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Recognition of morphologically complex words in Finnish: Evidence from event-related potentials

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ABSTRACT

The temporal dynamics of processing morphologically complex words was investigated by recording event-related brain potentials (ERPs) when native Finnish-speakers performed a visual lexical decision task. Behaviorally, there is evidence that recognition of inflected nouns elicits a processing cost (i.e., longer reaction times and higher error rates) in comparison to matched monomorphemic words. We aimed to reveal whether the processing cost stems from decomposition at the early visual word form level or from re-composition at the later semantic–syntactic level. The ERPs showed no early effects for morphology, but revealed an interaction with word frequency at a late N400-type component, as well as a late positive component that was larger for inflected words. These results suggest that the processing cost stems mainly from the semantic–syntactic level. We also studied the features of the morphological decomposition route by investigating the recognition of pseudowords carrying real morphemes. The results showed no differences between inflected vs. uninflected pseudowords with a false stem, but differences in relation to those with a real stem, suggesting that a recognizable stem is needed to initiate the decomposition route.

1. Introduction

In the study of the mental lexicon, processing of morphologically complex words, such as "horse+s", has long attracted research interest. Different models have been put forth in order to describe the mental representations of these words. Some models have suggested that the recognition of all morphologically complex words occurs via decomposing the stem and the affix during recognition (Taft and Forster, 1975), while others have assumed that all (familiar) complex word forms are stored as whole units in the mental lexicon (Butterworth, 1983). More recent models are based on the so-called dual-route architecture, assuming that both processing routes can be used (e.g., Chialant and Caramazza, 1995; Niemi

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et al., 1994; Schreuder and Baayen, 1995). These models often assume that several factors influence the way morphologically complex words are recognized. For instance, word form frequency has been suggested to be an important determinant of the processing route used. In support of the dual-route models, there is evidence that high-frequency words can develop full-form representations, while low-frequency words are still recognized by accessing the representations of the morphological constituents (e.g., Alegre and Gordon, 1999; Baayen et al., 1997; Frauenfelder and Schreuder, 1992; Lehtonen and Laine, 2003; Lehtonen et al., 2006a; New et al., 2004; Schreuder and Baayen, 1995). As decomposition is assumed to be slower and more error-prone than full-form processing, it is economical to represent words that are used often as full forms since that guarantees effective access to them.

1.1. *Recognition of inflected words in Finnish*

The structure of language can also affect the processing route used with inflected words. Finnish is a Finno-Ugric language with a very rich inflectional system, distinct from morphologically limited Indo-European languages such as English or German. Finnish nouns have about 13–15 case forms, and besides cases nouns can be marked with number, possessive suffixes and clitic particles. Each Finnish noun can theoretically have as many as 2000 different possible forms (e.g., the word “kouluissammekin” *koulu* + *i* + *ssa* + *mme* + *kin* = ‘school’, plural marker -*i*, inessive ending -*ssa*, possessive suffix -*mme*, clitic particle -*kin* = ‘also in our schools’) of which about 150 are paradigmatic core forms (Karlsson and Koskenniemi, 1985). It is plausible to assume that most Finnish inflected words are decomposed during recognition, as storing all the possible forms as a whole in the mental lexicon would not be economical for memory. Evidence for decomposition of inflected words in the Finnish language, i.e., longer reaction times (RTs) and/or higher error rates for inflected vs. monomorphemic nouns, has indeed been obtained from oral reading performance in aphasic patients (Laine et al., 1994, 1995) as well as from a number of behavioral studies with Finnish-speaking healthy participants using visual lexical decision (Laine and Koivisto, 1998; Laine et al., 1999; Niemi et al., 1994), progressive demasking (Laine et al., 1999) and eye-movement recordings (Hyönä et al., 1995).

Although most inflected Finnish nouns seem to be processed via morpheme-based recognition, the results of a single intensively studied aphasic patient (Laine et al., 1995) suggest that very high frequency inflected words can be represented as full forms even in Finnish. Lehtonen and Laine (2003) investigated the effect of frequency with healthy Finnish monolinguals and found that the difference between inflected and monomorphemic nouns was present in the low and to some extent in the medium-frequency range but disappeared with the high-frequency items, suggesting that the most commonly encountered inflected words may be processed via full-form representations. It is of interest to investigate whether their results could be replicated, and whether an interaction between morphology and frequency could also be found at the neural level when studying morphological processing with event-related potentials (ERPs).

The morphological decomposition process is assumed to encompass two major processing steps (Laine et al., 1994; Niemi et al., 1994; Schreuder and Baayen, 1995): (1) decomposition at the visual word form level and (2) integration of the meaning and syntactic aspects of the constituents at the semantic–syntactic level. The first of these stages has been attributed to prelexical affix stripping (e.g., Taft and Forster, 1975), or accessing the separate representations of the stem and affix at the level of the visual input lexicon (e.g., Laine et al., 1994; Niemi et al., 1994). The second stage, in turn, is assumed to involve two subprocesses (Schreuder and Baayen, 1995): licensing, where the combinability of the stem and affix is checked, and composition, where the meaning of the constituents is computed and integrated. Longer RTs and higher error rates for inflected than for monomorphemic words in lexical decision generally suggest that the decomposition route has been in use, but they do not reveal to what extent each of the major processing stages contributes to the processing cost. Hyönä et al. (2002) suggested that it is the later, semantic–syntactic stage that is more dominant, as the robust morphological processing cost observed with single words disappeared when inflected words were embedded in neutral sentence context. If the processing cost would stem from the visual word form level, it should be unaffected by the presence or absence of a neutral sentence context. Semantic–syntactic processing of inflected words, on the other hand, crucially depends on the presence of other sentence constituents. Also a recent functional magnetic resonance imaging (fMRI) study by Lehtonen et al. (2006b) found that the brain areas activated during recognition of inflected vs. monomorphemic words were those associated with semantic–syntactic processing [the left inferior frontal gyrus, Brodmann area (BA) 47; and the left posterior superior temporal sulcus, BA 22/21/39], suggesting that the processing cost stems from that level. In the current paper, we used the ERP method which provides millisecond-level accuracy and is thus particularly suitable for investigating the time-course of cognitive processes. We were interested in seeing at which point the processing of inflected nouns begins to differ from that of monomorphemic ones. The latency of such an effect can inform us as to whether these effects reflect early, visual word form processing or later semantic–syntactic processing.

1.2. *Previous ERP studies on morphological processing*

Previous electrophysiological studies of morphological processing have mostly been conducted with Indo-European languages (English, Spanish, Catalan, German and Italian), and they have mainly addressed the distinction between irregular and regular inflection. As Finnish has a fully regular inflectional system (albeit the system of phonological changes that the stem can undergo during inflection is quite complex), the contrast between irregular and regular words cannot be investigated in this language. The previous studies have employed primarily two types of paradigms, morphological priming with lexical decision (Barber et al., 2002; De Diego Balaguer et al., 2005; Domínguez et al., 2004; Münte et al., 1999; Rodríguez-Fornells et al., 2002; Weyerts et al., 1996), and reading of morphologically incorrect forms (morphological violations) either in sentences or in stories (Linares et al., 2006; Morris and Holcomb, 2005; Penke et al., 1997; Rodríguez-Fornells et al., 2001; Weyerts et al., 1997) or in single-word judgment tasks (Gross et al., 1998; Morris and Holcomb, 2005; Penke et al., 1997). To date, direct contrasts for matched inflected vs. monomorphemic words have not, to the best of our knowledge, been reported using ERPs. The electrophysiological components most commonly associated with morphosyntactic processing have been the left anterior negativity (LAN) with a time-window of about 250–550 ms and a left anterior topography, and the P600 component that typically has a centro-parietal maximum, onset between 300 and 500 ms, and a length of several hundred milliseconds. Also the N400, a component associated to lexical–semantic processing (e.g., Holcomb and Neville, 1990; Kutas and Federmeier, 2000), has been found to be sensitive to the regularity of the inflected words (Münte et al., 1999; Rodríguez-Fornells et al., 2002; Weyerts et al., 1996). The N400 appears at a similar time-window as the LAN but typically showing its peak at central–posterior locations.

