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Research Report

Lexical stress encoding in single word production estimated by event-related brain potentials

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ABSTRACT

An event-related brain potentials (ERPs) experiment was carried out to investigate the time course of lexical stress encoding in language production. Native speakers of Dutch viewed a series of pictures corresponding to bisyllabic names which were either stressed on the first or on the second syllable and made go/no-go decisions on the lexical stress location of those picture names. Behavioral results replicated a pattern that was observed earlier, i.e. faster button-press latencies to initial as compared to final stress targets. The electrophysiological results indicated that participants could make a lexical stress decision significantly earlier when picture names had initial than when they had final stress. Moreover, the present data suggest the time course of lexical stress encoding during single word form formation in language production. When word length is corrected for, the temporal interval for lexical stress encoding specified by the current ERP results falls into the time window previously identified for phonological encoding in language production.

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1. Introduction

Models of speech production (e.g., Caramazza, 1997; Dell, 1986; Garrett, 1975; Levelt, 1989; Levelt et al., 1999) assume that spoken word generation involves several cognitive processes, such as conceptual preparation, lexical access, word form encoding, and articulation. Phonological encoding is part of word form encoding. Levelt et al. (1999) presented one of the most fine-grained models of phonological encoding to date (see also Dell, 1986, 1988). According to this model, phonological encoding can start after the word form of a lexical item has been retrieved from the mental lexicon. First, the phonological encoding system must access the ordered set of segments (phonemes), and the metrical frame of a word form has to be retrieved or computed. The metrical frame

consists of – at least – the number of syllables and the location of the lexical stress. Segmental and metrical retrieval run in parallel (Levelt et al., 1999; Roelofs and Meyer, 1998).

During segment-to-frame association, previously retrieved segments are combined with their metrical frame. Segments are inserted incrementally into slots made available by the metrical frame to build a so-called *phonological word*, i.e. a sequence of one or more well-formed syllables. A phonological or prosodic word consists of one or more lexical items, bears one lexical stress, and constitutes the domain of phonotactic constraints and syllabification. The syllabification process is incremental and respects universal and language-specific syllabification rules (Roelofs, 1997). Thus, segment-to-frame association is the process that lends the necessary flexibility to the speech production system such

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that it can adapt to the verbal context. When the segments have been associated with the metrical frame, the resulting phonological syllables may be used to activate corresponding phonetic syllables in a mental syllabary (Cholin et al., 2004, 2006; Crompton, 1981; Levelt and Wheeldon, 1994; Schiller et al., 1996). Once the syllabic gestural scores are made available, they can be converted into neuro-motor programs, which are used to control the movements of the articulators. The execution of these neuro-motor programs results in overt speech (Goldstein and Fowler, 2003; Guenther, 2003). This study focuses on metrical encoding, i.e. the processes involved in retrieving and encoding the correct lexical stress of words.

Phonological encoding is an incremental process. The incremental nature of this process has been demonstrated time and again. For instance, Meyer (1990, 1991) used a preparation paradigm to show that participants are faster in naming a word if they could prepare segmental material of target words. The preparation effect increases with the size of the known word-initial stretch. However, no preparation effect occurred when segmental material from the final part of the word could be prepared. This result has been taken to support the hypothesis that segmental encoding proceeds in an incremental fashion from word beginning to word end.

More on-line data about the time course of segmental encoding during speech production comes from a study by Van Turennout et al. (1997). These authors used lateralized readiness potentials – a derivative of the human electroencephalogram (EEG) – to show that the first segment of a word is encoded approximately 80 ms earlier than the last segment. The words in their study were on average 1.5 syllables long. Van Turennout et al.'s result demonstrates not only the temporal ordering of segments during phonological encoding but also gives an indication of the speed of this process, i.e. 50 to 55 ms from syllable onset to syllable offset.

Additional evidence for the incremental nature of phonological encoding comes from a study by Wheeldon and Levelt (1995). In Experiment 3 of their study, they asked bilingual participants to monitor for pre-specified segments when generating the Dutch translation of an English word. Wheeldon and Levelt found that participants were 55 ms faster in monitoring for the first consonant in a $C_1VC_2C_3VC_4$ word (where C stands for consonant and V for vowel), such as *lifter* ('hitchhiker'), than for the second consonant. Furthermore, they were faster in monitoring for C_2 than for C_3 and C_3 was faster than C_4 , although this last difference did not reach significance. Wheeldon and Levelt took their results to confirm the incremental encoding of segments during phonological encoding in speech production. They argued that their monitoring effect occurred at the phonological word level, i.e. when a fully syllabified phonological representation of a word was generated. In one of their experiments (Experiment 1B), they included an articulatory suppression task which did not change the monitoring results in any principled way, suggesting that participants are not monitoring an articulatory-phonetic code. The fact that Wheeldon and Levelt found an effect of syllabic structure (Experiment 2) also indicates that a more abstract but fully prosodified representation was being monitored, e.g., the phonological word representation.

Interestingly, the monitoring difference between C_1 and C_2 (55 ms) corresponds nicely to the data found by Van Turennout et al. (1997) with another monitoring task (50 to 55 ms; see above). Wheeldon and Morgan (2002) replicated this result for English using a slightly different methodology (see also Morgan and Wheeldon, 2003), and Schiller (2005) replicated and extended the results for Dutch. For instance, Schiller found that metrical stress position influenced the monitoring latencies for segments in bisyllabic words, again implying a prosodified representation for monitoring. Importantly for the present study, if Wheeldon and Levelt (1995) were correct in assuming that the phonological word level was being monitored in their task, speakers should also be able to monitor metrical stress in self-generated words. Furthermore, if metrical stress is encoded in a comparable incremental manner as phonological segments, additional information about the time course of metrical encoding may be obtained. Alternatively, speakers may have access to the whole metrical frame representation of word forms at once, and thus no difference in timing between the access to initial and final stress is to be expected.

