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Published in:
Brain Research

DOI:
10.1016/j.brainres.2010.03.020

2010

Document Version:
Publisher's PDF, also known as Version of record

available at www.sciencedirect.com

ScienceDirect

www.elsevier.com/locate/brainres

BRAIN RESEARCH

Research Report

Word accents and morphology—ERPs of Swedish word processing

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ARTICLE INFO

Article history:
Accepted 6 March 2010
Available online 16 March 2010

Keywords:
Language processing
Prosody
Morphology
Word accent
Lexical tone
Inflection

ABSTRACT

Results indicating that high stem tones realizing word accents activate a certain class of suffixes in online processing of Central Swedish are presented. This supports the view that high Swedish word accent tones are induced onto word stems by particular suffixes rather than being associated with words in the mental lexicon. Using event-related potentials, effects of mismatch between word accents and inflectional suffixes were compared with mismatches between stem and suffix in terms of declension class. Declensionally incorrect suffixes yielded an increase in the N400, indicating problems in lexical retrieval, as well as a P600 effect, showing reanalysis. Both declensionally correct and incorrect high tone-inducing (Accent 2) suffixes combined with a mismatching low tone (Accent 1) on the stems produced P600 effects, but did not increase the N400. Suffixes usually co-occurring with Accent 1 did not yield any effects in words realized with the nonmatching Accent 2, suggesting that Accent 1 is a default accent, lacking association with any particular suffix. High tones on Accent 2 words also produced an early anterior positivity, interpreted as a P200 effect reflecting preattentive processing of the tone.

1. Introduction

To understand a spoken message, a complex phonological, morphological, syntactic, and semantic analysis needs to be accomplished online at a high speed. To make this possible, listeners use cues in the speech signal to predict upcoming words and structures. For example, in Central Swedish, main clauses are distinguished from subordinate clauses due to a high left-edge boundary tone and a fixed word order. Accordingly, hearing a high tone at the beginning of a clause increases listeners' expectation of upcoming main clause word order (Roll et al., 2009, in press). The present study uses event-related potentials (ERP) to investigate whether a similar process takes place at the word level, where a word-initial high stem tone might activate a certain class of associated suffixes. Thus, participants listened to Swedish sentences where stems spoken with a high or low tone were combined with suffixes requiring high or low tone on the stems. The goal was to see whether or not the stem tones increased the expectation for the associated suffixes. Results for stem tone–suffix mismatch were compared to those for morphological mismatch between stem and suffix as regards declension class.

1.1. *Swedish word characteristics*

In tone languages like Thai and Chinese, tonal patterns may distinguish words from each other. Thus, the Mandarin

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doi:10.1016/j.brainres.2010.03.020

Chinese syllable *ma* can refer to 'mother,' 'horse,' or 'hemp,' depending on which tone it is associated with (Brown-Schmidt and Canseco-Gonzalez, 2004). Similarly, in Central Swedish, a word like *malen* can either be interpreted as the definite noun 'the moth' or as the past participle 'ground,' depending on whether the stressed stem *mal* is associated with a low tone ('Accent 1') or a high tone ('Accent 2') (Bruce, 1977, 2005). Despite similarities regarding their distinctive function, a different formal status has been proposed for Swedish and Chinese tones. In psycholinguistic models, Chinese tones are assumed to form part of the phonological representation of words in the mental lexicon (Chen et al., 2002). Swedish word accent tones, in contrast, are rather considered to be prosodic information 'induced' onto word stems by grammatical suffixes (Riad, 1998, 2009; Rischel, 1963).[1] Thus, the stem *mal* 'moth' is realized with a low tone in the Accent 1 word *malen* 'the moth' together with the singular suffix –*en*, whereas it receives a high tone from plural –*ar* in the Accent 2 word *malar* 'moths.'

If word accents are 'morphophonological' in this sense, stem tones should function as cues for their associated suffixes. Hence, a listener would not expect a high-inducing suffix like plural –*ar* after a stem realized with a low tone. Consequently, the listener would have to re-analyze a word like *malar* 'moths' if *mal* carries the inappropriate low Accent 1 tone. If, however, word accent tones were instead phonological and linked to whole word forms like Chinese tones, *malar* 'moths' with a mismatching low stem tone would be expected to be perceived as an unfamiliar word form, causing problems in lexical retrieval.

In order to obtain a better understanding of the status of Swedish word accent tones in relationship to inflectional morphology, the processing of stem tone-suffix mismatches was compared with that of words involving stem–suffix declension mismatch. Swedish nouns are morphologically inflected for number and definiteness according to five different declension classes. Simple inflected forms are either indefinite plurals, like second declension *mink+ar* 'minks,' or definite singulars, such as *mink+en* 'the mink.' Swedish has no default plural formation rule like English and German –*s* suffixation. Therefore, the stem *mink* must be associated with its second declension class endings to obtain the correct plural form *minkar* 'minks.' In the present study, incorrect words were formed by splicing second declension stems with the first declension plural suffix –*or*, as in **minkor*.[2]

Although it is well known that inflectional endings co-occur with one of the two different word accents in Swedish, an unresolved issue is the relative morphophonological status of Accent 1 and 2 suffixes. Riad (1998, 2009) has hypothesized that the low stem tone in Accent 1 words is assigned as a default word accent in the absence of high tone-inducing (Accent 2) suffixes. Supporting this idea is the fact that words lacking an intrinsic word accent, e.g., recent loan words, are associated with Accent 1 (Bruce, 1977). In other words, whereas suffixes in Accent 2 words are assumed to induce the high tone onto the stem, suffixes in Accent 1 words are thought to be neutral regarding tone-specification. Due to the absence of an intrinsic association, the processing of Accent 1 suffixes would then be expected to be unaffected by the stem tone.