The studies investigating morphological priming effects with irregularly vs. regularly inflected words have all found attenuation for regular words in an N400-type component when compared to similar unprimed words (Münte et al., 1999; Rodríguez-Fornells et al., 2002; Weyerts et al., 1996), and sometimes also a difference in a positive late component (Weyerts et al., 1996). Priming effects for irregular words, in turn, have been markedly smaller or non-existent. These results speak for a dual-route account of inflection. Decomposing the word into stem and affix during recognition activates the representation of the stem and thus enables it to work as an effective prime. On the other hand, irregular words that cannot be decomposed activate a distinct lexical entry that is separate from the stem and thus does not produce as large priming effects. Importantly, these effects seem to be independent of orthographic/phonological priming effect. Thus the effects cannot be explained by the larger formal overlap between prime and target in regular than in irregular words.

Studies investigating morphological violations have typically employed two types of incorrect forms: (1) overregularization of irregular words (e.g. *run*→**runned*), and (2) irregularization of regular words (e.g. *peep*→**pept*). Results have most often shown clearer LAN effects for the former type of violations, assumedly because a morphological rule is misapplied in the case of violations of irregular words while no rule can be employed when irregularizing regular words (Gross et al., 1998; Penke et al., 1997; Rodríguez-Fornells et al., 2001). Also violations of stem formation have been studied (Gross et al., 1998; Linares et al., 2006; Rodríguez-Fornells et al., 2001). Generally LAN effects have been more robust in sentence contexts than in single-word tasks (Morris and Holcomb, 2005; Rodríguez-Fornells et al., 2001; Weyerts et al., 1997, but see Penke et al., 1997). In fact, Morris and Holcomb (2005), who found a LAN effect for morphological violations only in sentence context but a P600 component in both single-word and sentence tasks, suggested that the LAN reflects difficulties at the syntactic rather than morphological level, and that it seems to be related to integration of a word into a sentence. The P600 component, in turn, was interpreted to be sensitive to difficulties in combinatorial processes both at the morphological and at the syntactic level.

1.3. *The present study*

The first aim of the present study is to reveal which of the two processing stages, decomposition at the visual word form level or integration of the constituents at the semantic–syntactic level, shows more marked effects in ERPs when normal participants process inflected noun forms in a lexical decision task. Based on eye-movement and ERP data, Sereno and Rayner (2003) have proposed that the visual word form is accessed by 200 ms of the presentation of a word, and a few other studies have suggested time-ranges around 200–300 ms for lexicality effects (Cohen et al., 2000; Martin et al., 2006). If we see effects of morphology in such early time-windows, it would indicate differential processing for the two word types (decomposition for inflected words, full-form processing for monomorphemic words) at the visual word form level. On the other hand, if morphological effects are observed in the later time-windows reflecting semantic–syntactic aspects of processing (e.g., in N400 or P600), we would conclude that the inflectional processing cost stems from the semantic–syntactic integration stage.

The second aim was to see whether morphological effects in ERPs are modulated by word frequency as was suggested by the results of Lehtonen and Laine (2003): we expected the processing differences between inflected vs. monomorphemic words to be present in the low-frequency range but vanish in the high-frequency range, reflecting full-form processing of high-frequency inflected words.

Third, features of the decomposition route were studied further by systematically manipulating the morphological structure of the pseudowords included in the stimulus set. Specifically, we addressed the issue as to whether the stem and the suffix of an inflected word are accessed in parallel during visual recognition or whether the information of the stem is dominant and becomes available before the suffix. A behavioral study by Laine (1999) points to the latter alternative. To study this, we contrasted two types of pseudowords that carried a real stem against two other types that did not. If the stem dominance hypothesis holds, this contrast should show significant effects. At the same time, if a real stem is absent, a real suffix in a pseudoword should not exert any effects. This contrast was provided by the two types of pseudowords that did not carry a real stem: they were either "monomorphemic" (included no recognizable morphemes) or consisted of a false stem and a real suffix.

Another issue addressed by the manipulation of pseudoword structure dealt with the licensing stage of morphological decomposition (see Schreuder and Baayen, 1995) that is assumed to include the morphophonological legality check of the stem and suffix combination. Pseudowords with an illegal stem+suffix combination and thus a violation of morphophonological rules were included in the stimulus set. It was of interest to see how they manifest themselves in ERPs and whether LAN and/or P600 effects could be observed with these items in a single-word task. If left anterior negativities reflect grammatical rule violations at single-word level, we should observe a LAN effect for these items.

Table 1 – Mean response latencies (in ms) and error rates with standard deviations for the stimulus types

Word category		RT (SD)	Error (SD)
Real words			
Low frequency	Monomorphemic	653 (153)	2.19 (1.25)
	Inflected	754 (191)	10.0 (5.10)
High frequency	Monomorphemic	598 (147)	1.09 (1.36)
	Inflected	666 (164)	3.13 (3.45)
Pseudowords			
Monomorphemic		709 (123)	2.42 (2.16)
Pseudostem + suffix		713 (124)	2.89 (2.03)
Stem + pseudosuffix		665 (107)	1.09 (1.11)
Illegal stem + suffix combination		832 (155)	11.4 (7.08)

Accordingly, the following four types of pseudowords were included in the stimulus set: (1) "monomorphemic" pseudowords (e.g., a non-existing stem *kamsteri*), (2) pseudowords with a false stem but a real inflectional suffix (here called "pseudostem + suffix" pseudowords, e.g., **värö* + *ssä* = pseudostem **värö* + a real inessive ending -*ssä*), (3) "stem + pseudosuffix" pseudowords that included a real stem and a false suffix (e.g., **onni* + *tla* = real stem *onni*, 'happiness' + *-*tla* which is close to the real ablative ending -*lta*, 'from off of something'), and (4) pseudowords with an "illegal stem + suffix combination" where both the stem and the suffix were real but the combination violated the morphophonological rules of inflection for Finnish (e.g., **lammas* + *en* = 'sheep' + real genitive suffix; the correct form is *lampaa* + *n*).

2. Results

2.1. Behavioral results

Prior to the behavioral data analysis, incorrect responses and RTs longer than three standard deviations from the mean were excluded. The overall error rate (including both real words and pseudowords) varied from 1.09% to 7.97% (mean = 4.28, SD = 1.92). The RTs and error rates for each condition can be seen in Table 1.

Two-way repeated measures ANOVAs were performed for the RTs and error rates. As regards the real word RTs, a statistically significant main effect for morphology [$F(1,15) = 63.8$; $p < 0.001$] and for frequency [$F(1,15) = 54.2$; $p < 0.001$] was found, indicating that the inflected words were generally processed more slowly than the monomorphemic words and that the high-frequency words were recognized faster than the low-frequency words. Also a significant frequency by morphology interaction was observed [$F(1,15) = 8.55$; $p = 0.01$]. Inspection of the reaction times (Table 1) suggests that the interaction was due to a larger difference between inflected and monomorphemic words in the low- than in the high-frequency range. However, two-tailed paired *t*-tests revealed that the RT difference between inflected vs. monomorphemic words was significant both in the low-frequency range [$t(15) = 6.78$; $p < 0.001$] and in the high-frequency range [$t(15) = 8.53$; $p < 0.001$].

Error rates for real words showed a similar pattern as RTs: there was a significant main effect for morphology [$F(1,15) =$

