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Differences in word recognition between early bilinguals and monolinguals: Behavioral and ERP evidence

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ABSTRACT

We investigated the behavioral and brain responses (ERPs) of bilingual word recognition to three fundamental psycholinguistic factors, frequency, morphology, and lexicality, in early bilinguals vs. monolinguals. Earlier behavioral studies have reported larger frequency effects in bilinguals' nondominant vs. dominant language and in some studies also when compared to corresponding monolinguals. In ERPs, language processing differences between bilinguals vs. monolinguals have typically been found in the N400 component. In the present study, highly proficient Finnish–Swedish bilinguals who had acquired both languages during childhood were compared to Finnish monolinguals during a visual lexical decision task and simultaneous ERP recordings. Behaviorally, we found that the response latencies were overall longer in bilinguals than monolinguals, and that the effects for all three factors, frequency, morphology, and lexicality were also larger in bilinguals even though they had acquired both languages early and were highly proficient in them. In line with this, the N400 effects induced by frequency, morphology, and lexicality were larger for bilinguals than monolinguals. Furthermore, the ERP results also suggest that while most inflected Finnish words are decomposed into stem and suffix, only monolinguals have encountered high frequency inflected word forms often enough to develop full-form representations for them. Larger behavioral and neural effects in bilinguals in these factors likely reflect lower amount of exposure to words compared to monolinguals, as the language input of bilinguals is divided between two languages.

1. Introduction

The ability to use more than one language in the interchange of ideas is likely to be very useful in today's increasingly global environment, and bilingualism is thus constantly becoming more and more common. An important question in bilingualism research is whether the undeniable advantages in everyday life might be counterpoised by possible costs for the cognitive system. Such costs could be reflected, e.g., in modulated response times or brain activation during a language task. It has been argued that differences at both the cognitive and the neural level between bilinguals and monolinguals in one language may be due to the differential level of proficiency and/or age of acquisition (see, e.g., Johnson & Newport, 1989; Perani & Abutalebi, 2005). However, an intriguing and more scarcely explored question is whether adult bilinguals who have acquired both languages early and are highly proficient in both of them show differences to monolinguals in basic lexical processes.

In recent years, general advantages related to executive control processes in bilinguals have been observed (see, e.g., Bialystok, Craik, Green, & Gollan, 2009, for an overview), and they have been associated with the long experience of bilinguals of having to effectively control the use of their two languages. On the other hand, some costs related to bilingualism have also been reported. For example, several studies have found that bilinguals are at a disadvantage in contrast to monolinguals in naming pictures (Bialystok, Craik, & Luk, 2008; Gollan, Montoya,

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Fennema-Notestine, & Morris, 2005; Gollan, Fennema-Notestine, Montoya, & Jernigan, 2007; Gollan, Montoya, Cera, & Sandoval, 2008; Ivanova & Costa, 2008). Bilinguals tend to be slower than monolinguals even in their dominant language, and especially so with low frequency words (Gollan et al., 2008; Ivanova & Costa, 2008). As one interpretation for these findings in word production, Gollan et al. (2008) state that bilinguals tend to use both of their two languages constantly and when compared to the exclusive use of a single language by monolinguals, each word in the bilingual lexicon will receive less exposure and have a lower frequency. There will thus be weaker links between semantics and phonology in each lexical system, and words in the bilingual lexicon will be less easily available than those in the monolingual lexicon. This assumption has been coined "the weaker links hypothesis" (e.g., Gollan & Silverberg, 2001; Gollan et al., 2008). As word frequency is a crucial factor that affects the access and representation of words and the organization of the mental lexicon, it is plausible that also word recognition would be delayed in bilinguals when compared to monolinguals. In fact, Ransdell and Fischler (1987), in addition to Lehtonen and Laine (2003) and Lehtonen, Niska, Wande, Niemi, and Laine (2006), observed slower response latencies to words in a visual lexical decision task for early bilinguals than monolinguals.

Recent behavioral studies in bilinguals have revealed larger frequency effects (i.e., larger differences between high vs. low frequency words) in picture naming times even in the early bilinguals' dominant language (Gollan et al., 2005, 2008, 2011; Ivanova & Costa, 2008) in comparison to monolinguals. In visual word recognition, larger frequency effects have also been observed for the *late* bilinguals' nondominant vs. dominant language but not for their dominant language when compared to monolingual speakers (Duyck, Vanderelst, Desmet, & Hartsuiker, 2008; see also Lehtonen & Laine, 2003; Lehtonen et al., 2006, for larger effects in early bilinguals than monolinguals). Frequency effects can be seen as a result of an asymptotic learning process where the activation level of the lexical items is strengthened via exposure (Morton, 1970). As the slope of the logarithmic learning function is assumed to be steeper at the lower end of the scale, generally lower subjective frequencies result in larger frequency effects. Thus, according to Duyck et al. (2008), recognition of L2 words is like recognition of L1 words of lower objective frequency because L2 words have received lower amounts of exposure.

In addition to the frequency or exposure interpretation, Gollan et al. (2008) discuss the possibility that the bilingual disadvantage in word production could be due to control processes, i.e., that bilinguals constantly have to resolve potential competition between two languages during word generation. This idea is based on several studies that suggest that concepts automatically activate lexical representations in both languages during word production (see Costa, 2005; La Heij, 2005, for reviews), and translation equivalents may therefore compete for selection. Likewise, research on bilingual word recognition indicates that interference effects from the other language may also occur, as there is evidence of bilingual lexical access that is non-selective of language (Dijkstra and van Heuven, 2002; Spivey & Marian, 1999; Thierry & Wu, 2007; but see Rodríguez-Fornells, Rotte, Heinze, Nösselt, & Münte, 2002). However, the competition account does not seem to provide a clear explanation for the enhanced frequency effects in bilinguals (see Gollan et al., 2008, for a discussion).

In the present study, we investigate frequency effects in visual word recognition in early, highly proficient bilinguals. If different amounts of exposure are a key element in larger frequency effects of bilinguals vs. monolinguals, we should observe it particularly well in early bilinguals who have used both of their languages to a roughly equal extent throughout their lives, assumedly receiving only half of the input for each language than corresponding monolingual speakers have. At the same time, possible differences are unlikely to be due to major age of acquisition or proficiency differences to monolinguals. In addition to frequency effects, we extend the comparisons to two other basic lexical variables – morphology and lexicality – that have been found to be important in word recognition but, to the best of our knowledge, have not been previously studied in bilinguals vs. monolinguals by combining behavioral measures with simultaneous event-related potentials (ERPs) recordings during visual lexical decision. This online measure with a millisecond-level resolution enables us to look at the time-course of word recognition more directly than behavioral reaction times and error rates. By using ERPs, we thus hope to gain a better understanding of the different stages of processing involved in the effects.