1.2. *Neurophysiological effects of tone perception*

In ERP studies of Central Swedish, high tones related to left-edge prosodic boundaries have been seen to produce right-skewed anterior positive deflections after 200 to 350 ms, interpreted as a perceptual effect reflected in the P200 component (Roll et al., 2009, in press). P200s have previously shown greater amplitude for early than for late utterance–initial pitch peaks in German words (Friedrich et al., 2001; Heim and Alter, 2006). A P200 effect could hence be expected for perception of the high Central Swedish Accent 2 tone but not for the low Accent 1 tone. The variation that has been found in the P200 might reflect preattentive processing of pitch rises independently of their function. In support of this interpretation, Ren et al. (2009) found a right-lateralized mismatch negativity for passive listening to changes in pitch related to both Chinese lexical tone, sentence intonation, and hums in an overlapping time window, between 120 and 240 ms.

ERP studies of Chinese have supported the view that tones are associated with whole word forms in the mental lexicon. Thus, tones retrieving words that are semantically unexpected due to the context have been observed to yield negativities peaking between 300 and 400 ms following stimulus onset (Brown-Schmidt and Canseco-Gonzalez, 2004; Schirmer et al., 2005; Li et al., 2008). The negativity has been interpreted as an increase in the N400, a centroposterior negative peak occurring in the ERPs around 400 ms following stimuli with semantic content (Kutas and Hillyard, 1980). The N400 decreases as a function of how expected a word is in a particular semantic context, and thus how easy lexical retrieval is (Kutas and Hillyard, 1984). If Swedish word accents are associated with whole word forms in the mental lexicon, incorrect word accents should produce unfamiliar words, increasing the N400.

1.3. *Neurophysiological effects of inflection processing*

1.3.1. *Regular and irregular inflection*

Using priming paradigms, Weyerts et al. (1996) and Münte et al. (1999) found evidence in favor of 'dual route' models of inflection (Pinker, 1991), where regular words are stored as stems in the mental lexicon, whereas irregular words are assumed to have a specific entry for each inflected form. Results from these studies indicated that regular words are decomposed into stem plus suffix (*start+ed*) when processed, making subsequently presented forms sharing the stem (*start*) easier to retrieve, as seen in a reduced N400. Irregular words (e.g., *brought*), however, were not decomposed, and hence did not facilitate retrieval of morphologically related words (e.g., *bring*).

1.3.2. *Detection of morphological errors*

To capture the differential processing of regular and irregular inflection, Weyerts et al. (1997) investigated processing of visually presented German nouns. In German, whereas

[1] An exception is word accents in words that are not morphologically decomposable, such as pronouns and some names.

[2] The star indicates that the word form is incorrect.

regular nouns like *Karussell* 'carousel' build their plural form following a default –*s* suffixation rule, similar to regular English plurals, the plural of irregular nouns like *Muskel* 'muscle,' formed by attaching the suffix –*n*, has rather to be learned for the specific words, much like the irregular plural –*en* of *oxen* in English. Applying the regular –*s* rule to irregular words (**Muskels*) yielded a Left Anterior Negativity (LAN), whereas combining regular words with the irregular suffix (**Karussellen*) increased the N400 instead. Similar results have been found for inflection in German (Penke et al., 1997) and English verbs (Morris and Holcomb, 2005; Newman et al., 2007), as well as Catalan stem formation (Rodriguez-Fornells et al., 2001). LAN effects have also been observed for morphosyntactic violations, e.g., subject–verb incongruity (**the boys plays*) (Barber and Carreiras, 2005; Gunter et al., 2000; Osterhout and Mobley, 1995), suggesting that words containing illicit regular suffixes such as plural –*s* are analyzed as breaking an inflectional rule, whereas words with incorrect irregular suffixes are rather perceived as unknown whole words, causing lexical retrieval difficulties, seen as an increase in the N400.[3] Since there is no rule for default plural formation in Swedish, nouns with plural suffixes mismatching the stem's declension class would be expected to be treated as whole unfamiliar word forms, causing difficulties in lexical retrieval.

