berättaren menar alltså att vandalerna^{Ø} intog hela Gallien av en slump

The storyteller thinks thus that the Vandals conquered all of Gaul by a chance

Subjects listened to sentences of the conditions exemplified in Examples 1 to 6 and judged whether they were "ok" or "wrong" by pressing one of two buttons. At the same time, their brain activity was recorded using ERP to be able to monitor the degree of integration cost at different points during sentence processing.

Hypotheses

Left-edge boundary tone. In accordance with earlier results for accents and boundary tones associated with the left edge of clauses (Roll et al., 2009; Heim & Alter, 2006), the H is expected to yield a perceptual effect seen as a P200 effect in the ERPs at Reference Point 1.

Word order. If the participants show a preference for EMC, SC, or NC, the unexpected word orders are hypothesized to yield a P600 effect at the point of syntactic distinction, that is, at the onset of the sentence adverb at Reference Points 2 and 3.

Interaction between tone and word order. If the left-edge boundary tone influences the processing of EMC, SC, and NC structures differently, an effect of the interaction between tone and word order would be expected at Reference Points 2 and 3. In accordance with the findings in Roll et al. (2009), the absence of a tone can be hypothesized to produce a P600 effect selectively in EMC Ø, preceded by a short positivity. If left-edge tones inhibit SC structure, their presence would also be expected to induce a P600 effect in the SC H condition.

METHODS

Participants

Twenty-two right-handed students at Lund University, native speakers of Standard Swedish, participated in the experiment. Seventeen were women, and the mean age was 23.8 years (*SD* = 3.1 years), ranging from 18 to 31 years.

Materials

Test Sentences

Examples 1–6 show sentences illustrating the test conditions. All the main clause verbs were assertive, which made them compatible with both embedded main and subordinate clauses (Andersson, 1975). The EMC conditions (Examples 1–2) had an embedded main clause, with the verb *intog* "conquered" preceding the sentence adverb *inte*. In the SC conditions (Examples 3–4), *inte* "not" instead preceded *intog* "conquered," yielding subordinate clause word order. The NC conditions (Examples 5–6) had the adjective *hela* "all of" instead of the sentence adverb and were thus neutral regarding embedded clause structure. Half of the sentences had an H left-edge boundary tone associated with the last syllable of the first word of the embedded clause.

Control Sentences

In order for SC word order not to be unexpected because of a lower frequency of occurrence, the control conditions illustrated by Examples 7 and 8 were included in the material. In these sentences, the second word of the embedded clause is *inte* "not," which is followed by the verb *angrep* "attacked."

(7) Berättaren menar alltså att vandalerna^{H} inte angrep Gallien av en slump

The storyteller thinks thus that the Vandals not attacked Gaul by a chance

"The storyteller thus thinks that the Vandals didn't attack Gaul by chance"

(8) Berättaren menar alltså att vandalerna^{Ø} inte angrep Gallien av en slump

The storyteller thinks thus that the Vandals not attacked Gaul by a chance

Stimulus Generation

For each condition, 40 stimulus sentences were created, giving a total of 320 sentences. Twice as many unrelated filler sentences were also created. In all, there were thus 960 sentences in the experiment. The test sentences were spliced together from parts of original sentences recorded by a male native speaker of Standard Swedish in a soundproof echo-free room at the Humanities Laboratory, Lund University. The sampling frequency was 44.1 kHz, and the amplitude was normalized after recording. The original sentences were equivalent to the conditions EMC H, SC Ø, NC Ø, and the control sentence without an H tone (Examples 1, 4, 6, and 8). In addition, sentences corresponding to the EMC Ø condition (Example 2) were recorded after the control sentences. The sentences were cut in the occlusion phases of [t] in *att* and *inte* "not," obtaining three sections from each original recording (see Figure 1). In Examples 1–6, these would be as follows:

(i) *Berättaren menar alltså a*—"The storyteller thinks thus tha-";
(ii) *-tt vandalerna in*—"-t the Vandals con-/no-"; and
(iii) *-tog inte Gallien av en slump* "-quered not Gaul by accident," *-te intog Gallien av en slump* "-t conquered Gaul by accident," or *-tog hela Gallien av en slump* "-quered all of Gaul by accident."