Schiller et al. (2006a) investigated the monitoring of metrical stress information in internally generated speech behaviorally. When Dutch participants were asked to judge whether bisyllabic picture names had initial or final stress, decision times were significantly faster for initially stressed targets (e.g., *KANo* 'canoe'; capital letters indicate stressed syllables) than for targets with final stress (e.g., *kaNON* 'cannon'). It was shown that monitoring latencies are not a function of the word frequencies, picture naming latencies, or object recognition times to the same pictures. These results were replicated with trisyllabic picture names to demonstrate that they were independent of the default stress, which is initial in Dutch (see below). Schiller et al. (2006a) interpreted the outcome as demonstrating that metrical encoding in speech production is a rightward incremental process. However, although the incremental nature of metrical stress retrieval and encoding was established in the Schiller et al. (2006a) study, the monitoring latencies do not allow drawing any conclusions about the temporal properties of metrical encoding in real time.

The time course of information processing is an important aspect of language processing since it can help to constrain theoretical models of psycholinguistics (see review in Levelt et al., 1999). Recently, Indefrey and Levelt (2004) specified the whole time course of speech production based on a meta-study of word production experiments. They estimated on the basis of EEG and magnetoencephalography (MEG) data that phonological encoding during single word production takes place approximately between 200 and 400 ms after the onset of a stimulus (e.g., a picture) evoking the response (e.g., the corresponding picture name). However, these temporal estimations hold only for monosyllabic words of moderate to high frequency of occurrence. For more frequently occurring words, phonological encoding may take place earlier, and for longer – and less frequently occurring – words, phonological encoding may have a later time course (Jescheniak and Levelt, 1994).

The estimation of a time course includes the determination of a temporal order of certain processes and an estimation of the duration of those processes (see Indefrey and Levelt, 2004).

Several event-related potential (ERP) studies have been performed to assess the time course of information processing during language production and language comprehension (e.g., Rodriguez-Fornells et al., 2002; Schiller et al., 2003a,b, 2006b; Schmitt et al., 2000, 2001a,b; Van Turenhout et al., 1997, 1998), some of which formed the basis for the temporal estimation of language production processes provided by Indefrey and Levelt (2004). It is the goal of the present study to specifically investigate one part of phonological encoding, i.e. the time course of metrical encoding in single word production using an on-line processing task.

1.1. Metrical stress in Dutch

Although the intricacies of the Dutch metrical stress system are still under debate, I will provide a brief summary for bisyllabic words here (see Booij, 1995 and Kager, 1989 for overviews). In the theory of Trommelen and Zonneveld (1989, 1990) and Zonneveld et al. (1999), bisyllabic words receive stress on the initial syllable, except when the final syllable is a so-called super-heavy syllable, i.e. a syllable with a rhyme of the type VVC or VCC (where V stands for a short vowel, VV for a long vowel or a diphthong, and C for a consonant). In that case, stress falls on the super-heavy final syllable. According to this account, only words carrying stress on a final syllable that is not super-heavy are exceptional (e.g., *foREL* 'trout' in Dutch). The stress patterns of those words are assumed to be stored in the lexicon, whereas the remaining stress patterns could be generated by rules.

The psycholinguistic account of metrical stress representation put forward in Levelt's theory is less complicated (see Roelofs and Meyer, 1998). Levelt et al.'s. (1999) position is that the metrical structure of regular words is derived by a simple default rule (i.e. "stress the first syllable containing a full vowel"). A full vowel is any vowel except for schwa (e.g., the first vowel in the word *about* /əbʊt/), which can never be stressed in Dutch (or English or German; Kager, 1989). Only for irregular words (less than 10% of the word tokens), the metrical frame is stored in the lexicon. Note that some words, which are regular according to linguistic accounts, are irregular according to Levelt et al. (1999) position (e.g., *ciTROEN* /sitrun/ 'lemon', which has a super-heavy final syllable). Also note that another model of phonological encoding in language production, i.e. Dell (1986, 1988), is silent on the representation, retrieval, and computation of metrical stress. However, presumably Dell's model could be extended to capture the regularities of stress assignment during language production.

The empirical evidence for whether or not metrical stress is stored in the lexicon is inconclusive at the moment (see overviews in Schiller et al., 2004, 2006a). Possibly, metrical stress is computed for the majority of the words as long as their stress pattern can be derived by some linguistic rule including words that are irregular according to psycholinguistic definitions (see Fikkert et al., 2005 and Schiller et al., 2004). Here, we will not be concerned with whether metrical stress is stored or computed. The internal word generation and self-monitoring task used in the experiment reported below is assumed to have access to the phonological word level, i.e. a fully prosodified representation.

1.2. The N200

For the assessment of the temporal scheme of language processes, the use of a go/no-go paradigm can be very effective. In such a paradigm, individuals are asked to respond to one class of stimuli (*go* trials) and withhold their response to another class of stimuli (*no-go* trials). A specific ERP component was found to be related to response inhibition, namely the N200, a fronto-central negativity occurring approximately between 100 and 300 ms after stimulus onset (Gemba and Sasaki, 1989; Pfefferbaum et al., 1985; Sasaki et al., 1993; Thorpe et al., 1996). This N200 was more negative in no-go trials compared to go trials. The functional significance of this component is not yet clear, however, the amplitude of the N200 is seen as a function of neuronal activity required for "response inhibition" (Jodo and Kayama, 1992) occurring in a go/no-go task. Moreover, when the type of information on which the go/no-go paradigm is based has been defined, the peak latency of the N200 effect can be used to determine the moment in time at which this information is encoded or available in such a way that a response decision can be made. Thus, "an early N200 means that the information that blocked the response on no-go trials was available early and vice versa" (Kutas and Schmitt, 2003, p. 200). This was shown, for example, by Thorpe et al. (1996) who employed the N200 no-go effect to a visual categorization task with the aim of determining the minimum time needed for conceptual processing of pictures. Note that the N200 occurs later in time when it is related to language processing (for an overview, see Kutas and Schmitt, 2003).