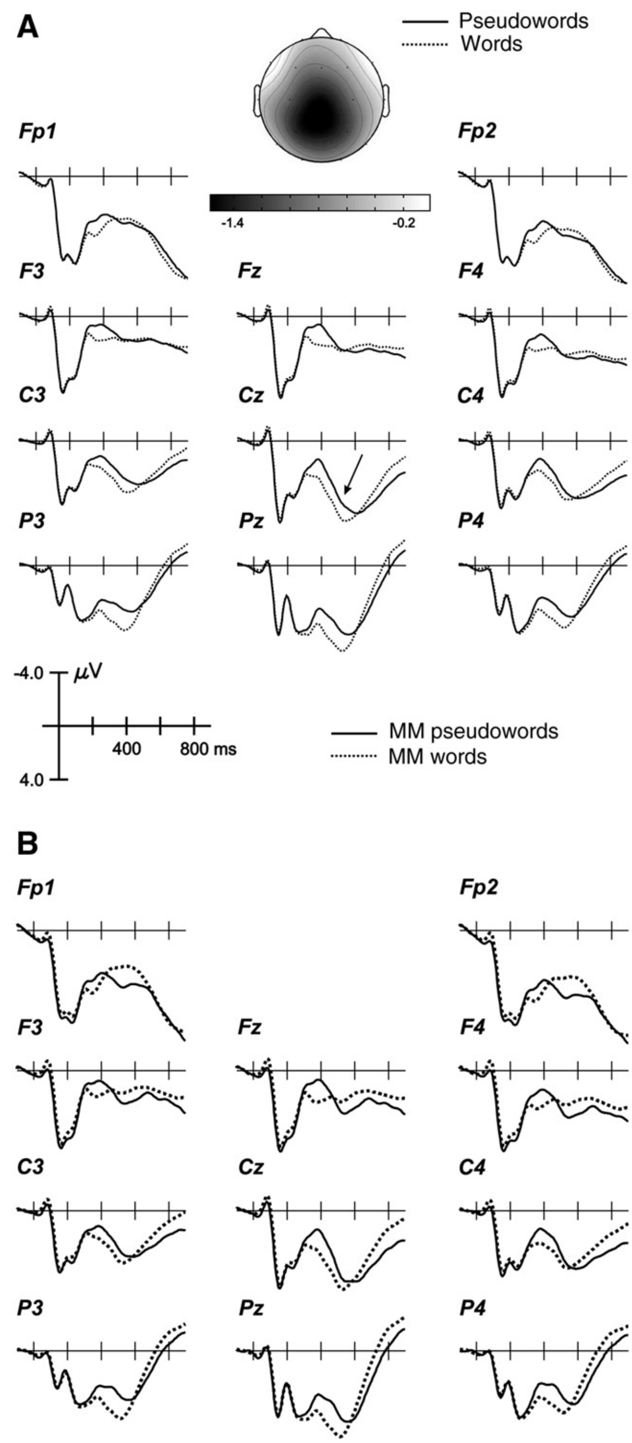

Fig. 1 – (A) Grand average potentials for words (dotted lines) and pseudowords (solid lines) collapsed across all conditions. Different electrode positions at fronto-central and parasagittal locations are shown. The arrow is showing the more negative deflection for pseudowords at 350–550 ms. The topographical map was computed from the difference waveform (pseudowords minus words) at the mean amplitude in the 350–550 time-window and using isovoltage mapping with spherical spline interpolation. (B) Grand average ERPs for the monomorphemic real words collapsed across frequency conditions (dotted lines) vs. the monomorphemic pseudowords (solid lines).

28.6; $p<0.001$] and for frequency [$F(1,15)=75.2$; $p<0.001$], indicating that in general the participants made more errors for inflected than monomorphemic words and more errors for low- than high-frequency words. The frequency by morphology interaction was also significant [$F(1,15)=30.2$; $p<0.001$], showing that the difference in error rates between inflected vs. monomorphemic words was larger in the low-frequency range. This difference was again significant both in the low-frequency range [$t(15)=6.02$; $p<0.001$] and in the high-frequency range [$t(15)=2.72$; $p<0.05$]. The fact that the RT and the error rate differences between inflected and monomorphemic items were significant in both frequency ranges indicates decomposition for both low- and high-frequency inflected items. The significant interaction, however, suggests that some of the high-frequency words might have been recognized via full forms.

As regards the pseudoword items, a one-way repeated measures ANOVA for RTs showed a main effect for pseudoword type [$F(3,45)=61.5$; $p<0.001$]. Two-tailed paired samples t-tests were performed for the contrasts of interest. The stem+pseudosuffix items showed the fastest responses and elicited significantly shorter RTs than the monomorphemic pseudowords [$t(15)=6.36$; $p<0.001$]. There was no difference in RTs between the monomorphemic and pseudostem+suffix pseudowords [$t(15)<1$]. The illegal stem+suffix combination pseudowords, in turn, elicited significantly longer reaction times than the pseudostem+suffix pseudowords [$t(15)=8.73$; $p<0.001$], and thus were the most difficult stimulus type of all. For error rates, the ANOVA again showed a significant main effect for pseudoword type [$F(3,45)=29.6$; $p<0.001$]. The difference between the monomorphemic and stem+ pseudosuffix pseudowords was only close to significance in this analysis [$t(15)=2.08$; $p=0.056$], and the difference between monomorphemic and pseudostem+suffix pseudowords was not significant [$t(15)=0.706$; $p=0.491$]. The error rates for the illegal pseudowords were significantly higher than for the pseudostem+suffix pseudowords [$t(15)=6.17$; $p<0.001$]. In sum, the results for the pseudowords showed that the stem+ pseudosuffix items with a real stem and a non-existing affix were processed faster than the other pseudoword groups. Monomorphemic pseudowords were recognized about equally fast and with an equal amount of errors as the pseudostem+ suffix pseudowords with a non-existing stem and a real affix, while the illegal stem+suffix combination pseudowords were clearly the ones eliciting the highest processing load.

2.2. ERP results

2.2.1. *Lexicality effects*

Grand average ERPs for all real words vs. all pseudowords, as well as for monomorphemic words (high- and low-frequency collapsed) vs. monomorphemic pseudowords, are illustrated in Figs. 1A and B, respectively. The first 200 ms of the ERP waveforms were not affected by lexicality in the first contrast (all words vs. all pseudowords). Differences between words and pseudowords started to emerge around 300–350 ms after stimulus onset (see Fig. 1A). This was related to an enhanced negativity for pseudowords (see Table 2A). The results of the distributional analysis (see Table 3A) showed that the lexicality effect was largest at central–posterior and medial locations.

When comparing monomorphemic words against monomorphemic pseudowords, an early main effect of lexicality on the N1 component was found due to a more negative N1 amplitude for words (see Table 2B). This N1 effect was located at anterior–central and medial locations. A main effect for lexicality, with an enhanced negativity for pseudowords, was also observed in later time-windows, starting at 350 ms (see Table 2B). The subsequent distributional analysis (see Table 3B) revealed that this lexicality effect for monomorphemic items was particularly notable at central–posterior and medial locations. The effect was larger over the right than the left hemisphere.

2.2.2. *Effects of morphology and word frequency*

The monomorphemic words began to differ from the inflected ones at about 450 ms, showing a broadly distributed negativity (Fig. 3). This main effect of morphology became statistically significant in the 550–650 ms time-window and remained

Table 2 – Omnibus ANOVA for: (A) *lexicality* (all real words vs. all pseudowords), (B) *lexicality for only monomorphemic* items (words vs. pseudowords) and (C) the effects of *frequency and morphology* in real words

	50–150	150–250	250–350	350–450	450–550	550–650	650–750	750–850
A.								
Lexicality				$p<0.01$	$p<0.05$			$p<0.05$
Lexicality x Electrode				$p<0.01$	$p<0.001$			$p<0.01$
B.								
MM (words vs. pseudowords)	$p<0.05$			$p<0.01$			$p<0.01$	$p<0.05$
MM x Electrode	$p<0.05$			$p<0.05$	$p<0.001$			$p<0.05$
C.								
Frequency							$p<0.05$	$p<0.05$
Morphology						$p<0.01$	$p<0.01$	$p<0.01$
Frequency x Morphology					$p<0.05$			
Frequency x Electrode			$p<0.01$		$p<0.05$		$p<0.001$	$p<0.001$
Morphology x Electrode					$p<0.01$	$p<0.05$	$p<0.01$	$p<0.001$

Notes. Electrode factor comprises 15 locations.
$p<0.05$ (light grey), $p<0.01$ (medium grey), $p<0.001$ (black).

Table 3 – Statistically significant results for decomposition of conditions showing an interaction in the omnibus ANOVA (Table 2): (A) *lexicality* (all real words vs. all pseudowords), (B) *lexicality for only monomorphemic* items (words vs. pseudowords) and (C) *morphology* and *word frequency* in real words, in the analyses including the topographical factors or certain other electrode positions [a]

Factors	Time-window (ms)	*F*-test, *p*-value
A. Lexicality		
Lexicality × A/P	350–550	$F(2,30)=4.56$, $p<0.05$
Lexicality × Lat	350–550	$F(1,15)=12.84$, $p<0.01$
B. Lexicality for monomorphemic items		
MM–Lexicality × A/P	80–120	$F(2,30)=7.66$, $p<0.02$
MM–Lexicality × Lat	80–120	$F(1,15)=4.55$, $p=0.05$
MM–Lexicality × A/P	350–550	$F(2,30)=6.66$, $p<0.02$
MM–Lexicality × Lat	350–550	$F(1,15)=17.39$, $p<0.001$
MM–Lexicality × Hem × Lat	350–550	$F(1,15)=5.70$, $p<0.05$
C. Morphology and Word Frequency		
Morphology × Frequency [b]	450–550	$F(1,15)=5.03$, $p<0.04$
Pairwise comparison: low-frequency monomorphemic vs. inflected words	450–550	$F(1,15)=6.12$, $p<0.03$
Frequency × Hem	300–400	$F(1,15)=4.59$, $p<0.05$
Morphology × Hem × A/P × Lat	450–550	$F(2,30)=3.92$, $p<0.05$
Morphology × Lat	600–800	$F(1,15)=24.72$, $p<0.001$
Morphology × Hem	600–800	$F(1,15)=4.78$, $p<0.05$

A/P = anterior/posterior, Lat = laterality, Hem = hemisphere.