The first section (i) was the same for all eight conditions. In half of the cases, it was taken from the EMC H recording, in half, from the SC Ø recording. The H conditions were then obtained by splicing the first (i) with the second section (ii) of the EMC H recording and the Ø conditions by splicing the first (i) with the second section (ii) of the SC Ø recording. The third section (iii) that was spliced was always from a Ø recording, even in the EMC case, where the EMC Ø recording was used to avoid effects of differing F0 levels in the second syllable of *inte*/*intog* "not/conquered." Context questions were used to elicit focus on the last word of each sentence.

The rise to the left-edge boundary tone in the H conditions began at the onset of the last syllable of the first word in the embedded clause (see Figure 1). The peak occurred within the first syllable of the next word, *in-*. The average rise in the H conditions was 4.48 semitones (st; 0 st = 100 Hz; *SD* = 0.57). There was also a minimal rise ($M = 0.87$ st, $SD = 0.34$ st) in the Ø conditions, $F(1, 39) = 1262.51$, $p < .001$, because of the presence of a lexical H tone in the syllable *in-*, which was augmented with the left-edge boundary tone in the H conditions. The duration of the rise was almost identical for the H (197 msec, $SD = 40$ msec) and the Ø conditions (198 msec, $SD = 37$ msec), $F(1, 39) = .029$, $p = .886$, giving a steeper slope in H ($M = 0.0234$ st/msec, $SD = 0.0042$ st/msec) than in Ø ($M = 0.0045$ st/msec, $SD = 0.0016$ st/msec), $F(1, 39) = 698.77$, $p < .001$. All sentences also had an H left-edge boundary tone associated with the last syllable of the first word of the main clause and a focal tone followed by a right-edge low boundary tone associated with the last word of the sentence, as seen in Figure 1.

Procedure

The participants were seated in front of a computer screen. The sentences were presented auditorily in pseudorandomized order through loudspeakers placed in front of the participants. The stimuli were divided into 24 blocks with 40 sentences in each, of which 13 to 14 were test sentences and 26 to 27 were filler sentences. The participants were instructed to judge the acceptability of the sentences by pressing one of two buttons.

EEG Recordings

EEG was recorded using a 64-channel Quik Cap, a SynAmps 2 amplifier, and the NeuroScan Acquire software. Impedance was kept below 5 kΩ. One electrode at the outer canthus of each eye as well as one above and one below the left eye measured the EOG. The electrodes were referenced to a central reference electrode on-line and were rereferenced to averaged mastoids off-line. The ground reference was a frontal cap-mounted electrode. The sampling rate was 250 Hz, and an on-line band-pass filter with cutoff frequencies of 0.05 and 70 Hz was used. Bad channel signals were replaced off-line using spherical spline interpolation with the surrounding electrodes.

Data Analysis

Behavioral response to the acceptability of the sentences was recorded and compared.

ERP effects were measured at three different reference points, which can be seen in Figure 1. Reference Point 1 was at the onset of the rise to the H, that is, the onset of the last syllable of the first word in the embedded clause. Reference Point 2 occurred 348 msec later (*SD* = 27.9 msec), at the distinction point for SC structure at the splice after the syllable *in-*. Reference Point 3 followed after 181 msec (*SD* = 17.8 msec), at the onset of *inte* "not" in the EMC and *hela* "all of" in the NC conditions, which was the point of distinction between EMC and NC structure.

Off-line EEG data were analyzed in EEGLAB (Delorme & Makeig, 2004). The EEG was first filtered with a 30-Hz low-pass filter and then divided into epochs from −50 msec before to 1600 msec following the analysis reference points. A time window of 300 msec before the splice point in *att* "that" was used for baseline correction because there was a difference in the conditions preceding the last two reference points. Ocular artifacts were compensated for using independent components analysis (Jung et al., 2000). Trials were removed whenever the amplitude exceeded ±100 μV after compensation for EOG artifacts. An 8-Hz low-pass filter was used for presentation only.

The electrodes were grouped in nine ROIs corresponding to three anterior/posterior and three laterality conditions: left anterior (LA) with electrodes F7, F5, F3, FT7, FC5, FC3; mid-anterior (MA) with F1, FZ, F2, FC1, FCZ, FC2; right anterior (RA) with F4, F6, F8, FC4, FC6, FT8; left central (LC) with T7, C5, C3, TP7, CP5, CP3; mid-central (MC) with C1, CZ, C2, CP1, CPZ, CP2; right central (RC) with C4, C6, T8, CP4, CP6, TP8; left posterior (LP) with P7, P5, P3, P07, PO5, O1; mid-posterior (MP) with P1, PZ, P2, PO3, PO4, OZ; and right posterior (RP) with P4, P6, P8, PO6, PO8, O2.