1.3.3. *Reanalysis*

In addition to the early negativities, both regular and irregular inflection violations in test words inserted in sentences have been observed to yield a late positivity (Lück et al., 2006; Morris and Holcomb, 2005; Newman et al., 2007). Positive deflections termed 'P600' due to a maximum around 600 ms have also been found following syntactic errors or ambiguity (Hagoort et al., 1993; Neville et al., 1991; Osterhout and Holcomb, 1992, 1993; Roll et al., 2007) and unexpected thematic role–assignment (Bornkessel et al., 2002; Hoeks et al., 2004; van Herten et al., 2005). In view of the diversity of processing complications leading to late positivity, Bornkessel and Schlesewsky (2006, 2008) proposed that the P600 reflects problems in 'generalized mapping' of information from different sources contributing to the pragmatic interpretation of a sentence, as well as subsequent reanalysis of the word form. Morris and Holcomb (2005) found a late positivity for both incorrect regular and irregular suffixes in sentence context, whereas only regular suffixes showed clear P600 effects in word list presentation. Hence, the P600 might reflect reanalysis of stem–suffix combinations in isolated presentation, as well as reanalysis of whole word forms to fit a particular sentence context. In the present study, both declensional and stem tone–suffix violations would therefore be expected to cause reanalysis seen in a P600 effect. Crucially, if high Accent 2 tones are induced by suffixes like plural –*ar* and –*or*, listeners should be able to identify mismatches between low stem tones and high tone-inducing suffixes even in incorrect word forms such as **minkor*, where additive P600 effects would be expected due to stem-suffix mismatches related to both declension and tone.

1.3.4. *Latency of inflection processing*

Lehtonen et al. (2007) used ERPs and a lexical decision task to investigate the latency of morphological processing in the visual modality. Inflected (low-frequency) words increased the N400 starting at 450 ms and produced a late positivity as compared to monomorphemic words, suggesting that inflection affects late semantic and syntactic processing. In a similar study testing the effects of presentation modality, the N400 effect was found to start 720 ms after word onset in auditorily presented words, corresponding to around 100 ms after average suffix onset time (Leinonen et al., 2009). Early widespread negativity has previously been argued to index lexical selection based on a preliminary acoustic analysis (Connolly and Phillips, 1994; Hagoort and Brown, 2000; van den Brink et al., 2001). The negativity for suffix processing might therefore reflect a choice among a limited set of suffixes based on their phonetic patterns and the activated word stem. By preparing spoken stimulus sentences using cross-splicing, the present study obtained a controlled uniqueness point at suffix onset, which provided the opportunity to investigate the latency of early negativities in relation to suffix onset.

1.4. *Interaction between prosodic and morphological information*

A number of previous studies have provided evidence for the influence of prosodic features on the processing of word formation suffixes. Thus, Koester et al. (2004) tested how the prosodic realization of the first constituent of German compounds, such as *Ohr* 'ear' in *ein Ohr-en-zeuge* 'an ear-(plural-)witness,' influenced processing of the linking element (–*en*), which is identical to the word's plural suffix. Increasing the duration and fundamental frequency of the first constituent (*Ohr*) made it resemble a single word. In consequence, the linking element (–*en*) was interpreted as a plural suffix, increasing the N400 between 600 and 900 ms after word onset if not agreeing with the preceding numeral (*ein* 'one'). Another study compared the German noun-forming suffixes –*heit* and –*keit*, which only attach to stems ending in a stressed (*Korrékt+heit* 'correctness') or unstressed (*Éinsam+keit* 'loneliness') syllable, respectively, with the suffix –*ung*, forming nouns exclusively from verb stems, as in *Förder-ung* 'promotion' from *förder-n* 'promote' (Janssen et al., 2006). Violation of both stress and word category requirements yielded posterior negativities, with a 200 ms earlier onset and a broader distribution for word category violations. The N400 effects found for unexpected combinations of prosodic patterns and word formation suffixes indicate that they cause late-timed difficulties in lexical retrieval. No previous studies, however, would appear to have shown that a morphophonological association between a prosodic feature and a suffix is used in word processing.

[3] When Lück et al. (2006) presented the same conditions used in Weyerts et al. (1997) auditorily, illicit irregular suffixes yielded a LAN rather than an N400 effect. The reason was probably that the regular stems were perceived first and activated the default –*s* suffixation rule, which the irregular suffixes violated. See Newman et al. (2007) for discussion of discrepancies between the results of Morris and Holcomb (2005) and Gross et al. (1998) on the one hand, and Weyerts et al. (1997) and Penke et al. (1997), on the other.

1.5. The present study

Processing of Swedish word accents and their associated suffixes was investigated in auditorily presented sentences. Brain activity was measured using ERP while participants evaluated test sentences as "ok" or "wrong." Test words were obtained by splicing stems with suffixes. Half of the stimulus words had a low (L) Accent 1 tone realized on their stressed stem syllable, half a high (H) Accent 2 tone as illustrated on the stem *mink* in Fig. 1. The stems were combined with either the neutral singular suffix *–en*, the high tone-inducing plural suffix *–ar*, or the declensionally incorrect, high tone-inducing plural suffix *–or*, forming the test conditions presented in Table 1.

ERP effects were expected in three time windows. Following onset of the word accent tone, a main effect for stem tone was expected to show the perceptual difference between the high (H) Accent 2 tone and the low (L) Accent 1 tone. After suffix onset, declensionally incorrect suffixes (INC) were expected to give rise to an N400 effect in an early time window. Word accent tones were hypothesized to have an effect in this time window only if they were associated with whole word forms and thus affected lexical retrieval. In a late time window, interaction between word accent and suffix information was expected. The Accent 2 suffixes *–ar* and *–or* might be cued by the high stem tone they are hypothesized to induce. If word accent tones are associated with suffixes, increased reanalysis reflected in a P600 effect would therefore be expected in LPL and LINC, where the plural suffixes *–ar* and *–or* were combined with stems realized with a mismatching low tone (Accent 1). The effect would be expected to be independent of the correctness of the stem–suffix combination as regards declension class.