In addition to frequency, with lexicality (comparing processing of pseudowords vs. real Finnish words) we further aim to investigate word recognition in bilinguals, e.g., the question whether there are temporal differences in the lexical search and word identification processes of bilinguals vs. monolinguals. Lower subjective frequencies for words and possibly more limited vocabulary in one language may make the differentiation between real words and pseudowords more demanding in bilinguals, possibly enhancing the N400 effect. Moreover, a factor that is assumed to have a role in the representation and access of words in the mental lexicon is the morphological structure of words (e.g., DOG + S). Interestingly, differential language exposure of bilinguals has previously been suggested to interact with effects of morphology. Behavioral studies in Finnish, a language with a particularly rich inflectional system, have typically demonstrated that most inflected nouns (e.g., AUTO + SSA, 'car' + inessive ending: 'in the car') show a processing cost (i.e., longer reaction times and higher error rates) in comparison to matched monomorphemic nouns in word recognition tasks (e.g., Laine & Koivisto, 1998; Laine, Vainio, & Hyönä, 1999; Niemi, Laine, & Tuominen, 1994). This finding has been interpreted as reflecting decomposition of most Finnish inflected nouns. Morphology has also been assumed to interact with frequency: it has been suggested that the higher the frequency of a morphologically complex word form, the more likely it is that it can (also) be processed as a full form, and not (only) by decomposing it into separate morphemes (e.g., Laine, Niemi, Koivuselkä-Sallinen, Ahlsén, & Hyönä, 1994; Schreuder & Baayen, 1995). In Finnish monolinguals, Lehtonen and Laine (2003) and Soveri, Lehtonen, & Laine (2007) showed that the morphological processing cost vanished in the (very) high frequency range, which suggests that such Finnish inflected nouns may be common enough to have developed full-form representations. However, for early Finnish–Swedish bilinguals the processing cost was present even for high frequency Finnish words, and the bilinguals thus seemed to be decomposing even the high frequency inflected words (Lehtonen & Laine, 2003). This was assumed to reflect the lower amounts of exposure to each word form that bilinguals receive when compared to monolinguals, due to language input being divided between two languages. The bilinguals' subjective frequencies for these word forms are thus lower than in monolinguals and presumably not high enough for full-form representations to develop.

Previous ERP studies with monolingual participants have shown that frequency, lexicality, and morphology are among factors that influence the N400 component, a negative waveform peaking at around 300–500 ms after the presentation of the word. Frequency effects have typically been observed in this component, with a more negative waveform for the low than for the high frequency words (e.g., Rugg, 1990; Smith & Halgren, 1987). Similarly, lexicality has been shown to affect the N400, with pseudowords eliciting stronger negativity than real words (e.g., Braun, Jacobs, Hahne, Ricker, Hofmann, & Hutzler, 2006; Carreiras, Vergara, & Barber, 2005). The N400 has also been sensitive to morphological manipulations: differences in N400 responses have been observed in repetition priming of regularly vs. irregularly inflected words (e.g., Domínguez, de Vega, & Barber, 2004; Münte, Say, Clahsen, Schilz, & Kutas, 1999; Rodríguez-Fornells, Münte, & Clahsen, 2002; Weyerts, Münte, Smid, & Heinze, 1996) and in visual and auditory lexical decision between otherwise matched inflected vs. monomorphemic words (Lehtonen et al., 2007; Leinonen et al., 2009). The functional role of the N400 has been generally assumed to be related to some form of semantic processing, particularly to access to semantic memory representations (e.g., Kutas & Federmeier, 2000) or semantic integration (e.g., Brown & Hagoort, 1993; Baggio & Hagoort, 2011). The N400 has also been linked to lexical access (Lau, Phillips, & Poeppel, 2008) and to dynamic creation of multimodal conceptual representations (Kutas & Federmeier, 2011).

The N400 component has also been found to be sensitive to the language background of the participants, i.e., whether they are bilinguals or monolinguals, in classical semantic violation paradigms. Laterality differences of the N400 effects have been observed between early bilinguals vs. monolinguals, and larger N400 effects for L2 vs. L1 of early bilinguals (Proverbio, Čok, & Zani, 2002). N400 effects have also been found to be delayed (Ardal, Donald, Meuter, Muldrew, & Luce, 1990; Weber-Fox & Neville, 1996) or longer lasting (Hahne & Friederici, 2001) in bilinguals in comparison to monolinguals, even in their L1 (Ardal et al., 1990), and also later for the bilinguals' nondominant than for the dominant language (Ardal et al., 1990; Moreno & Kutas, 2005). Some of these differences seem to be related to language proficiency and/or a late age of exposure to the language (see Moreno, Rodríguez-Fornells, & Laine, 2008, for a review).

Using ERPs, Lehtonen et al. (2007) studied the effects of word frequency and morphology on visual recognition of Finnish words in monolinguals, showing that the N400 was sensitive to both of these factors, as well as to lexicality. Interestingly, there was also an interaction between frequency and morphology in the 450–550 ms time-window at parieto-occipital electrode sites: differences were observed between inflected vs. monomorphemic words in the low frequency range but not in the high frequency range. One interpretation for this result is that, in line with the behavioral findings of Lehtonen and Laine (2003), some high frequency inflected words may be recognized as full forms in monolinguals whereas low frequency inflected words are decomposed. In the present study, one aim is to see whether a similar interaction between morphology and frequency, and thus evidence suggesting full-from recognition of inflected words, will be observed in early Finnish–Swedish bilinguals, or whether they will follow the behavioral pattern of Lehtonen and Laine (2003) in which bilinguals showed a processing cost even for high frequency inflected vs. monomorphemic words. ERPs should provide a more direct view on online lexical processing, in comparison to behavioral reaction times which represent an endpoint measure encompassing all stages involved in lexical decision.

In the present study we compare the effects of word frequency, morphological structure, and lexicality on visual word recognition in Finnish both behaviorally and with ERPs in early Finnish–Swedish bilinguals vs. a comparable group of Finnish monolinguals tested by Lehtonen et al. (2007). An identical setup was used for both groups: the participants performed a lexical decision task where frequency (high vs. low frequency words) and morphological structure (inflected vs. monomorphemic words) were manipulated. The task required half of the items to be pseudowords which also allowed the investigation of lexicality effects, i.e., differences between real words and pseudowords. As the N400 component has been found to be modulated by bilingualism and to be sensitive to the abovementioned factors in monolinguals, we focus the ERP analyses on the N400 time-windows (250–650 ms).