1.3. The experimental paradigm

The experiment was carried out in Dutch. Native Dutch participants saw pictures corresponding to bisyllabic, monomorphemic nouns, one at a time, on a computer screen and were asked to retrieve each picture name and classify it according to its lexical stress location (*initial* or *final*). In half of the trials, participants were required to carry out a right-hand button-press if the picture depicted a word with initial stress (e.g., *KAno*, 'canoe'; *go*=initial) and withhold their response when it had final stress (e.g., *kaNON*, 'cannon'; *no-go*=final). In the other half, participants were required to press the button when the picture referred to a word with final stress (e.g., *kaNON*, 'cannon'; *go*=final), but not when it had initial stress (e.g., *KAno*, 'canoe'; *no-go*=initial). This way, two difference waves (or two N200s) could be calculated: a difference wave of all trials with initial stress and a difference wave of all trials with final stress.

The present ERP study aims at using the peak latencies and amplitudes of the N200 to determine whether or not phonological information about initial stress can be retrieved earlier than phonological information about final stress. We can use the N200 and its shift in peak latency to estimate the time course of metrical stress encoding in word production. The difference between the go and no-go responses in the N200 provides an upper limit about the point in time when the necessary information must be available in order to determine whether or not to respond. If the metrical stress pattern of words becomes available all at once during

phonological encoding, no differences in N200 peak latencies to first and second syllable stress should be found. If, however, metrical encoding follows an incremental pattern, then initial stress should become available earlier in time than final stress. This would thus lead to an earlier N200 in case the no-go decision is based on initial stress than when it is based on final stress because participants can make the decision to withhold their response at an earlier point in time.

2. Results

2.1. Button-press latencies

Reaction times (RTs) faster than 350 ms or slower than 1500 ms were excluded from the analysis (4.1% of the correct responses fell outside these trimming criteria). Mean RTs for correct go responses were faster for picture names with

initial stress (885 ms; SD=75) than for picture names with final stress (971 ms; SD=89). This 86 ms difference was significant ($t_1(13)=4.98$, $p<0.001$; $t_2(79)=6.84$, $p<0.001$).

The RT effect was supported by the error analyses, that is, there were more errors in the final stress than in the initial stress condition. In total, 8.2% errors were made, of which 35% (2.9%) occurred in the initial stress condition and 65% (5.3%) in the final stress condition. The error rate in the initial stress condition was significantly lower than in the final stress condition, as reflected by a paired t test ($t_1(13)=2.64$, $p<0.05$; $t_2(73)=2.64$, $p<0.01$).

2.2. ERP analysis

The N200 analysis is built on the assumption that the maximum of the increased negativity for no-go trials compared to go trials reflects the moment in time at which relevant information necessary to withhold a button-press response must have been encoded. The time necessary to encode the

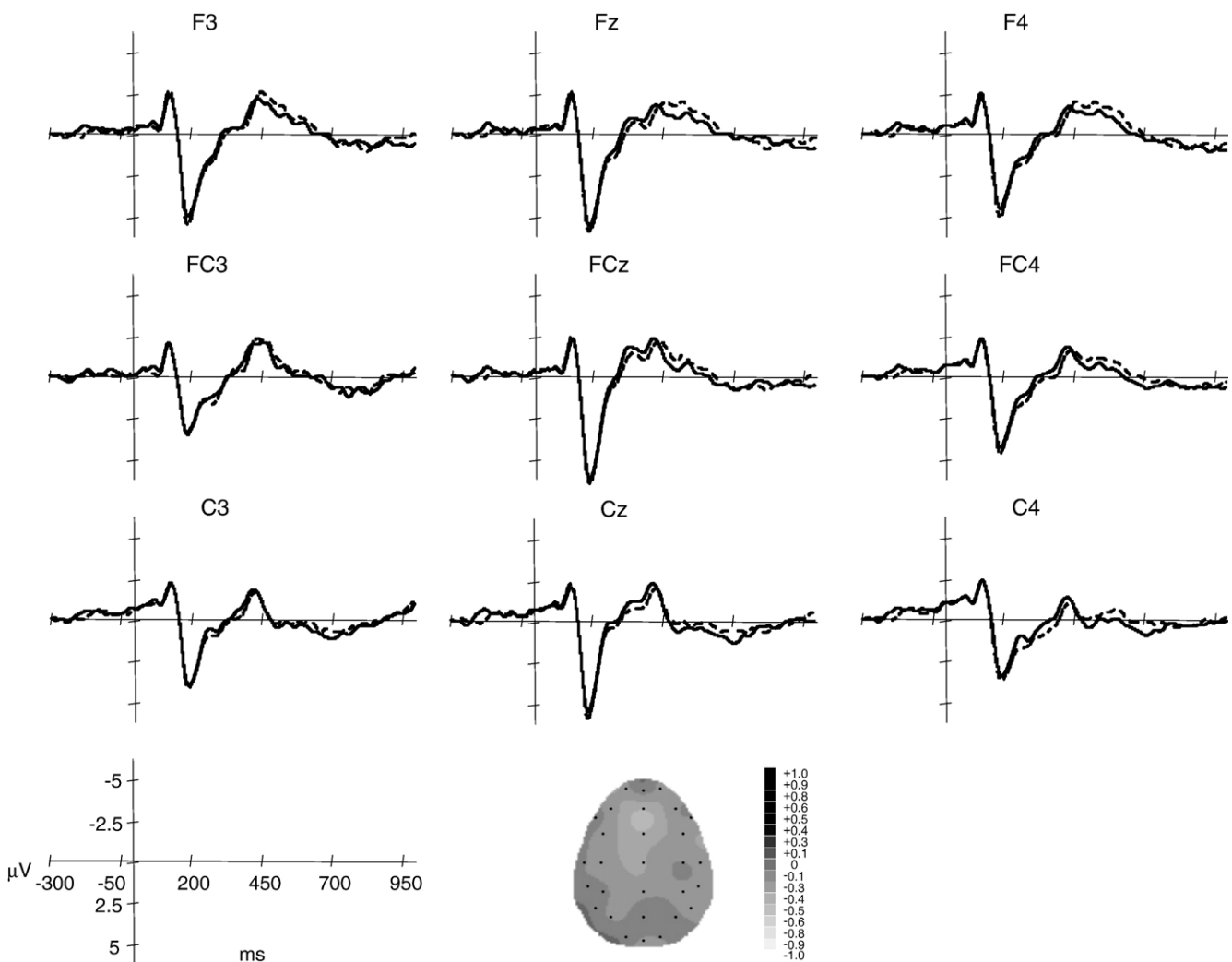


Fig. 1 – Grand average ERPs for go (solid lines) and no-go (dotted lines) trials in stress-initial condition. Displayed are data from 14 participants (160 trials per condition per participant minus rejected trials) over nine electrode sites (F3, Fz, F4, FC3, FCz, FC4, C3, Cz, and C4).