Statistical Analysis

ERPs were averaged in effect time windows identified after the reference points. All conditions were subjected to repeated measures ANOVAs in SPSS, with the two experimental factors *tone*, including the levels H and Ø, and *word order*, with EMC, SC, and NC, as well as the two topographical factors *anterior/posterior* (*ant/post*) and *laterality* (*lat*). *Ant/post* had the three levels: *anterior*, including LA, MA, and RA; *central*, involving LC, MC, and RC; and *posterior*, with LP, MP, and RP. *Lat* had the three levels: *left*, including LA, LC, and LP; *mid*, with MA, MC, and MP; and *right*, with RA, RC, and RP. At Reference Points 1 and 2, all conditions were tested, at Reference Point 3 only the EMC and NC conditions. When applicable, p values are reported with Greenhouse–Geisser correction. Only significant effects are described. The degrees of freedom are reported with sphericity assumed. Bonferroni correction was used for post hoc t tests. Whenever there was an interaction between an experimental and a topographical factor, the experimental factor was tested at each of the three levels of the topographical factor. Effect time windows were defined by dividing the epochs into 50-msec time windows to see where conditions started to differ significantly.

RESULTS

Behavioral Data

The subordinate clause (SC) and the structurally neutral clause (NC) conditions had a high acceptability rate regardless of the presence or absence of a left-edge boundary tone. The percentage of accepted cases was 89.5% (*SD* = 8.1%) in SC H; 89.9% (*SD* = 8.0%) in SC Ø, both ranging from 72.5% to 100%; 87.7% (*SD* = 11.3%) in NC H with a range between 65% and 100%; and 87.0% (*SD* = 10.7%) in NC Ø ranging from 67.5% to 100%. The embedded main clause (EMC) conditions received a lower rating: 40.2% (*SD* = 35.9%), ranging between 0% and 97.5% for EMC H, and 37.7% (*SD* = 36.6%), with a range from 0% to 100% for EMC Ø.

There was a significant effect of word order, $F1(2, 42) = 43.0$, $p < .001$, $F2(2, 78) = 909.94$, $p < .001$,[2] but no effect of tone, $F1(1, 21) = 1.39$, $p = .251$, $F2(1, 39) = .965$, $p = .332$, nor any Tone × Word Order interaction, $F1(2, 42) = 1.73$, $p = .190$, $F2(2, 78) = 3.26$, $p = .052$. Post hoc pairwise comparison of word order showed that the EMC conditions were significantly lower rated than both the SC and the NC conditions, $p < .001$. Thus, the acceptability ratings were clearly influenced by the word order, but not by the tone.

ERP Data

Figures 2, 3, and 4 show the ERPs at the left-edge boundary tone onset (Reference Point 1), with the points of detection of subordinate (Reference Point 2) and main clause word