[a] Note that the reported distributional analyses comprise 12 electrodes, due to the inclusion of the laterality and hemisphere factors (and thus the exclusion of the three midline electrodes). The analyzed time-windows are mostly based on the omnibus ANOVA (Table 2) and partly on visual inspection.

[b] This analysis is based on parietal–occipital (P3, P4, PZ, O1, O2) electrodes only.

constant until the end of the epoch (see Table 2C and Fig. 3B>). A significant *frequency × morphology* interaction, in turn, occurred in the 450–550 ms time-window (see Table 2C), and the effect was largest in parieto-occipital locations. The interaction between frequency and morphology in this time-window was thus further studied by introducing the parietal–occipital electrodes (P3, P4, Pz, O1, O2) as a region of interest in the analysis (see Table 3C). According to this analysis, the interaction was significant: in the low-frequency condition, the inflected words elicited a larger negativity than the monomorphemic words, but this effect was not observed in the high-frequency condition (see Fig. 2).

At the time range of 450–550 ms, the results also indicated topographical differences for the factors frequency and morphology (see Tables 2C and 3C). Waveforms for the low- vs. high-frequency words are depicted in Fig. 3A, collapsed across both morphology conditions. The low-frequency words showed a larger negativity than the high-frequency words around 300–400 ms at frontal locations (electrode mean amplitude at Fz, low-frequency: 1.49 ± 3.86 μV; high-frequency: 2.19 ± 3.73 μV). The frequency effect was more prominent over the right hemisphere.

The corresponding topographical analyses for morphology (see Table 3C and Fig. 3B, depicting all monomorphemic vs. all inflected words pooled across frequency conditions) revealed first an increased negativity beginning around 400–450 ms for the monomorphemic words, being more prominent over the right than over the left hemisphere at anterior and medial locations. Significant interactions with electrode position were also observed in the 600–800 ms time-window, with a positive deflection identified for the inflected words at medial and posterior electrodes (see Fig. 3B). This positivity was most notable at central locations over the right hemisphere.

2.2.3. *Pseudoword processing*

Grand average ERPs for the pseudowords are illustrated in Fig. 4. Significant differences between pseudoword conditions were found in three different time-windows (50–150, 450–550 and 650–850 ms after stimulus onset), as revealed by the omnibus ANOVA (see Table 4). Analyses at these three time-windows, consisting of pairwise comparisons between all conditions, were carried out, and further distributional analyses with topographical factors were also conducted when needed. The statistics of all the pairwise analyses with significant results are presented in Table 5.

2.2.3.1. Pseudostem + suffix pseudowords. Pseudowords with a non-existing stem and a real inflectional suffix did not show significant differences when compared to the monomorphemic pseudowords.

2.2.3.2. Stem + pseudosuffix pseudowords. Pseudowords with a real stem and a pseudosuffix differed from monomorphemic pseudowords in the 450–550 ms time-window. Stem + pseudosuffix pseudowords showed a more negative deflection (calculated for 450–650 ms) especially at lateral and anterior locations over the left hemisphere (see Fig. 4). A similar effect was observed in relation to pseudostem + suffix pseudowords.

2.2.3.3. Illegal stem + suffix combination pseudowords. Within the 50–150 ms time-window (more specifically at 80–120 ms), illegal stem + suffix combination pseudowords showed a significant difference to the monomorphemic pseudowords, eliciting a larger N1 component than the monomorphemic pseudowords. Further distributional analysis showed that this effect was found at anterior electrodes and

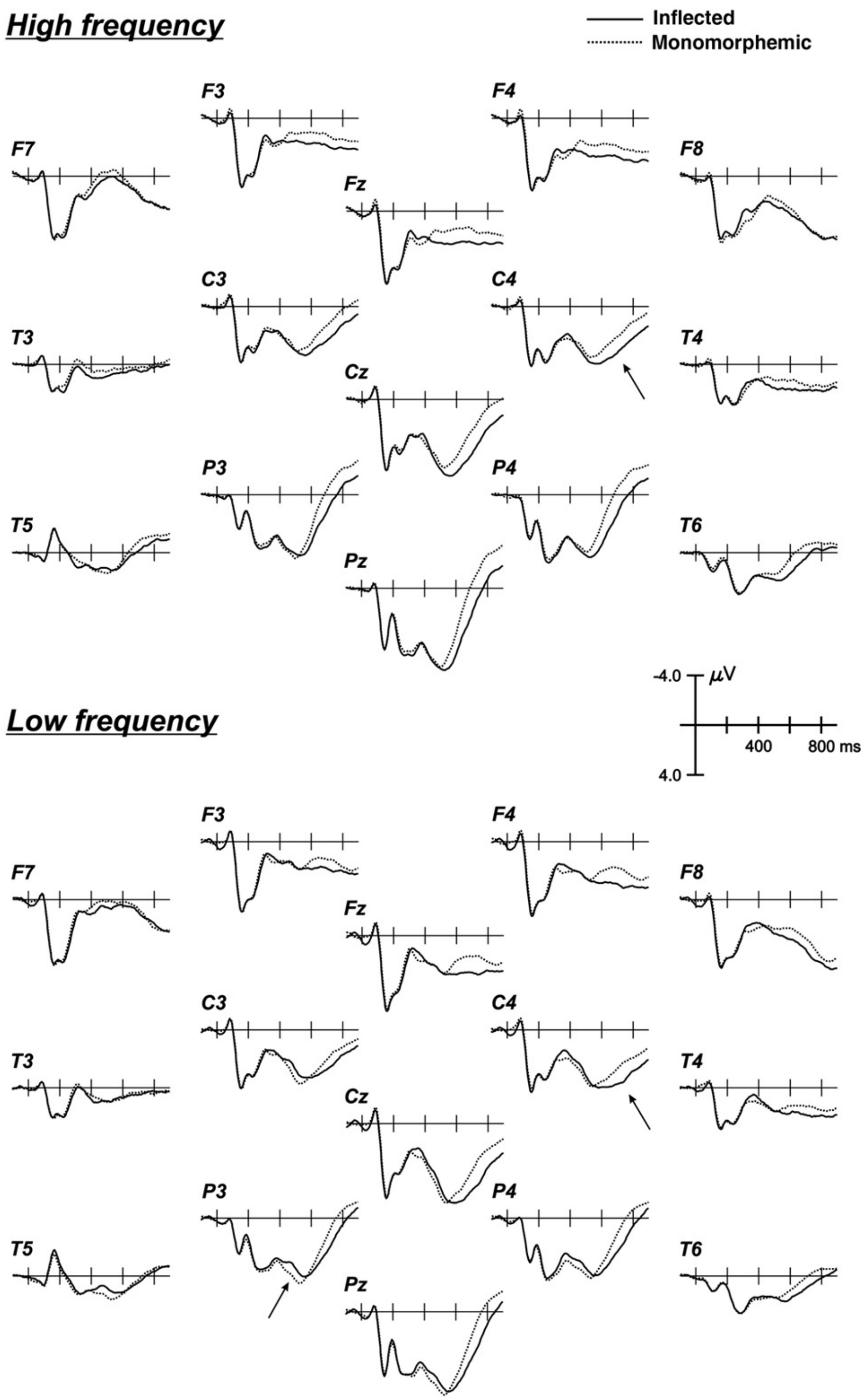

Fig. 2 – Grand average potentials at fifteen electrode locations depicted for the inflected (solid lines) and the monomorphemic nouns (dotted lines), separately for the high- and low-frequency conditions. The arrows are showing an example of the negative deflection for inflected words starting at 450 ms in the low-frequency range and of the late positive component at around 550–800 ms in both frequency ranges.

was largest at lateral locations over the left hemisphere.[1] Illegal stem + suffix pseudowords also differed from monomorphemic pseudowords in the 450–550 ms time-window, showing an increased negativity that was located over the left hemisphere (see Fig. 4). Furthermore, the same contrast produced an effect in later time-windows (650–850 ms), with the illegal stem + suffix combination items eliciting a larger positivity

[1] This effect was very weak and was not observed in all participants. Thus it may be a false positive finding.