2. Material and methods

2.1. Materials

The stimulus materials were the same as those used in Lehtonen et al. (2007) study. They 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 (altogether 640 items). The real word stimuli were taken from the unpublished Turun Sanomat lexical database (including 22.7 million word tokens) using a computerized search program (Laine & Virtanen, 1999). Two of the real word lists were collected from the low frequency (LF) range (see Table 1; surface frequency of 0.04–4.23 per million) and two from the high frequency (HF) range (surface frequency of 7.89–504 per million). In each frequency range, a list of monomorphemic words (e.g., *lusikka* = 'spoon') was contrasted with a list of bimorphemic inflected words with genitive, partitive, essive, inessive, elative, illative, adessive, ablative or allative case-endings (e.g., *hiha* + *ssa*: 'sleeve' + 'in' = 'in the sleeve'). Six of the cases were locative cases, and they, as well as the essive, can be seen as more "semantic" cases. Two of the cases (partitive and genitive) can be considered more "syntactic", but they also have a meaning of their own, i.e., their meaning cannot only be derived in sentence contexts. Most (about 3/4) of the inflected words in the current study included a partitive or genitive suffix. The inflected vs. monomorphemic items of both frequency ranges were matched for average word length in letters, lemma frequency, surface frequency, bigram frequency and morphological family size (see Table 1).

The four pseudoword groups (80 items in each, yielding altogether 320 pseudowords) represented different morphological structures. The first group consisted of "monomorphemic" pseudowords without any suffix (e.g., **lurkke*). The second and third group consisted of a real morpheme and a nonexisting morpheme, either an existing noun stem and a non-existing ending (stem + pseudosuffix pseudowords; e.g., *lasi* + **sso*) or a non-existing noun stem and a real ending (pseudostem + suffix pseudowords; e.g., **laspu* + *un*). The final group included an existing noun stem and an existing noun suffix, but their combination was morphophonologically illegal (illegally inflected pseudowords; e.g., *kylpy* + *n*; 'bath' + genitive ending, where the correct form is *kylvyn* with a consonantal change in the stem). The groups were matched for word length and bigram frequency. Here, only the monomorphemic pseudowords will be included in the lexicality analyses, to enable a more direct contrast where pseudoword processing is not influenced by the presence of real morphemes.

2.2. Participants

Sixteen bilingual university students (9 females, 7 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 of no reading difficulties and had normal or corrected-to-normal vision. The age of the participants varied between 18 and 29 years (mean 24.6, SD 3.2). The bilinguals all had acquired both Finnish and Swedish before school-age (i.e., by the age of seven). In the analyses, these participants were compared to the monolingual group of Lehtonen et al. (2007), consisting of 16 university students (8 females; age 21–29; mean 24.7 years, SD 2.4) who had acquired only the Finnish language before the age of seven.

Seventy-five percent of the bilinguals had had both languages spoken to them at home by the parents (by the one-parent–one-language method) while the rest (25%) had learned the other language outside home, e.g. in daycare. Most of them had attended Swedish-language schools during their whole education, but they all reported using both languages in everyday life (although more Swedish on average; see Table 2). They assessed their skills in Finnish, Swedish and one optional foreign language with a questionnaire using a 4-point scale (1 = deficient, 2 = satisfactory, 3 = good, 4 = excellent). The skills were estimated for four domains of language: speech comprehension, speaking, reading, and writing. According to the overall estimates (mean value across the four domains), the participants' skills in Finnish vs. Swedish were rather balanced (mean (SD) for Finnish, 3.81 (0.3); for Swedish, 3.86 (0.2); $t(15) = 0.588$, $p = 0.566$). In their Finnish language skill estimates, the difference between the monolinguals and the bilinguals was significant (mean for bilinguals, 3.81 (0.3); for monolinguals, 4.00 (0.0); $t(30) = 2.67$; $p = 0.012$). Yet, the

Table 1
Properties of the real word stimuli.

Word category	WL	SF	BF	BiF	FS
Low frequency					
Monomorphemic	6.30	0.93	5.37	1161	52.6
Inflected	6.39	0.81	5.51	1150	67.8
High frequency					
Monomorphemic	5.96	84.4	399	1137	783
Inflected	6.10	83.8	423	1193	972

Mean values 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 frequency are reported as frequencies per million.

Table 2
Language background of the bilingual participants.

Languages used during childhood			
Mother: Finnish; Father: Swedish[a]	Mother: Swedish; Father: Finnish	Both parents: Finnish; Swedish outside home	Both parents: Swedish; Finnish outside home
62.5%	12.5%	6.25%	18.75%

	Swedish	Finnish	Both	Other
Language at primary and secondary school	87.5%	–	12.5	–
Language at high school	93.75%	6.25%	–	6.25%
Language at university[b]	75%	–	18.75%	–

	Swedish	Finnish	Other
Estimated current language use (% of the time, mean (SD))[c]	59.2% (13.3)	34.5% (12.9)	6.3% (5.6)

Self-evaluation of language skills	Excellent	Good	Satisfactory	Deficient	No skills
Swedish					
Speaking	75%	25%	–	–	–
Speech comprehension	94%	6%	–	–	–
Reading	100%	–	–	–	–
Writing	75%	25%	–	–	–
Finnish					
Speaking	75%	25%	–	–	–
Speech comprehension	94%	6%	–	–	–
Reading	94%	6%	–	–	–
Writing	62.5%	37.5%	–	–	–

Digit reading task: Mean (SD) reading time (s) for	Swedish	Finnish
Bilinguals[d]	11.0 (3.1)	13.3 (2.6)
Monolinguals	7.6 (1.8) (Lehtonen et al., 2006)	11.9 (2.4) (Lehtonen et al., 2007)

[a] For one participant of this group, also English was introduced outside home before school-age.
[b] One participant had not studied at university at the time of testing.
[c] Three participants did not report percentages.
[d] Data is missing from one participant.

bilinguals' average Swedish language skill estimates also differed significantly from the native language estimates of the Finnish monolinguals ($t(30) = 2.52$; $p = 0.017$). In fact, whereas all the monolinguals estimated their language skills in Finnish to be excellent in all domains (SD, 0.0), some of the bilingual participants reported lower than excellent skills in *both* languages. This was sometimes the case even within the same domains of language (e.g., skill estimates being below the native level in speaking both Swedish and Finnish), suggesting that the bilinguals' own criteria for 'excellent skills' may have been somewhat stricter than those of the monolinguals. When considering only the estimates for reading, the domain most central for the present study, the bilingual group did not differ with regard to their Finnish vs. Swedish skill estimates ($t(15) = 1.00$, $p = 0.333$), or in comparison to the monolinguals in the target language Finnish ($t(30) = 1.00$, $p = 0.333$).