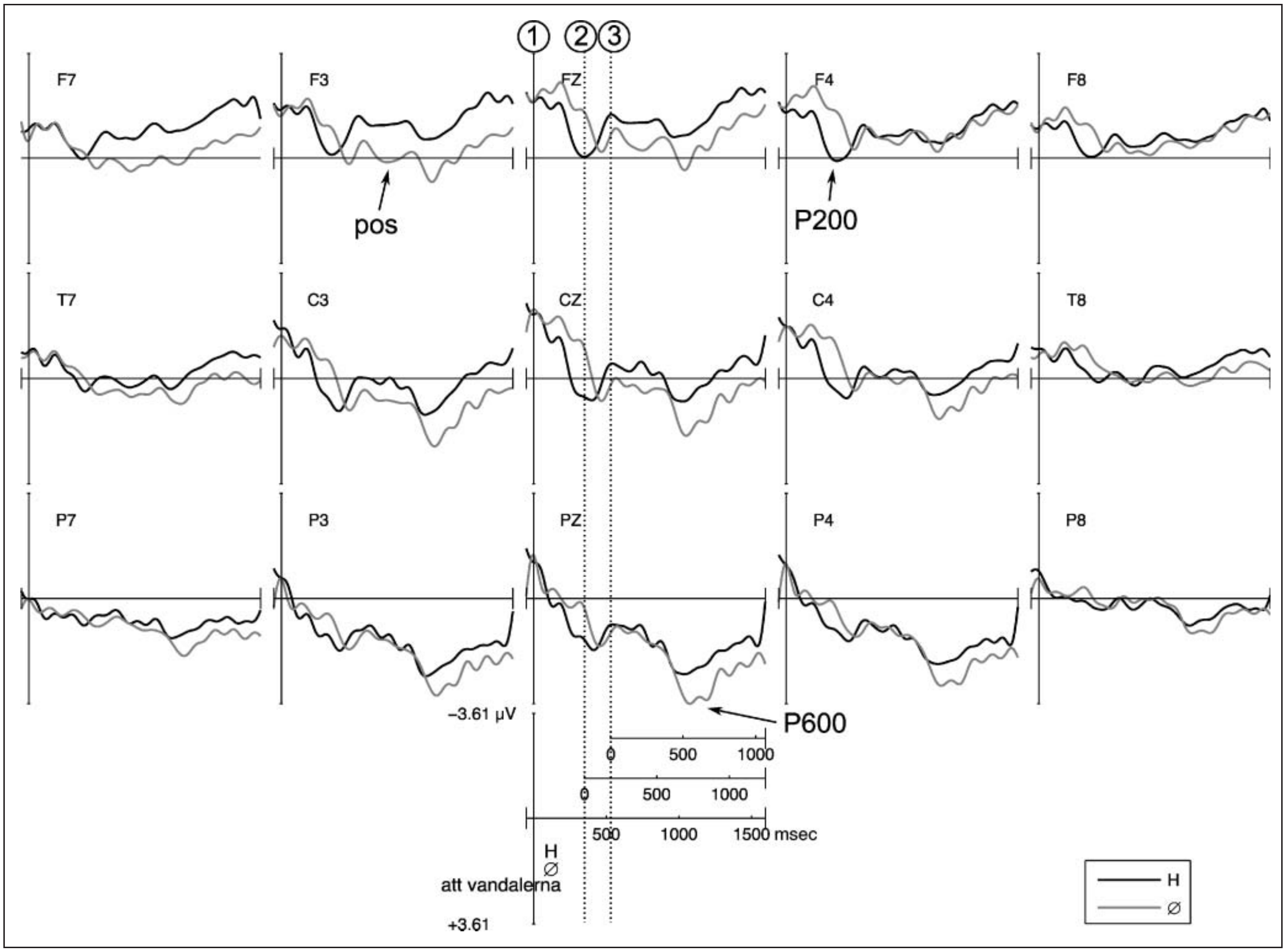

Figure 2. Average ERPs of all conditions with (H) and without (Ø) a left-edge boundary tone at Reference Point 1, the H onset (*Berättaren menar alltså att vandalerna…* "The storyteller thus thinks that the Vandals…"). The H tone gave rise to a fronto-central, right-skewed positivity at 250–350 msec (black line) (P200), whereas the absence of a tone yielded a positivity between 300 and 450 msec after the first syntactic distinction point (pos).

order (Reference Point 3) indicated with dotted lines. The time window used for baseline correction was 300 msec preceding the splice point in *att*. The average rejection rate was 12.8% (*SD* = 7.8%), ranging from 0% to 32.5% per subject and condition. The average proportion of interpolated channels was 1.1% (*SD* = 1.7%), range = 0–4.7%, of 64.

First Reference Point

At Reference Point 1, a difference was expected only for the tone factor. Figure 2 shows the effects of the H left-edge boundary tone averaged over all H and Ø conditions. The H yielded a centro-frontal, right-skewed positive peak between 250 and 350 msec after onset (P200), as seen in a main effect for tone, $F(1, 21) = 16.18$, $p < .001$, as well as interactions with ant/post, $F(1, 21) = 6.19$, $p < .02$, and lat, $F(2, 42) = 18.10$, $p < .001$. Resolving the interactions showed that the positivity was confined to anterior, $F(1, 21) = 16.37$, $p < .001$, and central ROIs, $F(1, 21) = 22.57$, $p < .001$, and that the effect size was larger over mid, $F(1, 21) = 27.24$, $p < .001$, $\eta^2 = .565$, and right regions, $F(1, 21) = 15.96$, $p < .001$, $\eta^2 = .432$, than over left regions, $F(1, 21) = 5.19$, $p < .05$, $\eta^2 = .198$.

Second Reference Point

Between 300 and 450 msec following the point of distinction of subordinate clause word order (Reference Point 2), there was a positivity in the conditions lacking a tone (Ø), as indicated by "pos" in Figure 2. The positivity gave rise to a main effect for tone, $F(1, 21) = 5.98$, $p < .05$.