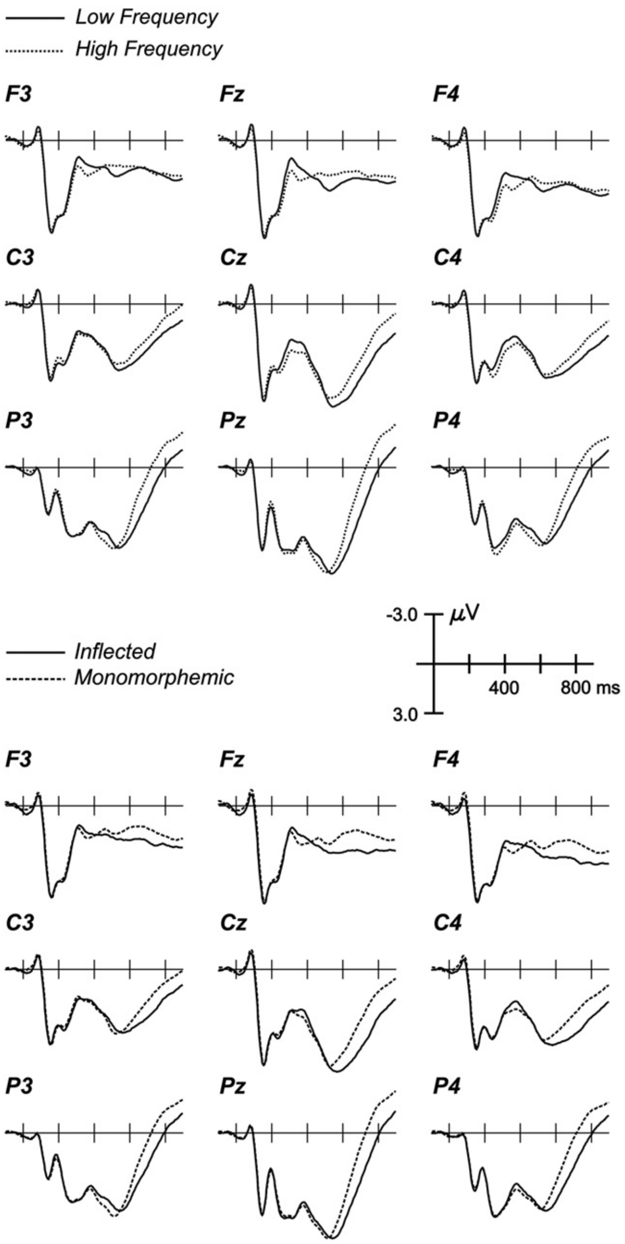

Fig. 3 – (A) Grand average ERPs for the low-frequency (solid lines) and the high-frequency (dotted lines) words collapsed across both morphology conditions (upper panel). (B) Grand average for the inflected words (solid line) and the monomorphemic words (dotted line) collapsed across both frequency conditions.

(mean amplitude, monomorphemic: 1.85±3.01 μV; illegal stem+suffix combination: 2.81±2.88 μV) which was especially prominent in medial locations over the right hemisphere. This late positive effect of the illegal stem+suffix combination pseudowords differed also from pseudostem +suffix pseudowords at 650–850 ms, eliciting a significant main effect of pseudoword type and an interaction with the electrode factor, reflecting a medial and right-sided distribution. A similar difference was also found in comparison to the stem+pseudosuffix pseudowords (mean amplitude, illegal stem+suffix combination: 2.81±2.88 μV; stem+pseudosuffix: 1.78±3.21 μV), and this effect was most prominent in medial and posterior locations. In sum, the illegal stem+suffix pseudowords showed a more negative waveform on the left side than the monomorphemic pseudowords in the 80–120 ms and the 450–550 ms time-windows, and a more positive deflection than all the other pseudoword types in the last time-window.

2.2.3.4. Comparisons between pseudowords carrying a real stem and real words. In order to investigate whether left anterior negative deflections were observed in comparisons between the two pseudoword types including a real stem (stem+pseudosuffix pseudowords and illegal stem+suffix combination pseudowords) and correct inflected and monomorphemic word forms, pairwise repeated measures ANOVAs were performed for conditions of interest in the time-window of 450–650 ms for three left anterior electrodes as a region of interest (F7, Fp1, F3). No statistically significant effects were observed for comparisons between stem+pseudosuffix pseudowords and real words (inflected or monomorphemic). An interaction with electrode was observed when contrasting the illegal stem+suffix pseudowords with inflected words [$F(1,15)=5.50$, $p<0.01$] and with monomorphemic words [$F(1,15)=6.05$, $p<0.01$]. These interactions reflected the fact that the conditions did not differ significantly from each other in electrode F7 while in electrode F3 the illegal stem+suffix combination pseudowords showed a more negative deflection than the real words in question. It, however, seems that this F3 effect resembles closely the waveforms of central and posterior electrodes, and is not solely observed in this left anterior site. To investigate whether the lack of a left anterior negativity between the contrasts above may reflect the fact that both stimulus types in each comparison carried a real stem (unlike in the previous within-pseudoword comparisons), monomorphemic pseudowords were compared with monomorphemic real words in this region of interest: this analysis showed a significant main effect of stimulus type [$F(1,15)=11.17$, $p<0.01$], stemming from a larger negativity for monomorphemic real words.

3. Discussion

The aim of the present study was to investigate the recognition of inflected nouns and its electrophysiological correlates in the morphologically rich Finnish language where most inflected nouns have been found to be decomposed during recognition. Specifically, we aimed to shed light on the question whether the processing load related to morphological decomposition stems from the early, visual word form level or from the later semantic–syntactic level. We were also interested in seeing whether surface frequency affects the processing of inflected words as has been found in previous studies (e.g. Alegre and Gordon, 1999; Lehtonen and Laine, 2003; Lehtonen et al., 2006a). Moreover, we manipulated the morphological structure of the pseudowords in the lexical decision task in order to investigate features of the decomposition route, especially whether the recognition of an inflected word proceeds via the stem.