important information may, thus, be seen in the peak latency and amplitude of the N200. ERP signals were averaged per participant and condition. Grand average ERPs were obtained separately for initial stress and final stress conditions. Figs. 1 and 2 show grand average waveforms for both conditions for 14 participants at nine fronto-central electrode sites (F3, Fz, F4, FC3, FCz, FC4, C3, Cz, and C4). As can be seen, both conditions showed an N200 with no-go responses being more negative than go responses.

ERP difference waveforms (no-go minus go) were calculated per participant and condition. Fig. 3 displays the grand average difference waveforms for initial and final stress conditions superimposed. The figure shows that the peak latency of the N200 effect corresponding to the initial stress condition precedes the final stress condition.

The statistical comparison of the ERP difference waveforms for the two conditions has been limited to three fronto-central midline sites (i.e. Fz, FCz, and Cz) since the N200 is usually most clearly visible on these electrodes

(Schmitt et al., 2000). For each participant, peak latency and peak amplitude (voltage value at the peak) of the N200 effect between 200 and 700 ms were measured at each of the three electrode sites for correct trials. For the peak latencies, as well as peak amplitudes, repeated measures ANOVAs were carried out with Lexical Stress Location (initial or final) and Electrode Site (Fz, FCz, or Cz) as factors.

Of interest was whether or not the peak latency characteristics of the N200 effects differed between initial stress and final stress targets. For the peak latencies, the main effect of Lexical Stress Location was significant, $F(1,13)=17.25$, $p<0.01$, indeed reflecting a difference in peak latencies. When the go/no-go decision was contingent on initial stress information, the mean peak latency of the N200 across electrode sites was 475 ms (SD=14). In contrast, when the go/no-go decision was contingent on final stress information, the mean peak latency of the N200 was 533 ms (SD=21). The mean latency difference of the two N200s was 58 ms across the three midline sites. The onset latencies

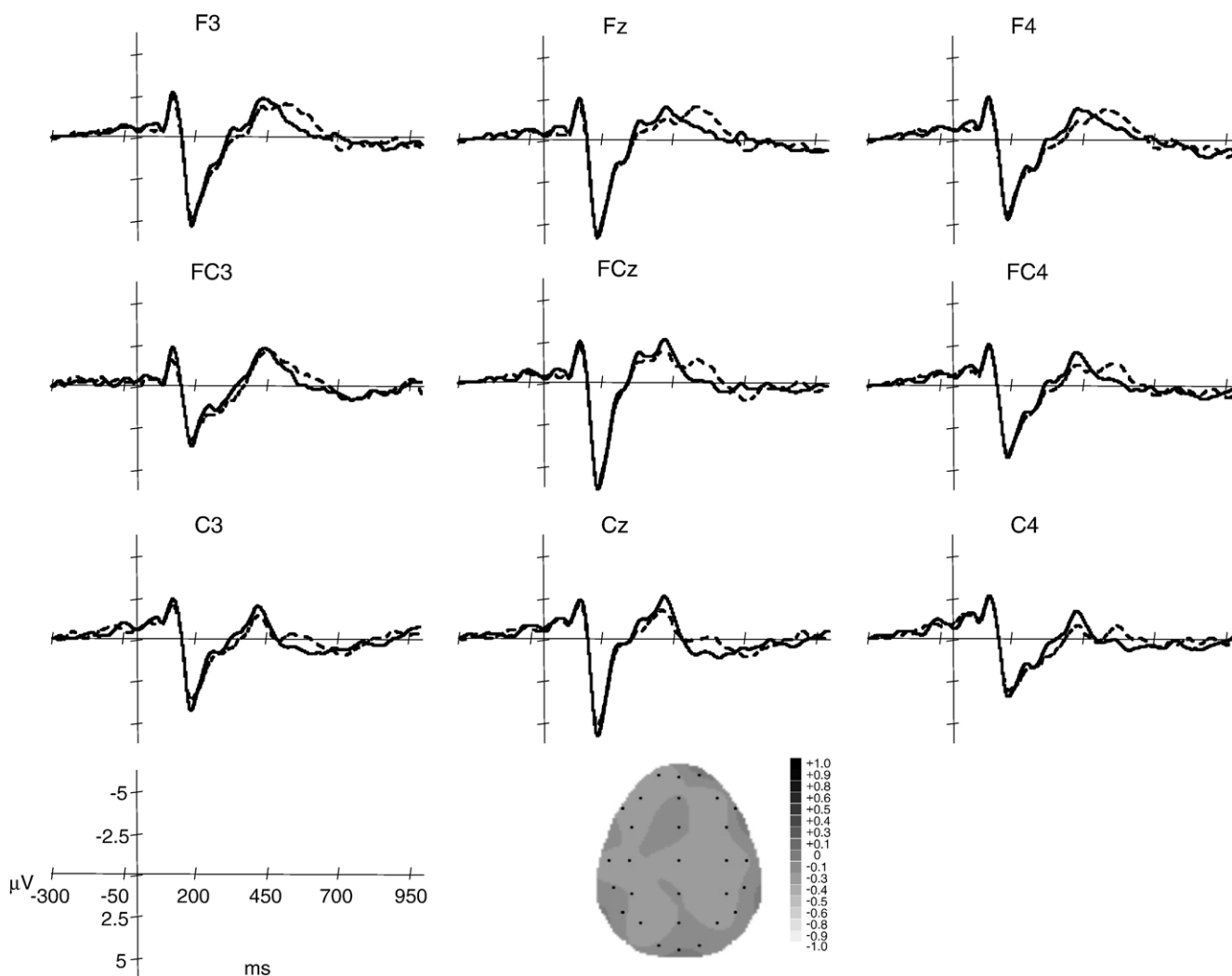


Fig. 2 – Grand average ERPs for go (solid lines) and no-go (dotted lines) trials in stress-final condition. Displayed are data from 14 participants (160 trials per condition per participant minus rejected trials) over nine electrode sites (F3, Fz, F4, FC3, FCz, FC4, C3, Cz, and C4).