2. Results

2.1. Behavioral data

The average acceptability rate for the conditions where the stem matched the suffix for both declension and word accent tone was 75.5% in HPL, SD = 24.7%, and 75.0% in LSG, SD = 26.3%.[4] There was a stem tone × suffix interaction, $F(2,42) = 11.54$, $P = 0.001$. In words with low Accent 1 tones, the effect of suffix, $F(2,42) = 78.59$, $P < 0.001$, was due to a lower rating of the stem tone–suffix mismatch condition LPL, M = 57.5%, SD = 31.4%, $P = 0.023$, as well as the condition LINC, M = 1.7%, SD = 1.8%, $P < 0.001$, where the suffix was both declensionally incorrect and mismatched the stem's word accent tone. In words with high Accent 2 stem tones, the effect for suffix, $F(2,42) = 133.7$, $P < 0.001$, was mainly due to a lower rating of the declensionally incorrect suffixes in condition HINC, M = 2.9%, SD = 2.5%, $P < 0.001$, whereas a decrease in the rating of suffixes not matching the stem tone in HSG was nonsignificant, M = 68.7, $P = 0.168$. Stem tone had an effect in words with both correct (PL), $F(1,21) = 12.08$, $P = 0.002$, and incorrect (INC) high tone-inducing suffixes, $F(1,21) = 6.60$, $P = 0.018$, but not in words with tone–neutral suffixes (SG), $F(1,21) = 3.32$, $P = 0.083$.

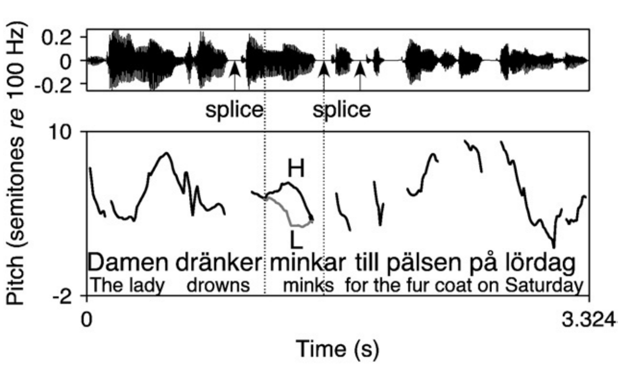

Fig. 1 – Waveform and intonation contour of a stimulus sentence containing the Accent 2 high (H) tone word *minkar* 'minks.' The tonal contour of the corresponding Accent 1 low (L) tone word *minken* 'the mink' is shown by the gray line.

Table 1 – The independent variables stem tone and suffix, and the resulting test conditions. SG = singular, PL = plural, INC = incorrect, L = low, H = high.

		Suffix		
		SG (*–en*, neutral)	PL (*–ar*, H-inducing)	INC, (*–or*, H-inducing)
Stem tone	L	LSG	LPL	LINC
	H	HSG	HPL	HINC

2.2. ERP data

The ERP data from onset of word accent tones/test words are shown in Figs. 2–4. The time window used for baseline correction was 300 ms preceding the splice point in the preceding verb. The average rejection rate was 10.5%, SD = 6.9%, ranging from 0% to 32.5% per subject and condition. The average proportion of interpolated channels was 1.1%, SD = 1.7%, range = 0% to 4.7%, of 64.

2.2.1. Tone perception

Fig. 2 shows the ERPs at the onset of the low (L) Accent 1 and high (H) Accent 2 stem tones, coinciding with word onset, averaged over all conditions. Accent 2 (H) produced a positive deflection at 200 to 300 ms (P200). A stem tone × antpost interaction, $F(1,21) = 4.46$, $P = 0.031$, showed that the effect was concentrated to anterior, $F(1,21) = 7.60$, $P = 0.012$, and central, $F(1,21) = 4.35$, $P = 0.049$, electrodes.

2.2.2. Morphological error detection

Between 100 and 250 ms following suffix onset (on average, 477–627 ms after word onset), a negativity for declensionally incorrect suffixes yielded a main effect, $F(1,21) = 10.07$, $P < 0.001$, as seen in Fig. 3 (N400). *Post hoc* comparison showed significant differences between incorrect plural suffixes (INC) on the one hand, and correct plural (PL), $P = 0.006$, as well as singular

[4] The somewhat low overall acceptability was probably due to the oddity of the sentences, resulting from the low number of phonetically appropriate words that could be combined. This effect was, however, stable across conditions.