In a digit reading task administered to the participants to estimate their fluency in each language, the bilinguals were not significantly slower in Finnish than the Finnish monolinguals of Lehtonen et al. (2007) (mean (SD), 13.3 s (2.6) for bilinguals; 11.9 s (2.4) for Finnish monolinguals; $t(29) = 1.48$; $p = 0.150$). However, the difference to Swedish monolinguals of a previous study (Lehtonen et al., 2006) was significant (11.0 s (3.0) for bilinguals; 7.6 s (1.8) for Swedish monolinguals; $t(30) = 3.87$; $p = 0.001$). For a summary of the bilinguals' language background and skill estimates, see Table 2.

2.3. Procedure

The procedure was the same as in Lehtonen et al. (2007) study with monolinguals, and all the bilingual participants were tested using the same equipment in the same laboratory as the monolinguals in Lehtonen et al. (2007). The whole experiment, including the communication with the experimenter, took place in Finnish. In the visual lexical decision task that was performed during the ERP recording, 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, with a short break between each of them.[1] The order of the blocks was counterbalanced across participants by using a balanced Latin square design, 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. All communication during the experiment took place in Finnish.

2.4. Electrophysiological recording

The ERPs were recorded from the scalp using tin electrodes mounted in an elastic cap (Electro-Cap International) and located at 19 standard positions according to the 10–20 system (Fp1/2, Fz, F7/8, F3/4, Cz, C3/4, T3/4, Pz, P3/4, T5/6, O1/2). Electrooculogram (EOG) activity 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 EEG signals were afterwards re-referenced off-line to the activity of the averaged mastoids. Trials with base-to-peak 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, monolinguals: 23.4%, bilinguals: 16.9%, $t(30) = 1.7$, $p > 0.100$).

2.5. ERP 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

[1] For the first four of the monolingual participants, the stimuli were divided in only two blocks with a counterbalanced order between participants.

starting 100 ms prior to the stimulus. In order to focus on the N400 component, we restricted the analysis to the four time-windows of interest (250–350, 350–450, 450–550, and 550–650 ms), covering the N400 time-course. Mean amplitude measures were calculated for these time-windows and used as dependent variables in the repeated-measures analysis of variance (ANOVA). This analysis was performed for the *lexicality* effect comparing 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 repeated measures ANOVA was performed for words only, introducing three within-subject factors: *frequency* (low vs. high), *morphology* (monomorphemic vs. inflected nouns) and *electrode* (15 locations), and the between-subjects factor *group*. In all cases with more than one degree of freedom in the numerator, the Huynh–Feldt epsilon correction was applied. In Section 3, the corrected *p*-value, and the original degrees of freedom together with the correction factor (epsilon) are reported. Only significant main effects or interactions involving lexicality, frequency, morphology and/or group are reported.

3. Results

3.1. Behavioral results

Prior to the behavioral data analysis, incorrect responses and RTs longer or shorter than three standard deviations from the individual mean were excluded. The overall error rate of the bilinguals (for all items) varied between 1.41% and 10% (mean, 4.95: SD, 2.32), and it did not differ significantly from that of the monolingual group (Lehtonen et al., 2007; $t(30) = 0.896$, $p = 0.377$). The overall RTs (for all items) were also significantly slower for bilinguals than monolinguals ($t(30) = 3.58$, $p = 0.001$). The bilinguals' and monolinguals' RTs and error rates for each condition of interest can be seen in Table 3.

For RTs and error rates, a two-way ANOVA with *lexicality* and *group* was performed for monomorphemic pseudowords vs. monomorphemic real words (low and high frequency collapsed together) in the current bilinguals vs. the monolinguals of Lehtonen et al. (2007).

These analyses in the RTs showed a main effect of *lexicality* ($F(1,30) = 31.9$, $p < 0.001$) and a close-to-significant interaction between *lexicality* and *group* $F(1,30) = 3.39$, $p = 0.075$), suggesting that the lexicality effect (difference between "monomorphemic" pseudowords and monomorphemic real words) was somewhat larger for bilinguals than for monolinguals. There was also a main effect of *group* ($F(1,30) = 10.6$, $p = 0.003$, respectively), indicating that the overall RTs of the bilinguals were significantly slower than those of the monolinguals. With regard to error rates, the lexicality analyses did not show significant main effects or interactions.

Table 3
Mean response latencies (in milliseconds) and error rates (%) with standard deviations for the stimulus types of the bilingual and the monolingual groups.

Bilinguals			
Word category		RT (SD)	Error (SD)
Low frequency	Monomorphemic	764 (74)	3.91 (2.6)
	Inflected	914 (118)	10.2 (6.2)
High frequency	Monomorphemic	678 (69)	1.33 (1.5)
	Inflected	781 (101)	2.97 (2.0)
Monomorphemic pseudowords		885 (170)	3.13 (3.9)
Monolinguals			
Word category		RT (SD)	Error (SD)
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)
Monomorphemic pseudowords		709 (123)	2.42 (2.16)

A mixed-model ANOVA with *frequency* and *morphology* as within-subjects factors and *group* as a between-subjects factor was also performed for the RTs and error rates of real words. The results for RTs showed main effects of *frequency* ($F(1,30) = 114.6$, $p < 0.001$), *morphology* ($F(1,30) = 170.5$, $p < 0.001$), and *group* ($F(1,30) = 6.52$, $p = 0.016$), as well as interactions between *frequency* and *group* ($F(1,30) = 5.06$, $p = 0.032$) and *morphology* and *group* ($F(1,30) = 6.60$, $p = 0.015$), stemming from larger frequency and morphology effects for the bilinguals than for the monolinguals. In addition, there was a significant interaction between *morphology* and *frequency* ($F(1,30) = 23.4$, $p < 0.001$), showing that morphology effects (difference between inflected vs. monomorphemic words) were larger in the low frequency range than in the high frequency range. However, this difference was similar in both participant groups, as shown by the non-significant three-way-interaction *frequency* × *morphology* × *group* ($F(1,30) < 1$). With regard to error rates, there was a main effect of *frequency* ($F(1,30) = 77.9$, $p < 0.001$) and of *morphology* ($F(1,30) = 63.0$, $p < 0.001$), but no main effect of *group*, or significant interactions between these factors and *group*. A *frequency* by *morphology* interaction was significant ($F(1,30) = 36.9$, $p < 0.001$), indicating a smaller difference between inflected and monomorphemic words in the high frequency range than in the low frequency range. This effect did not differ between groups ($F(1,30) < 1$).