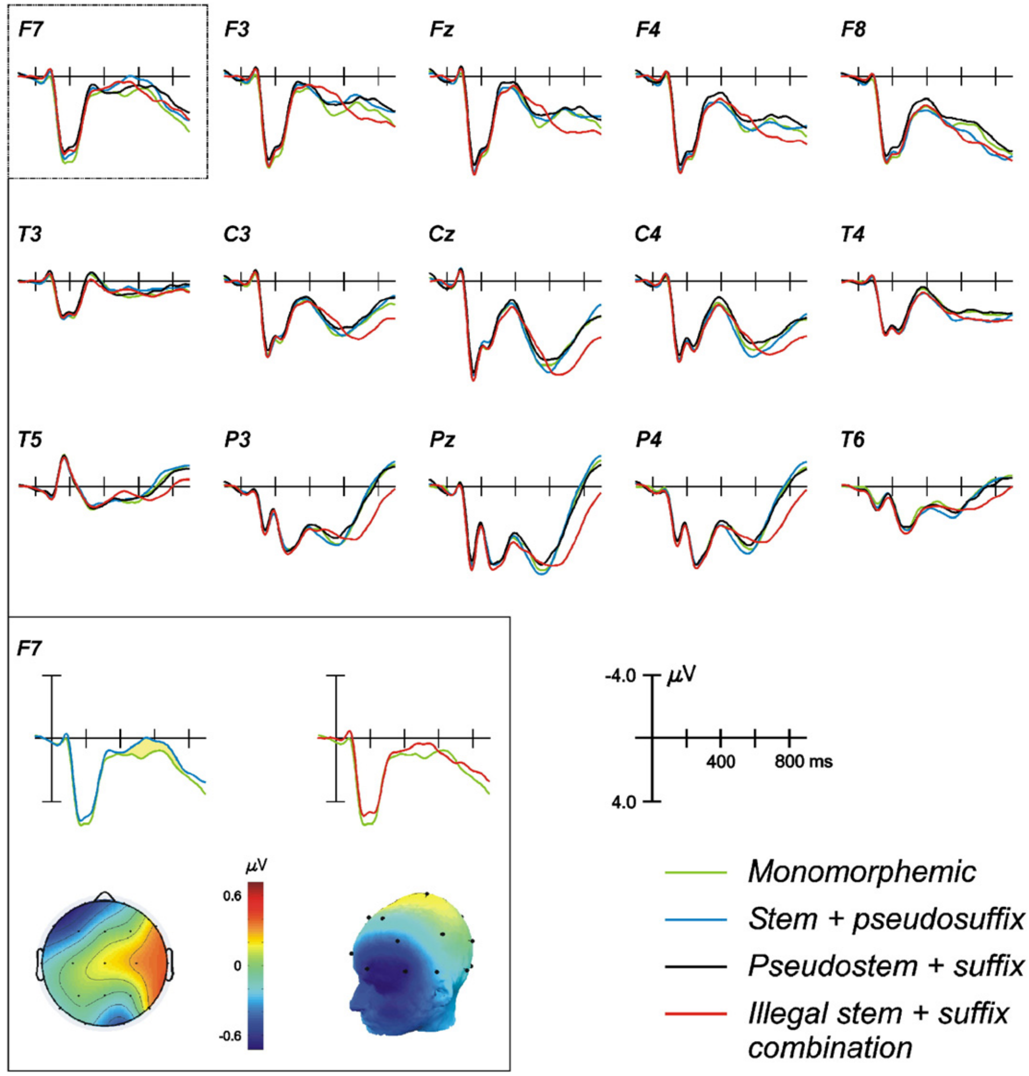

Fig. 4 – Grand average potentials for the pseudowords (monomorphemic: green line; stem + pseudosuffix: blue line; pseudostem + suffix: black line; illegal stem + suffix combination: red line). The lower panel shows the negative deflection at 450–650 ms for the stem + pseudosuffix pseudowords and for the illegal stem + suffix combination pseudowords in the position where the effects are maximal (electrode F7) in comparison to the monomorphemic and pseudostem + suffix pseudowords. In the same panel, the topography of this effect for the stem + pseudosuffix pseudowords is shown. Depicted is the mean amplitude at the 450–650 time-window using isovoltage mapping with spherical spline interpolation.

First, we investigated the effects of lexicality and word frequency on ERPs. The results showed a very early effect (in the 80–120 ms time-window) for lexicality, when comparing monomorphemic real words to monomorphemic pseudowords that included no real morphemes. However, a closer inspection of the individual data showed that this effect was clearly seen in the responses of a minority of the participants. Because the effect was rather weak, we believe that it might be spurious. A clear-cut lexicality effect was observed from 350 ms onwards, corresponding to the N400 lexicality component (e.g., Holcomb and Neville, 1990). A potential N400 effect, albeit with a more anterior distribution, was also observed for word frequency. The N400 component has been found to be sensitive to lexical and semantic aspects of words (e.g., Kutas and Federmeier, 2000).

3.1. *Real words*

The behavioral results for the real words showed a processing cost for both the low- and high-frequency inflected words, thus suggesting decomposition also for the high-frequency items. This is in contrast with our hypothesis that was based on the results of Lehtonen and Laine (2003) who suggested that high-frequency Finnish inflected words (and perhaps also some of the medium-frequency ones) have developed full-form representations. It is possible that the high-frequency words in the present study were not high frequent enough to be processed entirely via the full-form route. The high-frequency inflected words in the Lehtonen and Laine (2003) study had an average surface frequency of over 100 per million while the corresponding stimuli in the present study had a surface frequency of

Table 4 – Omnibus ANOVA for *pseudowords*

	50–150	150–250	250–350	350–450	450–550	550–650	650–750	750–850
Pseudoword type							$p<0.001$	$p<0.001$
Pseudoword type × Electrode	$p<0.05$				$p<0.001$		$p<0.001$	$p<0.001$

$p<0.05$ (light grey), $p<0.01$ (dark grey), $p<0.001$ (black).

about 84 per million. Also a recent study by Soveri et al. (submitted for publication) attempted to replicate the study by Lehtonen and Laine (2003) with a different design and suggested that only *very* high frequency inflected words (and not all high-frequency ones) might possess full-form representations in Finnish. This differs from the observations in the English, Dutch, Swedish or French language (Alegre and Gordon, 1999; Baayen et al., 1997; Lehtonen et al., 2006a; New et al., 2004; Sereno and Jongman, 1997) where decomposition appears to be used only for the rather low-frequency inflected items or not at all. In addition, it is possible that introducing a particularly demanding pseudoword type into the stimulus set, the illegal stem+suffix combination pseudowords, altered the processing strategy of the participants in the present study. These pseudowords, which were clearly the most difficult item type for the participants, may have prompted an analytical strategy where the legality of the stem and affix combination was checked more carefully. The participants' more analytical response strategy could thus have resulted in morphological decomposition even for the high-frequency inflected words. Yet, the fact that the difference between inflected vs. monomorphemic words was larger for both RTs and error rates in the

Table 5 – Statistically significant effects for pairwise comparisons between all *Pseudoword* conditions in significant time-windows of the omnibus ANOVA (see Table 3) first with factors *pseudoword type* and *electrode*, and then the distributional analyses including the topographical factors [a]

Factors	Time-window (ms)	*F*-test, *p*-value
Stem+pseudosuffix pseudowords vs. Monomorphemic pseudowords		
Pseudoword type×Electrode	450–550	$F(14,210)=4.44$, $p<0.001$
Pseudoword type×A/P	450–650	$F(2,30)=4.75$, $p<0.05$
Pseudoword type×Hem×Lat	450–650	$F(1,15)=8.10$, $p=0.01$
Pseudoword type×Hem	450–650	$F(1,15)=11.40$, $p<0.01$
Stem+pseudosuffix pseudowords vs. Pseudostem+suffix pseudowords		
Pseudoword type×Electrode	450–650	$F(14,210)=3.05$, $p<0.05$
Pseudoword type×Hem×A/P	450–650	$F(2,30)=4.60$, $p<0.05$
Pseudoword type×Hem	450–650	$F(1,15)=7.99$, $p=0.01$
Pseudoword type×Lat	450–650	$F(1,15)=6.27$, $p<0.05$
Illegal stem+suffix combination vs. Monomorphemic pseudowords		
Pseudoword type×Electrode	80–120	$F(14,210)=3.94$, $p<0.01$
Pseudoword type×A/P	80–120	$F(1,15)=7.05$, $p=0.01$
Pseudoword type×Hem×Lat	80–120	$F(1,15)=5.84$, $p<0.05$
Pseudoword type×Electrode	450–550	$F(14,210)=2.4$, $p<0.05$
Pseudoword type×Hem	450–550	$F(1,15)=6.49$, $p<0.05$
Pseudoword type	650–850	$F(1,15)=13.00$, $p<0.01$
Pseudoword type×Electrode	650–850	$F(14,210)=6.38$, $p<0.001$
Pseudoword type×Lat	650–850	$F(1,15)=12.42$, $p<0.01$
Pseudoword type×A/P	650–850	$F(2,30)=5.72$, $p<0.01$
Pseudoword type×Hem×Lat	650–850	$F(1,15)=8.96$, $p<0.01$
Illegal stem+suffix combination vs. Pseudostem+suffix pseudowords		
Pseudoword type	650–850	$F(1,15)=20.87$, $p<0.001$
Pseudoword type×Electrode	650–850	$F(14,210)=3.71$, $p<0.01$
Pseudoword type×Lat	650–850	$F(1,15)=14.11$, $p<0.01$
Pseudoword type×Hem×Lat	650–850	$F(1,15)=4.91$, $p<0.05$
Illegal stem+suffix combination vs. Stem+pseudosuffix pseudowords		
Pseudoword type	650–850	$F(1,15)=10.60$, $p<0.01$
Pseudoword type×Electrode	650–850	$F(14,210)=5.85$, $p<0.01$
Pseudoword type×Lat	650–850	$F(1,15)=13.55$, $p<0.01$
Pseudoword type×A/P	650–850	$F(2,30)=5.85$, $p=0.05$

A/P=anterior/posterior, Lat=laterality, Hem=hemisphere.

[a] Note that the reported distributional analyses comprise 12 electrodes, due to the inclusion of the laterality and hemisphere factors (and thus the exclusion of the three midline electrodes). The analyzed time-windows are mostly based on the omnibus ANOVA (Table 4) and partly on visual inspection.

low-frequency range than in the high-frequency range, suggests that some of the high-frequency words in the present study may have been recognized via the full-form route.