Between 550 and 1100 msec following Reference Point 2, EMC Ø showed increased positivity as compared with EMC H (P600 in Figure 3). In this time window, there were main effects for tone, $F(1, 21) = 6.20$, $p < .05$, and word order, $F(2, 42) = 12.61$, $p < .001$. A Tone × Word Order interaction, $F(2, 42) = 3.38$, $p < .05$, revealed that the tone effect was due to increased positivity in EMC Ø as compared with EMC H, $F(1, 21) = 8.98$, $p < .01$, as seen in Figure 3. Tone had no effect in SC, $F(1, 21) = .002$, $p = .966$, nor in NC, $F(1, 21) = 1.54$, $p = .228$. Word order was significant in both H, $F(2, 42) = 5.13$, $p < .02$, and Ø,

$F(2, 42) = 14.44$, $p < .001$. Pairwise comparison for the H and Ø conditions showed that EMC Ø was significantly more positive than both SC Ø and NC Ø, $p < .01$, whereas EMC H differed significantly only from NC H, $p < .05$.

At posterior leads in the same 550- to 1100-msec time window, the EMC conditions were more positive than the SC conditions, which were more positive than the NC conditions (P600 in Figure 4). A Word Order × Ant/Post interaction, $F(4, 84) = 11.19$, $p < .001$, showed an effect for word order at posterior, $F(2, 42) = 23.00$, $p < .001$, $\eta^2 = .523$, and central electrodes, $F(2, 42) = 13.69$, $p < .001$, $\eta^2 = .395$. As seen in Figure 4, in pairwise comparison, EMC was more positive than NC and SC at both central and posterior sites, $p < .01$. SC showed increased positivity as compared with NC at posterior sites, $p < .05$.

A Word Order × Lat interaction, $F(4, 84) = 10.78$, $p < .001$, disclosed larger effects at mid, $F(2, 42) = 13.93$, $p < .001$, $\eta^2 = .399$, and right, $F(2, 42) = 13.12$, $p < .001$, $\eta^2 = .385$, than at left electrode sites, $F(2, 42) = 7.25$, $p < .01$, $\eta^2 = .257$. EMC was significantly more positive than NC at all sites, $p < .01$, and more positive than SC at mid and right sites, $p < .01$.

Third Reference Point

Timed to the distinction point between EMC and NC (Reference Point 3), the time window for the increased positivity in EMC was 350 to 900 msec, $F(1, 21) = 16.56$, $p < .001$, which corresponded approximately to the 550- to 1100-msec time window from Reference Point 2 mentioned in the previous section (P600). An interaction with