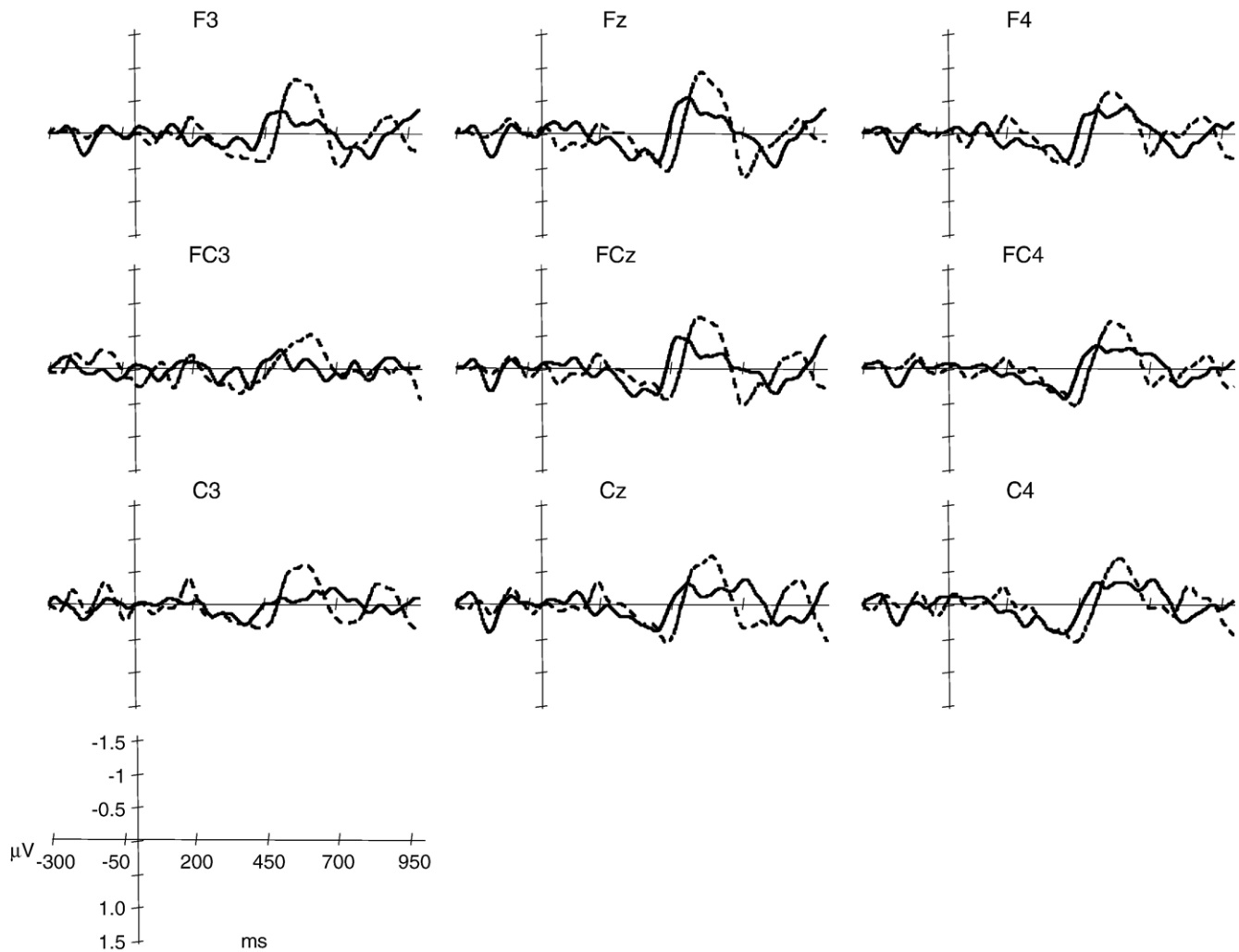


Fig. 3 – Grand average difference ERPs (no-go minus go) for stress-initial and stress-final conditions. Stress-initial (solid lines) and stress-final (dotted lines) difference waveforms are overlaid. Displayed are data from 14 participants (320 trials per condition per participant minus rejected trials) over nine electrode sites (F3, Fz, F4, FC3, FCz, FC4, C3, Cz, and C4).

of these peak amplitudes – as determined by continuous *t*-tests – were 456 ms across electrodes for initial stress and 512 ms for final stress, resulting in a mean onset latency difference of 56 ms. The main effect of Electrode Site was not significant ($F(2,26) < 1$), but the interaction between Electrode Site and Lexical Stress Location was significant ($F(2,26) = 6.00$, $p < 0.01$), reflecting a larger effect on Fz (63 ms) and FCz (62 ms) than on Cz (49 ms).

With respect to the peak amplitudes, only the main effect of Lexical Stress Location was marginally significant ($F(1,13) = 4.47$, $p = 0.054$), with initial stress ($-1.46 \mu\text{V}$) yielding less negative peaks than final stress ($-2.04 \mu\text{V}$) across midline electrode sites. Neither the main effect of Electrode Site ($F(2,26) = 1.77$, n.s.) nor the interaction between Lexical Stress Location and Electrode Site was significant ($F(2,26) < 1$).