3.2. ERP results

3.2.1. Effects of lexicality

The grand-average potentials for lexicality effects, i.e., monomorphemic pseudowords minus monomorphemic real words, for both bilinguals and monolinguals are depicted in Fig. 1. An omnibus ANOVA was carried out introducing the within-subject factors *lexicality* and *electrode* location (15 electrodes) and the between-subject factor *group* (monolinguals vs. bilinguals). The *group* × *lexicality* analysis showed an interaction from 500 ms onwards ($F(1,30) = 6.04$; $p = 0.020$, at 500–600 ms), reflecting the fact that the larger negativity (an N400-type effect) for pseudowords than real words was longer lasting in the bilinguals than in the monolinguals. These analyses also showed an interaction between *lexicality* and *electrode* in the 450–550 ms ($F(1,14) = 16.54$; $p < 0.001$) and in the 500–600 ms time-windows ($F(1,14) = 11.35$; $p < 0.001$), due to the N400-type effect being overall stronger in medial than lateral electrodes.

3.2.2. Effects of frequency and morphology

The grand-average potentials for both groups with regard to frequency and morphology effects in real words are depicted at Figs. 2 and 3, respectively. No main effect of *group*, or interactions with group and other factors were present in the first two time-windows. In the 450–550 ms time-window, a significant interaction was found between *group* and *frequency* ($F(1,30) = 5.1$, $p = 0.031$), and a close-to-significant trend was found between *group* × *morphology* × *electrode* ($F(14,420) = 2.21$, $p = 0.070$). In the following time-window (550–650 ms), two interactions were significant: *group* × *frequency* × *electrode* ($F(14,420) = 4.2$, $p < 0.01$) and *group* × *morphology* × *electrode* ($F(14,420) = 4.1$, $p < 0.01$). This omnibus analysis showed that group differences exist for morphology and frequency effects in specific electrode locations.

In order to decompose the previous interactions and study the topographical distribution of the effects, we performed the same ANOVA at midline locations (electrodes Fz, Cz and Pz), and two regions of interest at parieto-occipital locations (electrodes P3, Pz, P4, O1 and O2) and at frontal locations (electrodes F3, Fz, F4, Fp1 and Fp2). The analysis of the three ANOVAs is shown in Table 4. Significant *group* × *frequency* effects were present for midline and parietal–occipital locations, but not for the frontal region of interest

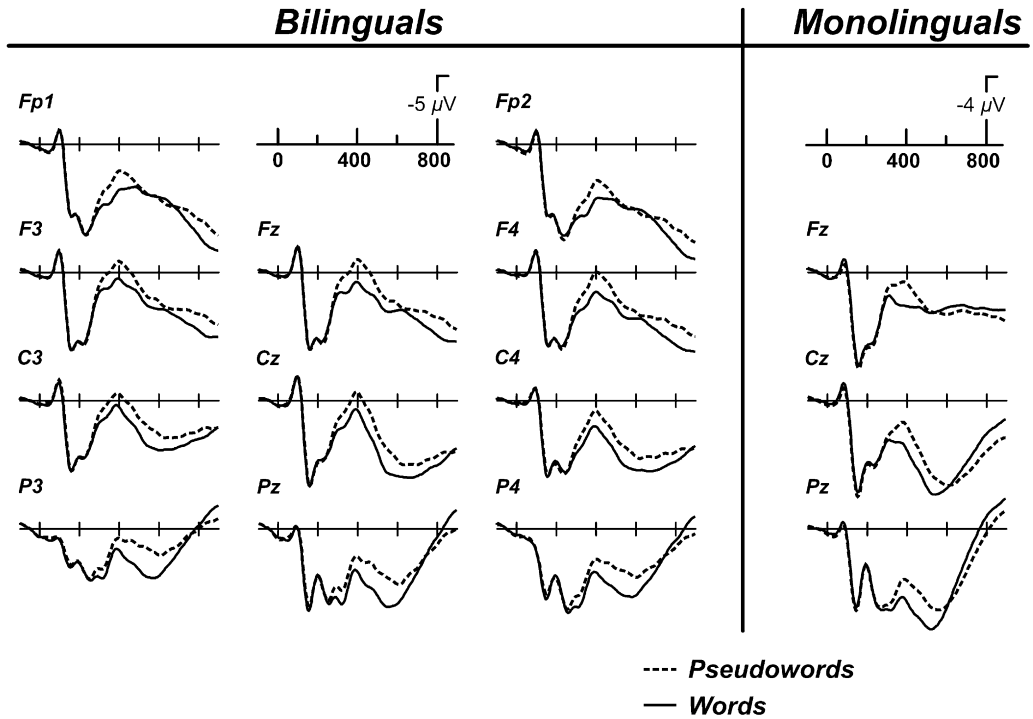

Fig. 1. Grand average ERPs for the monomorphemic real words (solid lines) vs. the monomorphemic pseudowords (dotted lines) for bilinguals (left panel) and monolinguals (right panel; midline electrodes).

in the last two time-windows (450–550 and 550–650 ms). Similarly, the *group* × *morphology* interaction was restricted to the midline and parietal ANOVAs.