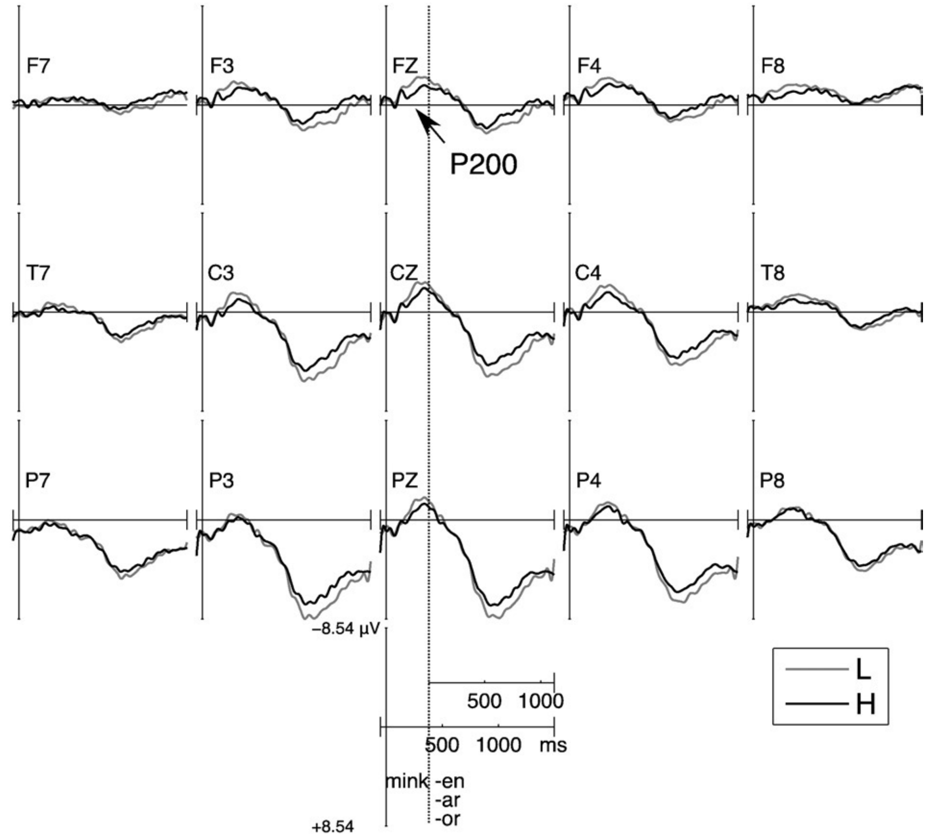

Fig. 2 – ERP effects of tone processing. High Accent 2 tones (H, black line) produced a frontal positive peak between 200 and 300 ms following tone/word onset (P200), absent for low Accent 1 tones (L, gray line).

suffixes (SG), $P<0.001$, on the other. There was no effect of stem tone in this time window.

2.2.3. Reanalysis

As seen in Fig. 3, between 450 and 900 ms following suffix onset (827–1377 after word onset), the declensionally incorrect suffix *–or* (INC) yielded a positive deflection as compared to the other conditions. Fig. 4 shows how, in the same time window, the morphologically correct high tone-inducing plural suffix –*ar* produced a positive effect in LPL, where it mismatched the low Accent 1 tone, as compared to its tone-matching condition HPL. Similarly, the declensionally incorrect high-inducing suffix *–or* in stem–tone mismatching LINC increased the positivity as compared to the incorrect but tone-matching HINC.

The effects were seen in a tone × suffix × laterality interaction, $F(4,84)=5.53$, $P<0.001$, revealing a tone × suffix interaction at mid, $F(2,42)=6.26$, $P=0.004$, and right sites, $F(2,42)=4.02$, $P=0.025$. At mid electrodes, stem tone had a significant effect on high tone-inducing suffixes, both the correct *–ar*, seen in a difference between HPL and LPL, $F(1,21)=10.59$, $P=0.004$, and the incorrect *–or* in HINC as compared to LINC, $F(1,21)=11.45$, $P=0.003$, but not on the tone-neutral singular suffix *–en* in HSG and LSG, $F(1,21)=0.851$, $P=0.367$. There were significant effects for suffix in words realized with both Accent 1, $F(2,42)=19.77$, $P<0.001$, and Accent 2, $F(2,42)=13.50$, $P<0.001$. *Post hoc* comparison showed a difference between the high-inducing *–ar* (LPL) and tone-neutral –en (LSG) suffixes in Accent 1 (low tone) stimuli, $P=0.021$, but not Accent 2 (high tone) stimuli (HPL and HSG), $P=0.273$. The declensionally incorrect suffix *–or* in LINC and HINC increased positivity as compared to the correct suffixes *–ar* and *–en* in LPL, LSG, HPL, and HSG, $P<0.002$. At right sites, effects of suffix for both Accent 1, $F(2,42)=20.08$, $P<0.001$, and Accent 2 stimuli, $F(2,42)=6.63$, $P=0.005$, revealed differences between declensionally incorrect (LINC and HINC) and correct suffixes (LPL, LSG, HPL, and HSG), $P<0.001$. Tone showed a significant difference between HINC and LINC, $F(2,42)=15.74$, $P=0.001$, a marginal difference between HPL and LPL, $F(2,42)=4.09$, $P=0.056$, and no difference between HSG and LSG, $F(2,42)=.578$, $P=0.456$.