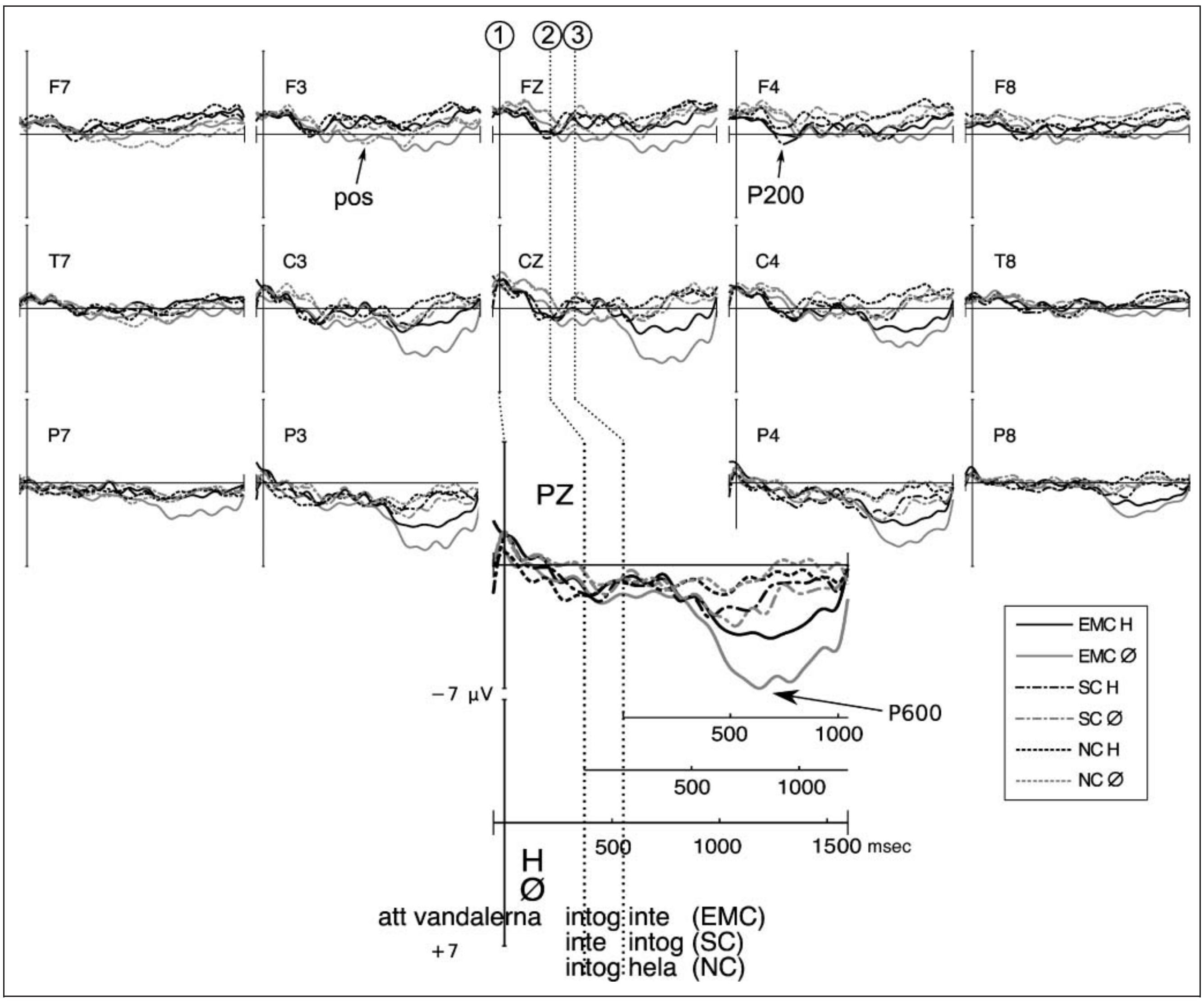

Figure 3. ERPs for embedded main clauses (EMC), subordinate clauses (SC), and neutral clauses (NC) at the H onset (Reference Point 1, *Berättaren menar alltså att vandalerna…* "The storyteller thus thinks that the Vandals…") with (H) or without (Ø) a left-edge boundary tone. The H tone selectively reduced a P600 effect in EMC H (black, solid line) as compared with EMC Ø (gray, solid line) but did not affect the SC (dash-dotted lines) or NC conditions (dashed lines).