Further, to investigate whether bilinguals show similar interactions between frequency and morphology at parietal–occipital sites to those of the monolinguals in the previous study, we analyzed the four conditions (low and high frequency inflected and monomorphemic words) for both groups at parietal–occipital locations (electrodes P3, Pz, P4, O1, O2). The *group* × *frequency* × *morphology* × *electrode* interaction performed at the 450–550 ms time-window was significant ($F(4,120) = 3.92$, $p = 0.011$). Further analyses in the separate frequency groups showed a significant interaction of *group* × *morphology* × *electrode* in the high frequency range, reflecting a larger effect of morphology (larger negativity for inflected than monomorphemic words) in the P3 electrode in bilinguals than monolinguals (see Fig. 4). There were no significant group interactions in the low frequency range, indicating that the negativity for low frequency inflected vs. monomorphemic words was similar in monolinguals and bilinguals. In other words, while monolinguals showed no difference

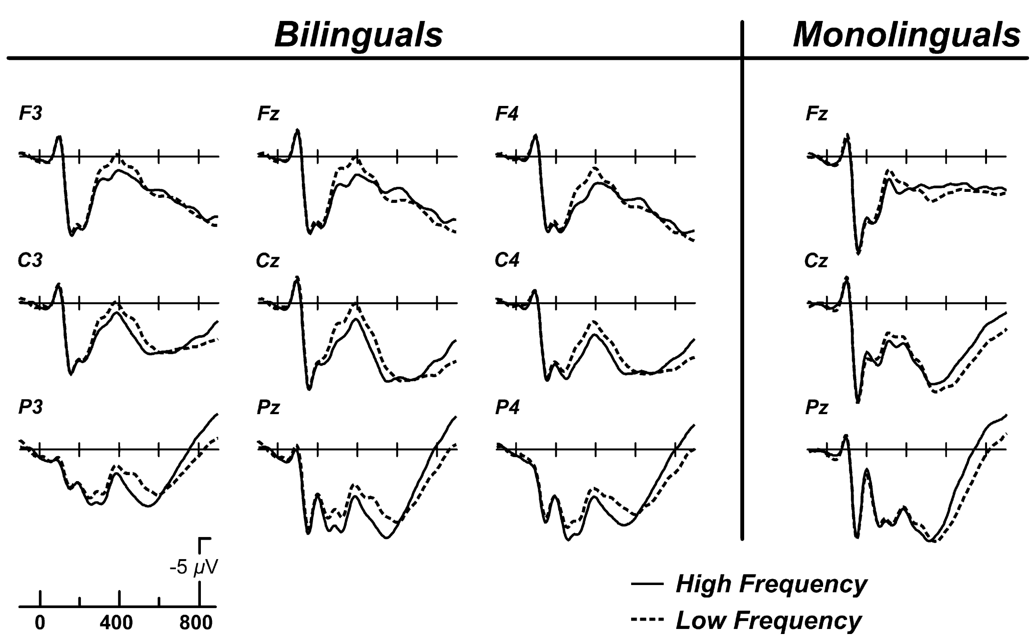

Fig. 2. Grand average ERPs for the low frequency words (dotted lines) vs. the high frequency words (solid lines) for bilinguals (left panel) and monolinguals (right panel; midline electrodes).

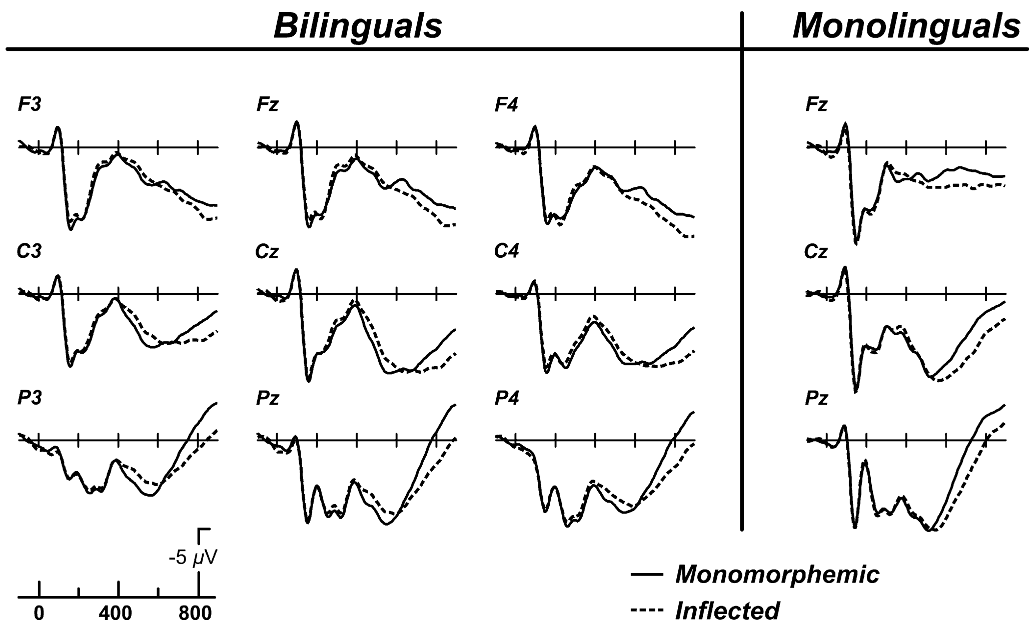

Fig. 3. Grand average ERPs for the inflected words (dotted lines) vs. the monomorphemic words (solid lines) for bilinguals (left panel) and monolinguals (right panel; midline electrodes).

Table 4
Quasicontinuous ANOVA for the analysis of *group* × *frequency* × *morphology* in real words performed at four time-windows. Three ANOVAs were carried out at frontal (+), midline (‡), and parieto-occipital (†) electrode locations.

	250–350	350–450	450–550	550–650
Frequency	+++,‡‡‡,††	+++,‡‡,†	†††	
Frequency × electrode	††		+,‡‡‡	
Group × frequency	†		‡,††	†
Group × frequency × electrode				‡‡‡
Morphology			+,‡,†	+++,‡,†
Morphology × electrode			+++,‡‡,†††	+++
Group × morphology			‡‡	‡,†
Group × morphology × electrode				++
Morphology × frequency	†		‡,†	‡,†
Morphology × frequency × electrode	‡			
Group × morphology × frequency × electrode			††	

Notes: Electrode locations included in the region of interest for the frontal ANOVA: Fp1, Fp2, F3, F4, Fz (*p*-values: $^{+}p < 0.05$; $^{++}p < 0.01$; $^{+++}p < 0.001$); in the region of interest for the midline ANOVA: Fz, Cz and Pz (*p*-values: $^{‡}p < 0.05$; $^{‡‡}p < 0.01$; $^{‡‡‡}p < 0.001$); in the region of interest for the parieto-occipital ANOVA: Pz, P3, P4, O1 and O2 (*p*-values: $^{†}p < 0.05$; $^{††}p < 0.01$; $^{†††}p < 0.001$).