3. Discussion

This study investigated whether stem tones realizing word accents function as prosodic cues for the suffixes they are associated with in online processing of Central Swedish. It was based on the hypothesis that high Accent 2 stem tones are assigned morphophonologically by tone-inducing suffixes. Such being the case, hearing a high tone would be thought to activate the associated suffixes. In the absence of a high tone on the stem, the suffixes would require reanalysis. Results were compared with those for suffixes that were incorrect due to their declension class. Effects were observed in three different time windows. First, the high stem tone of Accent 2 increased the

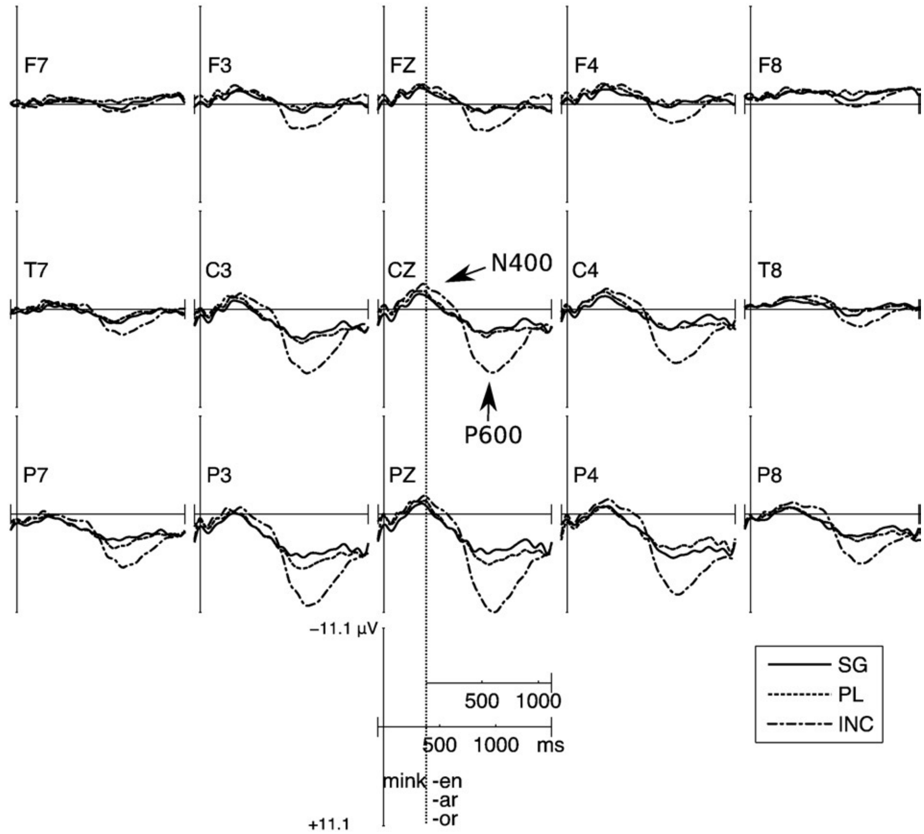

Fig. 3 – ERPs for suffix processing. Morphologically incorrect suffixes (INC) yielded a widely distributed increase in the N400 between 100 and 250 ms following suffix onset, and a later posterior positive deflection (P600) between 450 and 900 ms after suffix onset (dot-dashed line).

P200 component. Second, declensionally incorrect suffixes produced an increase in the N400. In a later time window, information from word accent and suffix interacted. Thus, incorrect suffixes yielded a positive deflection peaking at 600 ms following suffix onset. Both correct and incorrect high tone-inducing suffixes produced a more positive waveform in words realized with a mismatching low stem tone (Accent 1) in the same time window. The stem tone–suffix mismatch did not, however, affect the N400.

3.1. *Tone perception*

Between 200 and 300 ms from stem tone onset, test words with high stem tones (Accent 2) produced an anterior positive deflection. The time frame and distribution coincide with effects previously obtained for Swedish high left-edge boundary tones. The early latency of the P200 suggests that it is a preattentive effect of the perception of the pitch rise, processed in the anterior and temporal cortex.

3.2. *Morphological error detection*

Incorrect inflection produced a broadly distributed negativity in the second time window, at 100 to 250 ms following suffix onset (477 to 627 ms following word onset). This result is similar to N400 effects that have earlier been observed for irregular inflectional suffixes in German. The increased negativity has been interpreted as indicating that incorrect irregular words are treated as unfamiliar words, causing difficulty in lexical retrieval, rather than being decomposed by general morphological rules. Hence, "regular" Swedish nominal stems appear to be associated with their suffixes in the mental lexicon in a manner similar to irregular German nouns. Mismatch between word accent tone and suffix did not produce any N400 effect, suggesting that tonal discrepancies did not cause problems in lexical retrieval. Hence, word accent tones do not seem to be associated with whole word forms in the mental lexicon.

The early latency of the negativity in relation to suffix onset is in line with previous studies that have measured effects of suffix from word onset. The broad distribution in addition to its earliness makes the negativity similar to N200 effects, which have been argued to reflect lexical choice based on a preliminary acoustic analysis. In the present context, the negativity could thus stem from a conflict in the choice among a limited set of possible endings based on a rapid acoustic analysis.