There was also a P2 effect visible on some (frontal) electrodes for initial stress (see Fig. 1). This P2 effect was analyzed on the following nine electrodes: F3, Fz, F4, FC3, FCz, FC4, C3, Cz, and C4. However, the amplitude of the P2 was not significantly different between the go and the no-go condi-

tions neither for initial stress ($F(1,13) = 1.09$, n.s.) nor for final stress ($F(1,13) < 1$).

3. Discussion

The influence of lexical stress location on the speed of phonological decision-making was investigated by using a simple go/no-go paradigm combined with high-temporal resolution ERP. In this particular case, the N200 results speak to the time course of information flow related to response inhibition. Specifically, the N200 effect (“no-go minus go” ERPs) reflects an upper limit about the point in time at which information about whether an actual response needs to be made or withheld must have become available. This time is typically captured by the mean peak latency of the N200 (e.g., Rodriguez-Fornells et al., 2002; Schiller et al., 2003a,b, 2006b; Schmitt et al., 2000, 2001a,b).

The behavioral results replicate earlier results by Schiller et al. (2006a). In that study, a 70 ms effect between monitoring

initial and final stress was found for bisyllabic picture names. The 86 ms difference found here nicely replicates this result. Furthermore, there were significantly more errors on final stress targets (5.3%) than on initial stress targets (2.9%), mirroring the RTs. Note that in Schiller et al. (2006a; Experiment 1) there was a similar pattern (12.1% vs. 15.5%, respectively for initial and final stress; the overall higher error percentages may be due to the fact that participants were not pre-selected), albeit this difference was not significant. Presumably, monitoring initial stress is easier than monitoring final stress due to more “noise” in the production system the further away the stress is located from the beginning of the word. Noise could refer to any component that degrades the precision of the encoding process. This proposal is consistent with the increasing error percentages found for three-syllable targets in Schiller et al. (2006a), i.e. 6.5% for first, 7.3% for second, and 8.2% for third syllable stress.

However, the current study also extends the earlier findings. In the present study, I showed that the N200 effect varied in latency as a function of the condition in which the go/no-go lexical stress decision was made. More specifically, I found that the N200 peaked 58 ms earlier when the go/no-go phonological decision was made for pictures corresponding to words with initial stress than when it was made for pictures referring to words with final stress. This means that the information that blocked the response on no-go trials was available earlier in the initial stress condition than in the final stress condition. Whereas the RTs only give an indication about the magnitude of the relative effect, the N200 peak latencies also provide a close estimate about the point in time of metrical encoding or the monitoring of stressed syllables in real time.

The N200 effect peak latencies (475 ms and 533 ms, respectively) are well within the range of N200 effects reported in the language processing literature (Rodríguez-Fornells et al., 2002; Schmitt et al., 2000, 2001a,b). Furthermore, the latency of the N200 (400–500 ms time window) fits well with the claim that a phonologically encoded representation of the target word is used for stress monitoring. Indefrey and Levelt (2004) claimed that phonological encoding of words takes place approximately between 200 and 400 ms after picture onset in a picture naming task. However, the targets used in the present study were slightly longer (bi- instead of monosyllabic) and slightly less frequently occurring than the stimuli Indefrey and Levelt (2004) based their claims on. Note that Wheeldon and Levelt (1995) as well as Van Turennout et al. (1997) estimated the phonological encoding of one syllable to take approximately 50–55 ms (see above). Moreover, the mean naming latencies for the current pictures are more than 800 ms (see Schiller et al., 2006a), i.e. 200 ms more than the average picture naming latency assumed by Indefrey and Levelt (2004), i.e. 600 ms. Taking these two factors into account, i.e. word length and frequency, it may seem justified to correct the time window of phonological encoding for the current targets by about 100 ms to an interval of about 300 to 500 ms.

One may argue, of course, that initial stress is the default lexical stress position in Dutch (as in other Germanic languages) and that therefore participants were faster to monitor initial stress than final stress. However, Schiller et al. (2006a) demonstrated that the effect can also be observed for trisyllabic words when monitoring for pre-final vs. final stress

position or when monitoring for all three stress positions (initial, pre-final, and final). The reason why bisyllabic instead of trisyllabic targets were chosen for this ERP study had to do with the number of available items: while there were 40 bisyllabic items available for initial and final stress, there were only 14 trisyllabic items available for each stress position. Furthermore, naming latencies for trisyllabic items were longer and name agreement on the pictures was lower (see Schiller et al., 2006a for details). Due to these practical problems, it was decided to only test bisyllabic targets in the current study.

Another point of criticism often made about internal monitoring studies is that they do in fact not measure production but perception processes, that is, participants generate the target word form and then “scan” it in some sort of buffer before articulation for the target stress position. Although I cannot entirely refute this criticism on the basis of the current data, earlier monitoring studies have shown that this is unlikely to be the case. In fact, certain production characteristics of the target words are reflected in the monitoring latencies. For instance, in their phoneme monitoring study, Wheeldon and Levelt (1995) found that the monitoring latencies increased the further away the target phoneme occurred from the beginning of the word, that is, initial phonemes were detected faster than final phonemes (see Introduction). However, the monitoring latencies were not a linear function of the position. Instead, the increase in monitoring latencies was attenuated towards the end of words. Wheeldon and Levelt (1995) accounted for this attenuation by proposing that segments were retrieved at the same speed, but the insertion into the phonological frame was somewhat slower. Therefore, the further away segments occur from the beginning of the word, the less time the insertion process has to wait until segments become available for insertion into the frame. As a consequence, later segments can be inserted relatively faster than earlier segments. Since a prosodified phonological code is monitored, the monitoring latencies reflect characteristics of the production system.

A similar effect was also found for the detection of lexical stress in Schiller et al. (2006a). In that study, monitoring latencies to third syllable stress were longer than those to second and first syllable stress. However, the increase in monitoring latencies from first to second to third syllable stress was not linear, either. Instead, the difference between second and third syllable stress was relatively smaller than the difference between first and second syllable stress. Schiller et al. (2006a) proposed that, for stress to become encoded, segments and syllable boundaries also have to be encoded. If encoding of later segments is relatively delayed compared to earlier segments, this may also account for the relatively delayed encoding of metrical stress the further away the metrical stress occurs from the beginning of the word.