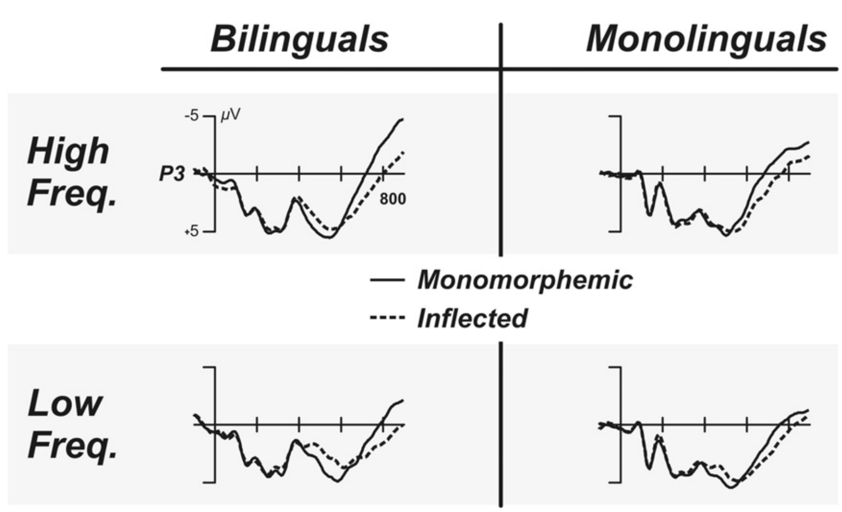

Fig. 4. Grand average ERPs for the inflected vs. monomorphemic words in the high and low frequency range in the electrode P3 for bilinguals (left panel) and monolinguals (right panel).

between inflected vs. monomorphemic words in the high frequency range, the bilinguals did, as did both groups in the low frequency range.

4. Discussion

We set out to investigate how the effects of frequency, morphology, and lexicality on word recognition might differ between monolinguals and early bilinguals. The manifestation of the effects of these basic psycholinguistic factors has been very little studied using ERPs in a bilingual context, even though bilinguals have, e.g., shown delayed N400 latencies or differentially lateralized N400 effects in other language tasks (Ardal et al., 1990; Hahne & Friederici, 2001; Moreno & Kutas, 2005; Proverbio et al., 2002). Behaviorally, we found that the effects for each of our factors, when compared to the monolingual Finnish group of Lehtonen et al. (2007), were larger in Finnish–Swedish bilinguals even though our bilinguals had acquired both languages early and had very high proficiency in them. The overall reaction times were also significantly slower for bilinguals than for monolinguals. The ERP effects were in line with the behavioral results. Group differences for lexicality were observed from 550 ms onwards, indicating that an increased negativity (an N400-type effect) for pseudowords was longer lasting in bilinguals than monolinguals. There was also a group by frequency interaction in the 250–350 ms, the 450–550 ms, and in the 550–650 ms time-windows, reflecting the fact that the N400 effect (larger negativity for low than high frequency words) was more pronounced and longer lasting in bilinguals than monolinguals. Similarly in the 450–650 ms time-windows, the effect of morphology, a larger negativity for inflected than monomorphemic words, was greater in bilinguals than monolinguals. Our behavioral and ERP results thus indicate that bilinguals are more sensitive to fundamental stimulus manipulations in word recognition, which is likely to reflect less exposure to word forms than in monolinguals.

The behavioral findings and the exposure interpretation are in line with the reasoning of Duyck et al. (2008): the subjective frequencies of words are lower in bilinguals than monolinguals, and as the function of the activation levels of words with regard to frequency is assumed to be logarithmic, the differences are larger at the lower end of the scale (Morton, 1970). Another view on frequency, cited by both Duyck et al. (2008) and Gollan et al. (2008), posits that the mental lexicon is organized on the basis of frequency-ordered bins where low frequency words are located further away than high frequency words (Murray & Forster, 2004). Words would be serially ranked according to relative frequencies, and in lower frequency ranges (where L2 words are overrepresented) the number of lexical entries is larger than in higher frequencies. The system would thus have to consider more words before arriving at the correct one in the bin, and search time would increase nonlinearly with decreasing frequency. As there are more items in the bilinguals' lexicon, especially in the low frequency range, it would take relatively more time to find the correct item (if one assumes that the search is not selective to a language). Either of these accounts could explain the larger frequency effects observed here in bilinguals. Similar explanations can also be applied to the lexical search and identification processes that are at work when distinguishing real words from pseudoword items, i.e., in lexicality effects that were found to be longer lasting in bilinguals than in monolinguals. Moreover, the larger morphology effects (i.e., the larger difference between inflected vs. monomorphemic words) could be due to having to access two representations instead of one, each of which is of relatively lower frequency than in monolinguals. Another, albeit more speculative possibility is that bilinguals would have less automatized language processing mechanisms related to morphological decomposition in particular. This might also be related to the other language Swedish that is morphologically much more limited and might therefore call for morphological decomposition less frequently than the morphologically rich Finnish.

The behavioral frequency effects for our early bilinguals differed from those of the late bilinguals by Duyck et al. (2008). They found different frequency effects in a visual lexical decision task between the two languages of the late bilinguals (L1, Dutch; L2, English), but not when comparing the magnitude of L1 frequency effects to the effect in English monolinguals. Duyck et al. (2008) state that their bilinguals (university students) had received L2 instruction for at least 5 years prior to the experiment but they do not report the exact age of acquisition or, for example, estimated percentages of use for the two languages. A later learned L2 has been in use for a clearly shorter period of time than L1. Thus, the exposure difference with regard to L1 between monolinguals and bilinguals is likely to be larger in early bilinguals who have spent a more equal time between the two languages than in late bilinguals. Different amounts of exposure might be one important reason for the differences in contrast to Duyck et al. (2008) study, i.e., that their bilinguals did not show differences to monolinguals in L1.

In picture naming, Gollan et al. (2008) found differences not only between the bilinguals' dominant (English) vs. the nondominant language (Spanish) but also in contrast to monolinguals with regard to the dominant language. Ivanova and Costa (2008) also found larger frequency effects in the dominant L1 (Spanish) of Spanish–Catalan bilinguals in contrast to Spanish monolinguals. The participants of Gollan et al. (2008) and of Ivanova and Costa (2008) had also acquired both languages at a relatively early age: at home or at (pre) school, respectively. In contrast, the very recent findings of Gollan et al. (2011) seem discrepant from the present behavioral results: they found differences in frequency effects between English-dominant Spanish–English bilinguals vs. English monolinguals only in production, not in comprehension (in reading or lexical decision). With regard to the present participants, although there was some variation in the language usage and background of their two languages, all of them were highly proficient in their language skills (see Table 2).[2] Due to the length of the ERP experiment, it was not possible to test their other language (Swedish) in the same study. As language exposure and proficiency level are likely to correlate with each other, future studies will have to resolve exactly how the magnitude of frequency, morphology, and lexicality effects correlates with the extent of language dominance and different age of acquisition and proficiency levels of bilinguals in word recognition.