3.3. *Interaction of stem tone and suffix information*

In a third time window, between 450 and 900 ms after suffix onset, i.e., 827 to 1377 ms following word onset, information from tone and suffix was observed to interact. Suffixes from an incorrect declension class yielded a positive deflection

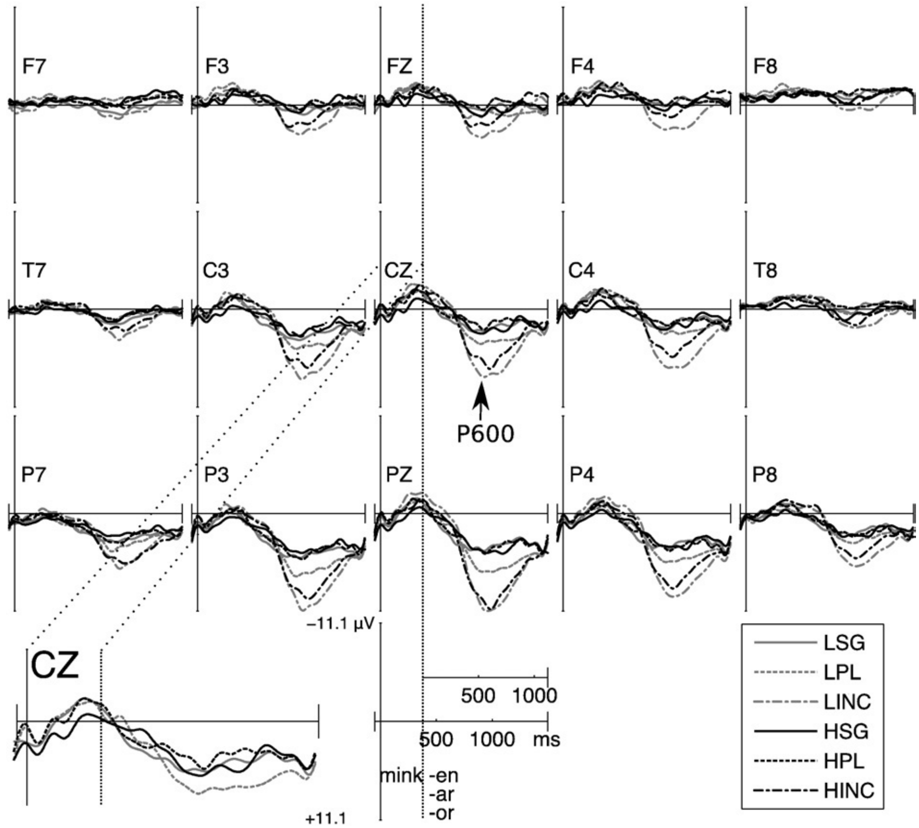

Fig. 4 – ERPs for all conditions. High tone-inducing suffixes yielded a P600 effect after low stem tones (L), whether morphologically correct (LPL) or incorrect (LINC). The enlarged CZ channel shows the ERPs of declensionally correct suffixes. The mismatch between stem tone and suffix in LPL did not yield any N400 effect.

peaking at around 600 ms (977 ms following word onset). The positivity is probably a P600, reflecting reanalysis of the stem–suffix combination. There was a similar P600 effect for high tone-inducing suffixes following stems realized with a low Accent 1 tone. It thus seems that the morphophonological information from tone and suffix interacted in a late time window, where the low tone of the stem was replaced by the high tone required by the suffix. Low Accent 1 stem tones increased the P600 for mismatching high tone-inducing suffixes independently of whether the suffix was declensionally correct or incorrect. The reanalysis effect in the incorrect words suggests that there is a specific association between the high tone-inducing suffixes and the high stem tone, since it is highly unlikely that the subjects would have heard the whole incorrect word forms and their associated tonal pattern enough times to establish a relationship between them.

Mismatch between high test word tones (Accent 2) and suffixes normally co-occurring with low Accent 1 stems did not result in any P600 effect. This would seem to indicate that the low tone of Accent 1 is not induced by the suffix, but is rather a default tone, realized in the absence of high-inducing suffixes, as has been previously assumed.

3.4. *Conclusions*

Summarizing, the results indicate the following course of word processing in the test sentences: first perception of tone and processing of lexical information took place, processes that are reflected in the P200 and N400 components, respectively. Complication in lexical retrieval due to incorrect suffixes increased the N400, starting at 100 ms following suffix onset. Suffixes mismatching the stem tone did not increase the N400, and thus did not seem to impede lexical retrieval. In a later time window, high tone-inducing suffixes not cued by a high stem tone yielded reanalysis of the word form, seen in a P600 effect similar to that of suffixes mismatching the stem's declension class. In conclusion, results indicate that high Accent 2 tones are induced onto stems by certain suffixes rather than being associated with full word forms in the mental lexicon. Therefore, high stem tones function as cues activating their associated suffixes. In the absence of a high stem tone, high-inducing suffixes are unexpected and trigger reanalysis.

4. Experimental procedures

4.1. *Participants*

Twenty-two right-handed healthy students at Lund University, native speakers of Central Swedish, participated. Seventeen were female, and the mean age was 23.8 years, SD = 3.1 years, ranging from 18 to 31 years.

4.2. Stimuli

All test sentences had the same syntactic and prosodic structure as the one presented in Fig. 1: *Damen dränker minkar till pälsen på lördag* 'the lady drowns minks for the fur coat on Saturday,' but the words varied across all sentences. The test word was always an unfocused direct object realized by a second declension noun, such as *minkar* 'minks' in Fig. 1. Two versions of each sentence were recorded. One had the indefinite plural suffix *–ar*, yielding a word with a high tone (H) associated with the stressed stem vowel, as shown by the black fundamental frequency contour in Fig. 1. In the other version, the object contained the definite singular suffix *–en*, producing a word with a low stem tone (L), as indicated by the gray line. Additionally, sentences with the same prosodic characteristics, but with first declension words containing the indefinite plural suffix *–or* were recorded to obtain the incorrectly inflected nouns. Sentences with fifth declension words were also recorded, and a control condition with words containing the incorrect definite singular Accent 1 suffix *–et* (e.g., **minket* 'the mink') was created. This condition prevented the Accent 2 tone from becoming more frequently associated with morphologically incorrect suffixes than the Accent 1 tone.