In the ERPs, morphological effects started to emerge at rather late time-windows, from 450 ms onwards. An interaction between morphology and frequency was observed at the 450–550 time range in parietal and occipital locations. This reflected the presence of an N400 effect (more negative for the inflected than for the monomorphemic words) in the low-frequency range but not in the high-frequency range, suggesting that the processing of the high-frequency inflected words was different from that of the low-frequency inflected words. N400 has been typically found to be sensitive to lexical and semantic aspects of words, and thus this effect could be assumed to reflect greater demands for lexical and semantic integration in the low-frequency inflected items than in the monomorphemic words of that frequency range. For the high-frequency words, however, the integration demands reflected in the N400 component seem to be similar irrespective of the words' morphological structure. These results support the idea that some of the inflected words may have been accessed via full-form representations, as suggested above based on the significant frequency × morphology interaction in the behavioral results.

Morphology also elicited a late positive effect that was larger for the inflected than for the monomorphemic words at the 600–800 ms time-window, reflecting delayed processing of the inflected words possibly due to larger morphosyntactic processing demands (e.g., Kaan et al., 2000), or reflecting a more demanding general linguistic reanalysis that is based on different types of information (e.g., Friederici et al., 2001). This effect appears to be post-lexical since the average lexical decision RTs for the real word conditions were in this time range. Besides, this effect did not seem to depend on frequency. Thus, it could be that these demands are similar for all inflected words irrespective of frequency. In any case, the observed morphological effects in a rather late time-range, in the N400 and a late positive component, suggest that the morphological processing cost stems mainly from the later, semantic–syntactic level of processing. Our results are thus consistent with the previous behavioral evidence by Hyönä et al. (2002), as well as with the recent fMRI evidence by Lehtonen et al. (2006b) who found that the left hemisphere areas activated during recognition of Finnish inflected vs. monomorphemic nouns were those associated most often with semantic or syntactic processing. Although the results were obtained for a language that has a larger inflectional system than the languages most commonly studied in this field, it is possible that similar late effects would be obtained in other languages in a similar contrast between inflected vs. monomorphemic words, in case a processing cost related to decomposition is also present. The precise character of the later effects could, however, differ depending on the inflectional affix used and its specific properties (e.g., whether the inflection is mainly syntactic vs. semantic; affixal homonymy[2]). The present finding does not necessarily implicate that decomposition at the early visual word form level would not take place. The mapping of the visual input to (separate) existing morpheme representations might be such an automatic process that it is only more difficult to catch with the present methodology.

3.2. Pseudowords

The behavioral results for the pseudowords showed that the RTs and error rates were similar for the monomorphemic and the pseudostem + suffix pseudowords that in turn differed from the two pseudoword types that carried a real stem. This supports the hypothesis that the decomposition route proceeds via the stem, since the existence of a stem affected the RTs, but the presence of a real affix did not have a significant effect on the behavioral measures. This result is in line with a picture–word matching study by Laine (1999) who showed that stem-related information becomes available before that of the inflectional suffix. However, as some lexical decision studies have found a significant RT difference between pseudostem + suffix and monomorphemic pseudowords (e.g. Laine, 1996), it is possible that the effects in some way depend on the differences in other aspects of the stimulus materials between studies, such as the types of pseudowords employed. The present ERP data was consistent with the behavioral observations in the present study: the waveforms showed no significant differences between the monomorphemic and the pseudostem + suffix pseudowords[3] but they differed from the pseudowords carrying a real stem, thus supporting the stem dominance interpretation.

The stem + pseudosuffix items were the easiest pseudowords to make a lexical decision on. This may be due to a privileged access to the real word stem, and a quick check of whether the suffix is a real one or not. Due to the limited number of suffixes in a language, the check-up for the existence of a suffix should go fast. At the other extreme, the illegal stem + suffix combination pseudowords were particularly tricky since they call for a careful check of the morphophonological legality of the stem–suffix pair. As mentioned above, this checkup may then have also been implemented with the real word inflected stimuli in the present study, thus strengthening the behavioral morphological effect in the high-frequency range.

In the ERPs, the stem + pseudosuffix pseudowords elicited a left anterior negative deflection in comparison to monomorphemic and pseudostem + suffix pseudowords beginning at approximately 400 ms. The illegal stem + suffix combination pseudowords also showed a left-preponderant negativity at this time-range, although not only at anterior electrodes. As the latter pseudoword group includes a violation of morphophonological rules, and the first group a violation of an "affixation rule", these effects might be interpreted as LAN components which have been suggested to reflect violations of grammatical rules.[4] Since both of these pseudoword types had a real noun stem, it could be that morphosyntactic processes (which assumedly failed here, causing LAN) do not activate before a

[2] A suffix is homonymic when it serves more than one function (e.g., the suffix -s in English is used both in noun plural forms and in third person present tense verb forms). Affixal homonymy has been found to promote full-form processing (e.g., Bertram et al., 1999; Bertram et al., 2000).

[3] This conclusion is, of course, based on weak evidence, i.e., lack of an effect.

[4] It should be noted that LAN effects have been previously found to appear only in misapplications of morphophonological rules, not for fake affixes per se.

Table 6 – Properties of the real word stimuli

Word category	WL	SF	BF	BiF	FS
Low frequency					
Monomorphemic	6.30 (1.2)	0.93 (0.9)	5.37 (5.1)	1161 (403)	52.6 (43)
Inflected	6.39 (1.2)	0.81 (0.8)	5.51 (1.7)	1150 (487)	67.8 (67)
High frequency					
Monomorphemic	5.96 (1.3)	84.4 (79)	399 (732)	1137 (374)	783 (668)
Inflected	6.10 (1.3)	83.8 (66)	423 (450)	1193 (458)	972 (663)

Mean values (SD) of word length (WL) in letters, surface frequency (SF), base frequency (BF), bigram frequency (BiF) and morphological family size (FS) for the different word groups. Surface and base frequencies are reported as frequencies per million.

real stem has been identified and a potential suffix has been observed in the letter string. On the other hand, if the left negativities of these pseudowords really reflect grammatical violations encountered after successful identification of the stem, they should manifest themselves also in comparison to real words (both to monomorphemic words and to those with a correct stem+suffix combination, i.e., inflected words). These comparisons may, however, be problematic because the pseudowords and real words were matched with each other only for word length but not with regard to bigram frequency (see Tables 6 and 7) and are therefore not fully comparable. In any case, in these circumstances such left anterior effects were not observed in comparisons with real words. The emergence of the "LAN" component in the present study seemed to require a contrast of a real stem with a fake one and did not seem to be related to any morphosyntactic violation per se. In support of this interpretation, a left anterior negative deflection was observed even for monomorphemic real words in comparison to monomorphemic pseudowords at 450–650 ms. It is important to note that in previous studies, LAN effects have typically been observed earlier in time and more lateralized to the left hemisphere, and the present effect (with an onset at about 450 ms) might thus not be comparable to the anterior negativities previously observed.

The illegal stem+suffix pseudowords differed from the rest of the pseudowords by showing a more positive waveform in a very late time-window (650–850 ms). This effect may simply reflect the generally prolonged processing of these particularly difficult pseudoword items (reminiscent of a P3 effect) or possibly the fact that these items included a violation of morphophonological rules (a P600 effect).

3.3. *Conclusion*

Our findings for the real words, showing effects for morphology at later ERP components reflecting semantic and possibly syntactic integration demands, suggest that the processing cost observed for inflected vs. monomorphemic words stems mainly from the later processing stage where the meaning and syntactic aspects of the constituent morphemes are integrated. This finding is in line with both a previous behavioral study by Hyönä et al. (2002) and with a recent fMRI study by Lehtonen et al. (2006b). Behaviorally, it was found that even high-frequency words may be decomposed in Finnish, although the most frequent ones may have developed full-form representations. The interaction of morphology and frequency at the N400 component suggested that the semantic integration was indeed easier for the high-frequency inflected words than for the low-frequency ones. Yet, the late positive component showed a similar effect for morphology irrespective of frequency, suggesting that the syntactic integration demands are similar for both low- and high-frequency inflected words.

The manipulation of the morphological structure in pseudowords with a fake stem did not elicit any differences in behavioral or ERP measures, but differences were observed in relation to pseudowords with a real stem. Thus, it appears that the recognition of the stem occurred prior to that of the suffix. Conditions with a real stem also elicited a left anterior negative deflection in contrast to conditions with a non-existing stem, but in contrast to many previous accounts on the LAN component, this negativity did not seem to be sensitive to grammatical violations per se.

Table 7 – Properties of the pseudoword stimuli

Word category	WL	BiF
Monomorphemic	6.30 (1.1)	1070 (341)
Pseudostem+suffix	6.29 (0.9)	997 (382)
Stem+pseudosuffix	6.29 (1.0)	1081 (377)
Illegal stem+suffix combination	6.28 (1.1)	1088 (365)

Mean values (SD) of word length (WL) in letters and bigram frequency (BiF).