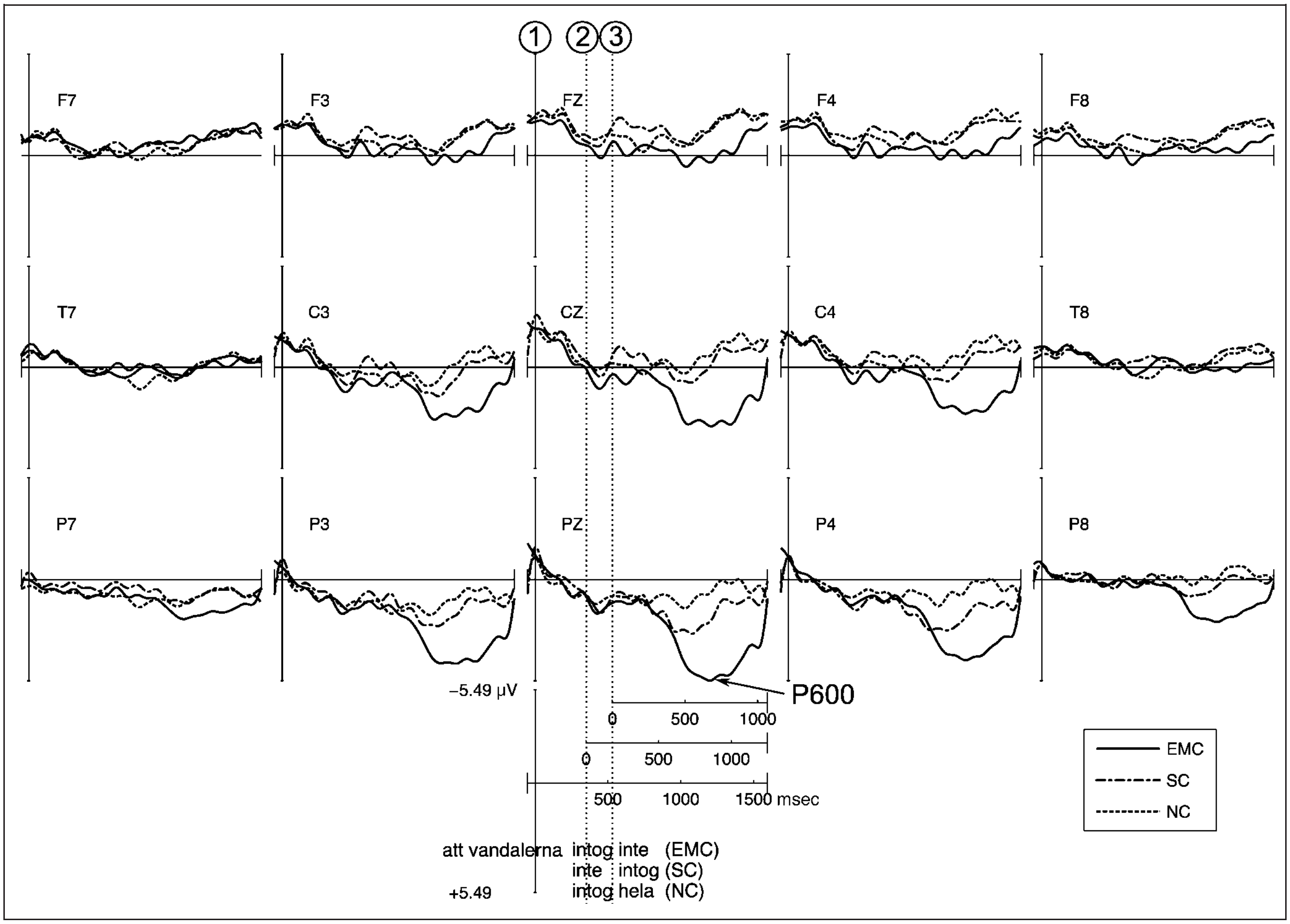

Figure 4. ERPs for embedded main clauses (EMC), subordinate clauses (SC), and neutral clauses (NC) at the H onset (Reference Point 1, *Berättaren menar alltså att vandalerna…* "The storyteller thus thinks that the Vandals…"). EMCs (solid line) produced a posterior P600 effect, also visible with lower amplitude in SC (dash-dotted line).

ant/post, $F(2, 42) = 11.42, p < .01$, showed the same central, $F(1, 21) = 18.47, p < .001$, and posterior, $F(1, 21) = 27.87, p < .001$, distribution. There was also an interaction with lat, $F(2, 42) = 14.49$, stemming from a similar right skew of the positivity. Thus, the effect size was larger over mid, $F(1, 21) = 17.27, p < .001, \eta^2 = .451$, and right sites, $F(1, 21) = 17.17, p < .001, \eta^2 = .450$, than over left sites, $F(1, 21) = 11.58, p < .01, \eta^2 = .355$.

The increase in the positive deflection due to the absence of a tone in EMC Ø occurred later than the onset of the positivity for word order (P600), as can be seen in Figure 3. Thus, between 500 and 900 msec following Reference Point 3, there was a Tone × Word Order × Lat interaction, $F(2, 42) = 3.38, p < .05$, which revealed a Tone × Word Order interaction at mid sites, $F(1, 21) = 7.31, p < .02$, where EMC Ø was more positive than EMC H, $F(1, 21) = 9.77, p < .01$. Tone had no effect in the NC conditions, $F(1, 21) = .057, p = .814$.

Correlation of Behavioral and ERP Data

To get a better understanding of the function of the observed ERP components, we tested their Pearson correlation with acceptability ratings at the individual level, evaluated with two-tailed t tests. The ERP difference between H and Ø at 250 to 350 msec following H onset (P200 in Figure 2) did not correlate with acceptability ratings of any condition. The positive effect for Ø as compared with H between 300 and 450 msec following point 2 (pos in Figure 2) was greater the lower the participants had rated SC Ø, $r = -.441, p < .05$. Finally, the positivity for EMC as compared with NC between 550 and 1100 msec following point 2 at posterior electrodes (P600 in Figure 4) increased the lower participants had rated EMC H and EMC Ø, $r = -.429/-.448, p < .05$, and at right sites, the lower the ratings EMC H had received, $r = -.424, p < .05$.

DISCUSSION

The study tested the ERP effects of left-edge boundary tones and word order on the syntactic processing of embedded main clauses, subordinate clauses, and structurally neutral clauses in spoken Swedish. Embedded main clauses are associated with a high left-edge boundary tone, whereas subordinate clauses are not. Therefore, left-edge boundary tones can be assumed to activate a main clause pattern with postverbal sentence adverbs.