In addition to the exposure ("weaker links") hypothesis, performance differences between bilinguals and monolinguals might also be explained by interference from the other language (see, e.g., Gollan et al., 2008). In word recognition, there is evidence of bilingual lexical access that is non-selective of language (Dijkstra and van Heuven, 2002; Spivey & Marian, 1999; Thierry & Wu, 2007): a visually presented word activates representations for orthographically overlapping words in both languages (Grainger & Dijkstra, 1992). However, it is not clear exactly how the interference hypothesis would explain augmented frequency effects in

[2] Even though the bilinguals were all highly proficient in their Finnish and Swedish skills, there was some variation in their language background. We therefore classified each bilingual participant as being either more Swedish-dominant, more Finnish-dominant, or balanced with regard to his/her language background information and language skill self-estimates. These subgroups were too small to be compared directly with one another, but the behavioral and ERP data were re-analyzed after excluding the more Swedish-dominant bilinguals ($N = 6$). Consequently, the effects became somewhat weaker, as one might expect due to reduced statistical power. However, the main pattern of results remained, indicating that the inclusion of the more Swedish-dominant bilinguals was not the main source of the differences to monolinguals.

bilinguals (Gollan et al., 2008). It is also in principle possible that both "weaker links" and cross-language interference mechanisms would be at work. As the interference is primarily driven by the relationships between targets and their competitors, interference effects should be more pronounced when the competitors' relative frequencies or "dominance" is higher. Clearly, more research is needed to resolve this issue e.g. by examining the effects of systematic manipulations of target-competitor frequency relationships on word recognition.

The N400 component that the presently examined factors had an effect on has been related to processes of accessing information in semantic memory (Kutas & Federmeier, 2000; Lau et al., 2008) or of creating a conceptual representation from information potentially derived from many sources (Kutas & Federmeier, 2011). One of the factors that the N400 component has been observed to be modulated by is the language proficiency and/or the age of acquisition of the participants. The N400 effects, most often studied with a semantic violation paradigm, tend to be later and sometimes longer lasting for later learned and less well mastered languages (e.g. Ardal et al., 1990; Weber-Fox & Neville, 1996; see Kutas & Federmeier, 2011; Moreno et al., 2008, for reviews). In the present study, the N400 effects were larger and also longer lasting even in early, highly proficient bilinguals than monolinguals. As the proficiency level was high and the age of acquisition early, the differences to monolinguals are likely to be due to a somewhat lower exposure to Finnish words of the bilinguals than Finnish monolinguals, as these bilinguals have divided their language input between the two languages. Exposure has thus an effect on brain responses indirectly via word frequencies.

It should, however, be noted that our larger frequency N400 effect for bilinguals is discrepant from the findings of (Rodríguez-Fornells, Rotte, et al., 2002; Rodríguez-Fornells, Münte, et al., 2002). They reported of similar N400 frequency effects for early Spanish–Catalan bilinguals as compared to Spanish monolinguals. One factor that could have affected their differential results is that Spanish and Catalan are closely related languages with an unusually high proportion of lexical overlap, i.e., shared cognate words. It is possible that the subjective frequencies of such words in bilinguals are in fact higher than what would be otherwise expected on the basis of the objective frequencies in each language, and the bilingual exposure.

Interestingly, at parietal electrodes, there was a four-way interaction between morphology, frequency, group, and electrode: in bilinguals both the high and the low frequency inflected words differed from monomorphemic words, but in monolinguals the high frequency inflected words did not differ from high frequency monomorphemic words. In some models of morphological processing (see, e.g., Niemi et al., 1994; Schreuder & Baayen, 1995), higher word form frequency is assumed to lead to full-form representations in morphologically complex words, while lower frequency word forms are assumed to be decomposed into morphological constituents. The main effect of morphology suggests that most Finnish inflected words are indeed decomposed into a stem and a suffix during recognition. However, the present interaction could suggest that monolinguals may process some inflected words of high frequency similarly to monomorphemic words, as whole entities. Following Lehtonen and Laine (2003), the difference to bilinguals can be explained by different amounts of exposure to the word forms. As bilinguals have to divide their language input between the two languages, the subjective frequencies for word forms in each language are lower than in monolingual speakers of that language. In this way, bilinguals do not encounter inflected word forms with even high objective frequencies often enough to develop full-form representations for them.

Whereas frequency effects were observed already in the earliest time-window of the N400 component (after 250 ms), morphological effects were not observed before 450 ms. The rather late locus of the morphology effects suggests that they are reflecting the later stage of decomposition (see, e.g., Lehtonen et al., 2007; Niemi et al., 1994) where the lexical-semantic representations of morphemes are accessed and integrated and possibly where the syntactic combinability of the constituents is checked (licensing), instead of early segmentation of the constituents at the visual word form level. The suggested later level of processing (lexical-semantic access or integration) is also in line with a recent MEG study which compared the same Finnish inflected vs. monomorphemic words as those used here in a word reading task in monolinguals. The effect of morphology that appeared from 200 ms onwards was located to the left superior temporal cortex (Vartiainen et al., 2009), an area that has been associated with lexical-semantic processing. Furthermore, if the time-window of our morphology effects reflects integration of the constituents rather than accessing lexical representations, the lack of a difference between high frequency inflected vs. monomorphemic words in the monolinguals might not necessarily be due to full-form representations for inflected words. In that case, the finding could also reflect smaller semantic integration demands of the common stem + suffix combinations of the high frequency inflected words in monolinguals than in bilinguals.

To summarize, behaviorally, early balanced bilinguals demonstrated larger effects of frequency, morphology, and lexicality than monolinguals. Differences were also seen in the ERPs, in particular in the N400 component where the effects of the bilinguals for each of these factors were larger and/or longer lasting than in monolinguals. These results extend the earlier findings that have observed N400 differences in semantic anomaly manipulations between monolinguals and bilinguals to key psycholinguistic factors in word recognition. They also show that differences can be seen in contrast to monolinguals even when the bilinguals have acquired two languages early and are highly proficient in them. The differences are likely to reflect lower amounts of exposure to the words, as the bilinguals divide their language input between the two languages.

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