4. Experimental procedure

4.1. *Materials*

The stimulus materials consisted of four lists of Finnish nouns, including 80 words each, and four lists of pseudowords which also contained 80 items each and followed the phonotactic rules of Finnish. Thus, altogether 640 items were included in the experiment. The real word stimuli were taken from the unpublished Turun Sanomat lexical database (which includes 22.7 million word tokens) using a computerized search program (Laine and Virtanen, 1999). Two of the real word lists were collected from the low-frequency range (surface frequency of 0.04–4.23 per million) and two from the high-frequency range (surface frequency of 7.89–504 per million). In each frequency group, one list included only monomorphemic words (e.g., *lusikka*='spoon') and the other list only bimorphemic inflected items (e.g., *hiha+ssa*:

'sleeve' + 'in' = 'in the sleeve'). The inflected words used in the present study included nine different case suffixes. Six of them (inessive, elative, illative, adessive, ablative or allative) were locative cases (denoting position in their most concrete meaning), and these can be seen as more "semantic" cases, as can the essive case usually denoting some sort of role (e.g., *tyttö + nä* = 'as a girl'). Two of the cases were grammatical cases (genitive and partitive) and could be considered more "syntactic". However, these can also be seen to have a separate meaning, i.e., their meaning cannot only be derived in sentence contexts. Most (about 3/4) of the inflected words in the present study included a grammatical case suffix. The two morphologically different lists of both frequency ranges (low-frequency monomorphemic vs. low-frequency inflected; high-frequency monomorphemic vs. high-frequency inflected) were matched for average word length in letters, lemma frequency, surface frequency, bigram frequency and morphological family size (see Table 6).

The four pseudoword groups were matched for word length and bigram frequency (see Table 7), and they represented different morphological structures. The first group consisted of "monomorphemic" pseudowords without any suffix (e.g., *lurkke*). The second group, stem + pseudosuffix pseudowords, included pseudowords with an existing noun stem and a non-existing ending that was similar to real case-endings (e.g., *lasi + sso*: 'glass' + "-sso" which resembles the inessive case-ending "-ssa"). The third group, pseudostem + suffix pseudowords, consisted of items that had a pseudoword stem and a real case-ending (e.g., *laspuun*: nonword *laspu* + real illative case-ending). Finally, the fourth group, illegal stem + suffix combination pseudowords, was comprised of words that had an existing noun stem and an existing noun suffix but their combination was morphophonologically illegal (e.g., *kylpy + n*; 'bath' + genitive ending, where the correct form is *kylvyn* with a consonantal change in the stem).

4.2. Participants

Sixteen university students (8 females, 8 males) participated in the experiment after giving their informed consent. They were neurologically healthy, right-handed (as confirmed by the Edinburgh Inventory; Oldfield, 1971), reported no reading difficulties and had normal or corrected-to-normal vision. They were rewarded with lunch coupons for participation. The age of the participants varied between 21 and 29 years (mean = 24.7, SD = 2.39), and they were all native speakers of Finnish and had acquired only the Finnish language before school age. They also assessed Finnish to be their strongest language (mean = 4.0, SD = 0) in a language skills questionnaire using a 4-point scale (1 = deficient, 2 = satisfactory, 3 = good, 4 = excellent). They all had also learned English and Swedish at school, and estimated themselves to have on average from satisfactory to good skills in these foreign languages.

4.3. Procedure

In the visual lexical decision task, which was performed while the ERPs were recorded, the participants were instructed to decide as quickly and accurately as possible whether the letter string appearing on a computer screen is a real Finnish word or not, and to press a corresponding button. Half of the participants responded with their right hand and half with their left hand. Each trial began with an asterisk appearing in the middle of the screen for 500 ms, and the participants were to fixate their eyes on it. The asterisk was followed by a 500 ms blank screen, after which a stimulus item was presented at the position of the previously shown asterisk. The item was visible for a maximum of 2500 ms after which it disappeared. If the response was given sooner, the item would also disappear, leaving the screen black for the remaining trial period. Each trial lasted for 3500 ms.

The stimuli were divided into four blocks,[5] and a short break was held between the sessions. The order of the blocks was counterbalanced across participants by using a balanced Latin square, and the proportion of all stimulus types was similar in all of them. The order of the items within each block was randomized separately for every participant. Prior to the experiment, 30 practice trials (consisting of stimuli not included in the actual experiment) were administered in order to familiarize the participants with the task.

4.4. Electrophysiological recording

The ERPs were recorded from the scalp using tin electrodes mounted in an electrocap (Electro-Cap International) and located at 19 standard positions (Fp1/2, Fz, F7/8, F3/4, Cz, C3/4, T3/4, Pz, P3/4, T5/6, O1/2). Electrooculogram activity (EOG) was monitored from two electrodes, at the outer canthus and infraorbital ridge of the right eye. All electrode impedances were kept below 5 kΩ. Linked mastoids served as ground, whereas an electrode on the tip of the nose served as the reference.

The electrophysiological signals were filtered on-line with a bandpass of 0.1–50 Hz (half-amplitude cutoffs) and digitized at a rate of 250 Hz. The biosignals were afterwards re-referenced off-line to the activity of the averaged mastoids. Trials with base-to-peak electrooculogram (EOG) amplitude of more than 50 μV, amplifier saturation, or a baseline shift exceeding 200 μV/s were automatically rejected off-line (mean percentage of rejection was 23.4%).

4.5. Data analysis

Artifact-free and correct trials (minimum 40 trials per average and subject) were stimulus-locked and averaged for each condition over epochs of 1024 ms starting 100 ms prior to the stimulus.

As an exploratory analysis, mean amplitude measures were calculated in an omnibus repeated measures analysis

[5] This was done in an attempt to avoid fatigue in the participants and thus to reduce muscle artifacts. However, for the first four participants the stimuli were divided in only two blocks with a counterbalanced order between participants.

of variance (ANOVA) for eight 100 ms time steps starting at 50 ms. The results of the omnibus ANOVAs are presented in Tables 2 and 4. This analysis was performed for the *lexicality* effect comparing at first words (all conditions pooled together) vs. pseudowords (all conditions pooled together), and then monomorphemic words (high- and low-frequency conditions pooled together) vs. monomorphemic pseudowords. In both analyses, the electrode factor was introduced (15 locations: Fz, F7/8, F3/4, Cz, C3/4, T3/4, Pz, P3/4, T5/6). Another similar repeated measures ANOVA was performed for words only, introducing three within-subject factors: *frequency* (low vs. high), *morphology* (monomorphemic vs. inflected words) and *electrode* (15 locations). For pseudowords, the four different conditions were introduced into a similar omnibus one-way repeated measures ANOVA together with the electrode factor (15 locations). In time-windows where significant effects were found, pairwise comparisons between all pseudoword conditions were carried out (with factors pseudoword type (2 levels in each contrast) and electrode). The results of the pairwise comparisons are presented in Table 5. With regard to further comparisons investigating left anterior negative deflections of illegal stem+suffix combination pseudowords and stem +pseudosuffix pseudowords in contrast to real word forms, and of monomorphemic pseudowords vs. monomorphemic words, pairwise comparisons were conducted approximately in the time-window that showed left anterior effects in previous pairwise analyses between pseudoword types (450–650 ms). These analyses were conducted for three left anterior electrodes (F7, Fp1, F3).

With regard to all conditions (lexicality, real words and pairwise contrasted pseudowords), a decomposition of the interactions in specific time-windows (either the 100 ms time-steps or other time-windows based on visual inspection) was performed when a lexical condition × electrode interaction was significant. Twelve electrodes were used for topographical analysis (F7, F3, T3, C3, T5, P3, F8, F4, T4, C4, T6, P4), divided according to three factors: *hemisphere* [left (F7, F3, T3, C3, T5, P3) vs. right (F8, F4, T4, C4, T6, P4)], *anterior–posterior* [anterior (F7, F3, F8, F4), central (T3, C3, T4, C4), posterior (T5, P3, T6, P4)] and *laterality* [lateral (F7, T3, T5, F8, T4, T6) vs. medial (F3, C3, P3, F4, C4, P4)]. In all cases with more than one degree of freedom in the numerator, the Huynh–Feldt epsilon correction was applied. In Tables 3 and 5 of the Results section, the exact *p*-value after the correction is reported, and only the significant main effects or interactions involving the factors lexicality, frequency, morphology and/or pseudoword type are reported.

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