The stress monitoring results presented in this study may speak to the interplay between language production and comprehension processes (see also Christoffels et al., *in press*). Internal monitoring of planned speech proceeds via the comprehension system (Wheeldon and Levelt, 1995). Therefore, internal monitoring may reflect characteristics of the speech planning process, e.g., phonological encoding, which only become explicit via the comprehension system. In the

present case, the time course of metrical encoding is reflected by increased monitoring latencies for final relative to initial stress. That is, internal monitoring may form a crucial connection between the speech production and the comprehension system.

To conclude, the N200 was employed to monitor on-line language production. More precisely, I investigated whether or not lexical stress location influenced phonological decisions. The ERP data showed an earlier N200 effect for stress-initial items than for stress-final items, suggesting that initial stress is encoded earlier during the time course of phonological retrieval than final stress. Furthermore, when lexical factors (long word length, low frequency of occurrence) of the present stimulus material are corrected for, the N200 peak latencies fall into the time interval independently determined for phonological encoding. This study shows how we can make use of ERPs with their high temporal resolution to find out more about the time course of processing in language production.

4. Experimental procedures

4.1. Participants

Fourteen right-handed native speakers of Dutch (12 female and 2 male; mean age: 23 years) received a small financial reward to take part in the experiment after having given written informed consent. The ethical committee of the Faculty of Psychology of Maastricht University approved the study. All participants were undergraduate students, reported to be neurologically healthy, and had normal or corrected-to-normal vision.

4.2. Materials

Eighty pictures were selected, all depicting bisyllabic Dutch nouns. Half of the pictures depicted nouns with initial stress (KA_{no}, 'canoe'), the other half referred to picture names with final stress (kaNON, 'cannon'; see Appendix A for the whole list of materials). Target pictures were selected on the basis of earlier studies on the processing of lexical stress (Schiller et al., 2003a, 2006a). The pictures used here consisted of everyday objects with which participants were highly familiar. Pictures were taken from a database of simple line drawings at the Max Planck Institute for Psycholinguistics in Nijmegen, The Netherlands. Importantly, pictures referring to words with initial and final stress did not show any differences in picture recognition latencies and the corresponding words had similar word frequencies (Baayen et al., 1995; for details see Schiller et al., 2003a, 2006a). All pictures fitted into a 7 cm by 7 cm square.

4.3. Design

The experiment consisted of three parts. First, there was a familiarization block in which all pictures were presented on the screen one at a time with the designated name printed below it. Participants were free to decide when to go to the next picture by pressing the right shift key. Second, all pictures were shown again in a different random order, but this time without their names printed below. Participants were asked to name

the pictures aloud. In the rare event that participants did not use the designated picture name, they were corrected by the experimenter. Third, the experiment proper started. Participants were tested on two types of experimental blocks (*go/no-go initial stress* and *go/no-go final stress*) with the same set of pictures. In one block, participants were asked to respond to pictures corresponding to words with initial stress (and thus withhold their response if confronted with a picture corresponding to a word with final stress). In the other block, participants were asked to do the opposite, i.e. respond to final stress pictures and withhold the response if confronted with an initial-stress picture. Thus, for each stress position (i.e. initial and final), go trials as well as no-go trials were created. Participants received four practice trials, two of initial-stress pictures and two of final stress pictures, before two experimental blocks of 80 trials each were presented. Half of the participants started with a block in which they had to actively respond to pictures with initial stress. When all eighty pictures were presented, the second block followed, but this time participants were asked to actively respond to pictures with final stress. Following each block, there was a short break. The other half of the participants was presented with the reversed block order. The sequence of words was randomized in each block and for each participant. To increase the power, both blocks were repeated once. Each experimental block lasted approximately 10 min, and the entire experiment lasted about 2 h, including the running of the pretest (see below), the placement of the electrode cap, and the breaks between blocks.

4.4. Procedure

Participants were tested individually while seated in a sound-proof, electrically shielded chamber in front of a computer screen. Instructions were given verbally and visually displayed on the screen. In each experimental block, participants were required to make a decision about the lexical stress location by means of a right hand button-press. A trial began with the presentation of a fixation cross (font size: 14 pt.) in the center of the computer screen for 500 ms. The fixation point was followed by a picture after a variable delay of between 1800 and 2300 ms. The period between fixation and stimuli presentation was varied in order to avoid that participants would build up a systematic expectancy in the form of a contingent negative variation (Walter et al., 1964). Participants were requested to respond to the picture (if necessary) as fast as possible. Press-button reaction times were registered automatically. The picture disappeared after a response was given or otherwise automatically after 2000 ms. The next trial started after an inter-trial interval of 1000 ms. Participants were instructed to rest their arms on the elbow rest of the armchair and to put their right index finger on the right button of the button-box in front of them. They were instructed not to speak, blink, or move their eyes while a picture was on the screen.

4.5. Apparatus and recordings

Button-press responses were measured from picture onset with a time-out limit (the moment in time after which responses were registered as missing) of 2000 ms. Time-outs

(outliers) and errors (wrong responses) were excluded from further analyses. The EEG was recorded from 29 scalp sites (extended version of the 10/20 system) using tin electrodes mounted in an electrode cap with reference electrodes placed at the mastoids. ERP signals were collected using the left mastoid electrode as a reference and re-referenced off-line to the mean of the activity at the two mastoid electrodes. The EEG signal was digitized at 250 Hz. To monitor vertical eye movements and blinks, electrodes were placed above the eyebrow and under the lower orbital ridge in a bipolar montage. Bipolar electrodes placed on the right and left external canthus monitored horizontal eye movement. Eye movements were recorded for later off-line rejection of contaminated trials. Electrode impedance was kept below 5 k Ω for the EEG and eye movement recordings. Signals were amplified with a band-pass filter from 1 to 30 Hz and off-line band-pass-filtered from 1 to 8 Hz for graphical display (Picton et al., 1995, 2000). Epochs of 1300 ms [–300 ms to +1000 ms] were obtained, including a 100 ms pre-stimulus baseline. The original number of trials per condition per individual was 160.