Left-edge Boundary Tone

The high tone produced a positive peak in the ERPs between 250 and 350 msec after its onset. This can be interpreted as an effect on the P200 similar to what has previously been detected for left-edge accents and boundary tones. The skewing of the effect toward frontal and right electrodes is consistent with earlier findings of involvement of the right frontal and temporal cortex in pitch processing (Zatorre, Evans, & Meyer, 1994; Zatorre, Evans, Meyer, & Gjedde, 1992). Its rather late appearance and wide time window can be assumed to be due to the use of only naturally produced stimuli, where the rise to the H varies with regard to timing and slope.

Word Order

Between 550 and 1100 msec following the point where subordinate clauses were distinguished, there was a posterior positive deflection in the embedded main and subordinate clause conditions, which was largest for the embedded main clauses. In embedded main clauses, its onset was 350 msec following the point where word order was discriminated. The positivity was similar to the effect we have previously found for embedded main clauses that were unexpected because of the bias of the embedding verb. The larger amplitude of the P600 thus indicates that embedded main clauses were structurally less expected than subordinate clauses with preverbal sentence adverbs, which in turn were less expected than neutral clauses. The increased processing cost for subordinate and embedded main clauses containing a negation as a sentence adverb is in line with previous findings that negative clauses take relatively more time to generate and are more difficult to remember than affirmative clauses (Miller & McKean, 1964; Mehler, 1963). The elevated processing cost for embedded main clauses over subordinate clauses is probably due to their low normative status, reflected in their lower degree of acceptability. The amplitude of the P600 for embedded main clauses was larger the less acceptable subjects had found the main clause word order.

Effects of Tone on Word Order Processing

There was an interaction between information from left-edge boundary tone and word order at the syntactic distinction points. The tone selectively reduced the P600 in embedded main clauses, predominantly at mid electrodes. The left-edge boundary tone thus seems to specifically activate the main clause structure it is associated with. Moreover, it did not increase the P600 effect of the competing subordinate clause structure. The participants showed a clear bias toward subordinate rather than embedded main clauses, as shown by the lower amplitude of the P600 and higher ratings for subordinate clauses. Thus, although the left-edge boundary tone prepares the listener for an upcoming main clause, it does not suppress the expectation of the normatively more accepted subordinate clause structure.

As in Roll et al. (2009), the P600 was preceded by a shorter positivity at 300 to 450 msec following the first word order distinction point. In the present study, however, the first peak of the biphasic positive sequence appearing in the absence of a left-edge boundary tone was functionally dissociated from the P600. Whereas in the P600 time window, tone interacted with word order, the preceding positivity showed only a main effect for the absence of tone. Further, it was larger the lower participants had rated subordinate clauses without left-edge tones (recall that subordinate clauses otherwise represented the most accepted conditions). The positive effect might be accounted for in light of a previous observation that long spoken utterances tend to sound more natural if divided up prosodically into smaller units (Frazier, Clifton, & Carlson, 2004). In this vein, the short positivity preceding the P600 could reflect a reaction to the absence of a prosodic cue to break up the rather long sentences. The negative correlation with the ratings would then suggest that the higher the predilection listeners had for left-edge boundary tones, the more they tended to perceive sentences containing subordinate clauses as unnaturally long and complex in the absence of a tone.

Interpretation of the P600

The correlation between the posterior P600 for embedded main clauses and test participants' negative judgments indicates that the P600 at least in part reflects well-formedness evaluation. However, subordinate clauses also produced a P600 effect as compared with neutral clauses, and the absence of a left-edge boundary tone increased the P600 for embedded main clauses, without any correlation with the behavioral response. In these cases, it is therefore more likely that the late positivity indexes reanalysis of unexpected structures. Thus, neutral clauses were the most expected because they are easiest to process. Subordinate clauses, which involved negative sentence adverbs, required a certain degree of reanalysis because they are more complex. Embedded main clauses were the least expected because they are not normatively accepted by all speakers. However, a left-edge boundary tone functioned as a cue that made its associated embedded main clause word order more expected, thus reducing the P600.

The study shows that left-edge boundary tones can play a specific role in syntactic processing by selectively facilitating the processing of the structure they are associated with. They are not, however, as constraining as right-edge boundary tones and thus do not inhibit competing structures.

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Notes

1. The prosodic boundary is marked by "‖."
2. *F*1 is a within-subjects ANOVA, and *F*2 a within-items ANOVA.

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