The onsets of the second syllable of the verb (e.g., *–ker* in *dränker* 'drowns') and the direct object (*–kar* in *minkar* 'minks'), as well as the onset of the following preposition, were always voiceless stops. The sentences were cut in the occlusion phase of these stops, generating four different parts, e.g., *Damen drän–* 'The lady drown–,' *–ker min–* '–s (the) min–,' *–kar/–ken/–kor/–ket* 'pl (decl 2)/sg (decl 2)/pl (decl 1)/sg (decl 5),' and *till pälsen på lördag* 'for the fur coat on Saturday.' The four parts were then spliced together to obtain high and low tone words with the four different suffixes. Sentences with the same word accent were thus identical across conditions until the onset of the suffix of the test word.

The onset of the suffix, i.e., the uniqueness point of the word, occurred on average 377 ms following word onset, SD = 71 ms. Fundamental frequency differed minimally at suffix onset: 5.2 semitones (st, *re* = 100 Hz) for *–en*, SD = 0.98, 5.0 st for *–ar*, SD = 0.91, 5.0 st for *–et*, SD = 0.83, and 5.3 st for *–or*, SD = 0.85.

Forty sentences in each of the six test conditions and the two control conditions were constructed from original recordings of a male speaker of Central Swedish made in an echo-free room at the Humanities Laboratory, Lund University. A total of 320 test sentences were constructed. Another 640 unrelated filler sentences were also prepared. All in all, there were thus 960 sentences in the experiment. The test sentences started with a left-edge boundary tone, the high tone seen over the second (unstressed) syllable of *Damen*, and had sentence focus elicited on the content word of the first adverbial phrase, seen as a rise in the stressed first syllable of *pälsen* 'the fur coat' in Fig. 1. The sampling frequency was 44.1 kHz, and the amplitude was normalized after recording.

4.3. Procedure

Subjects were seated in front of a computer screen. The sentences were presented auditorily in pseudorandomized order through loudspeakers placed in front of the subjects, who were instructed to judge sentence acceptability by pressing one of two buttons.

4.4. 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 electrooculogram (EOG). The electrodes were referenced to a central reference electrode online, and were re-referenced to averaged mastoids offline. The ground reference was a frontal cap-mounted electrode. The sampling rate was 250 Hz, and an online band-pass filter with cutoff frequencies of 0.05 and 70 Hz was used. Bad channel signals were replaced offline using spherical spline interpolation with the surrounding electrodes.

4.5. Data analysis

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

Offline EEG data were analyzed in EEGLAB (Delorme and Makeig, 2004). The EEG was filtered with a 30-Hz low-pass filter and divided into epochs from 50 ms before to 1500 ms following the onset of the word accent tones, coinciding with the onset of the test words. A time window of 300 ms before the splice point in the preceding verb (*–ker* in Fig. 1), where the conditions were identical, was used for baseline correction. Ocular artifacts were compensated for using independent components analysis (ICA) (Jung et al., 2000). Trials were removed whenever the amplitude exceeded ±100 μV after compensation for EOG artifacts. The electrodes were grouped into nine regions of interest corresponding to three anterior/posterior and three laterality conditions: left anterior with electrodes F7, F5, F3, FT7, FC5, and FC3; mid anterior with F1, FZ, F2, FC1, FCZ, and FC2; right anterior with F4, F6, F8, FC4, FC6, and FT8; left central with T7, C5, C3, TP7, CP5, and CP3; mid central with C1, CZ, C2, CP1, CPZ, and CP2; right central with C4, C6, T8, CP4, CP6, and TP8; left posterior with P7, P5, P3, P07, PO5, and O1; mid posterior with P1, PZ, P2, PO3, PO4, and OZ; and right posterior with P4, P6, P8, PO6, PO8, and O2.

Behavioral and ERP results were submitted to repeated measures ANOVAs in SPSS with the two test factors 'stem tone' (H, L) and 'suffix' (SG, PL, INC), as well as the two topographical factors 'antpost' (anterior, central, posterior) and 'laterality' (left, mid, right).[5] The test conditions are found in Table 1. Greenhouse–Geisser correction was used when applicable. Subject averages were used as raw data for the statistical analysis. Effect latencies were determined through a timeline analysis, where the ERP epochs were divided into 50-ms time windows. Contiguous significant 50-ms windows were averaged as larger time windows. Interactions with topographical factors were resolved by assessing the test factors at each of the levels of the topographical factor.

[5] Mixed logit models have proven to give more accurate results for proportional data than ANOVA (Dixon, 2008; Jaeger, 2008), which is used in the present study for simplicity.

Acknowledgments

This research was supported by the Swedish Research Council under grant 70175901 and by the Linnaeus Center for Cognition, Communication and Learning, Lund University. We are grateful to two anonymous reviewers whose comments considerably improved the interpretation of the results.

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