Correct response trials were visually inspected, and trials contaminated by eye movement or technical failure within the critical time window were rejected and excluded from averaging by a computer program using individualized rejection criteria. On average, 12.5% of the trials were excluded from further analysis (including ERP artifacts and incorrect responses). The N200 was calculated for all electrode sites. To isolate the N200, difference waves were computed by subtracting the ERP of the go trials from those of the no-go trials. In the difference waveforms, the latency and amplitude of the most negative peak in the 200–700 ms time window were established. Visual inspection of the waveforms showed that the second negative peak fell within this time window. Moreover, peaks were verified visually. As the N200 is generally largest for midline fronto-central electrodes (Thorpe et al., 1996), the analyses were restricted to the frontal midline electrode sites Fz, FCz, and Cz. One-tailed serial t-tests were used to verify the peak onset differences between initial and final stress conditions (see Schmitt et al., 2000 for a similar procedure). Significant divergence from baseline was defined as the point in time at which three consecutive t-tests (step size: 4 ms) showed a significant difference from zero.

4.6. Pretest

A pretest was developed to create the opportunity to test participants beforehand on their ability to assign lexical stress. This pretest was necessary to prevent exclusion of data afterwards because lexical stress assignment is known to be relatively error-prone (Schiller et al., 2006a). Only those participants who successfully completed the pretest underwent the experiment proper. The pretest consisted of three different tasks.

In the first task, participants were asked to pronounce bisyllabic non-words that appeared on the screen as if they had initial or final stress on indication. This way, it was tested if participants could assign lexical stress on demand.

In the second task, participants saw bisyllabic words on the screen and simultaneously heard two successive beeps, one louder than the other. The loudest beep represented the

stressed syllable. In half of the cases, the presented beeps corresponded to the actual metrical stress pattern of the words, in the other half, the beeps did not correspond to the metrical stress pattern of the words. For example, participants saw the Dutch word *MOEder* ('mother') in upper case letters and heard a loud tone followed by a softer one. Thus, in this example, the sequence of beeps corresponded to the stress pattern of the word. Participants were asked to respond verbally as to whether or not the presented sequence of beeps matched the actual stress pattern of the words. With this task, it was tested if participants were able to recognize stressed syllables in printed words.

In the third task, four different bisyllabic nouns were presented per trial. Three of these words had initial stress and one had final stress (or three words had final stress and one had initial stress). Participants were asked to name the deviant word. For instance, in the set *LEpel* ('spoon'), *REIger* ('heron'), *SPIJker* ('nail'), and *taPIJT* ('carpet'), *tapijt* was the deviant word. With this task, it was tested if participants were able to generate stress patterns from written words internally. See Appendix B for a complete overview of the pretest trials.

Ten of the 24 undergraduate students who were approached for participation in this experiment did not pass the pretest because they made more than 25% errors and/or did not respond within the time-limit of 2 s. Consequently, they did not participate in the experiment proper. All other participants took part in the main experiment, and none of them had to be excluded afterwards due to too many errors.

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Appendix A. Target picture names (and English translations) used in the experiment

Targets with initial stress	Targets with final stress
Bezem ('broom')	Balkon ('balcony')
Borstel ('brush')	Banaan ('banana')
Boter ('butter')	Beha ('bra')
Bunker ('bunker')	Biljart ('pool')
Cactus ('cactus')	Bonbon ('candy')
Cirkel ('circle')	Bureau ('desk')

(continued on next page)

Appendix A (continued)

Emmer ('pail')	Citroen ('lemon')
Gieter ('watering can')	Dolfijn ('dolphin')
Gondel ('gondola')	Fabriek ('factory')
Halter ('weight')	Fontein ('fountain')
Hamer ('hammer')	Garnaal ('shrimp')
Herder ('shepherd')	Gebit ('dentures')
Kano ('canoe')	Geweer ('rifle')
Kegel ('bowling pin')	Giraf ('giraffe')
Ketel ('kettle')	Gitaar ('guitar')
Koning ('king')	Kalkoen ('turkey')
Lepel ('spoon')	Kameel ('camel')
Lifter ('hitch hiker')	Kanon ('cannon')
Molen ('wind mill')	Karaf ('pitcher')
Motor ('motor bike')	Kasteel ('castle')
Nagel ('nail')	Kompas ('compass')
Navel ('navel')	Konijn ('rabbit')
Panther ('panther')	Lantaarn ('lantern')
Pinguin ('penguin')	Libel ('dragonfly')
Pleister ('band aid')	Magneet ('magnet')
Ratel ('rattle')	Parfum ('perfume')
Robot ('robot')	Penseel ('brush')
Sleutel ('key')	Pincet ('tweezers')
Spijker ('nail')	Piraat ('pirate')
Stempel ('stamp')	Pistool ('gun')
Tafel ('table')	Pompoen ('pumpkin')
Tijger ('tiger')	Raket ('rocket')
Toren ('tower')	Sandaal ('sandal')
Tractor ('tractor')	Sigaar ('cigar')
Varken ('pig')	Skelet ('skeleton')
Vlieger ('kite')	Soldaat ('soldier')
Vlinder ('butterfly')	Tampon ('tampon')
Vogel ('bird')	Tomaat ('tomato')
Wortel ('carrot')	Trompet ('trumpet')
Zebra ('zebra')	Vampier ('vampire')

eerste toon harder gerepresenteerd (benadrukt), kun je zeggen dat deze toon als het ware een beklemtoonde lettergreep van een woord voorstelt. De bedoeling is dat je bepaalt of de gepresenteerde tonen overeenkomen met de manier waarop je het woord zou uitspreken." (In this second task, you see a bisyllabic word on the screen and simultaneously you will hear two beeps. One beep representing the stressed syllable is presented louder than the other. Your task is to determine whether the presented beeps correspond to the actual stress pattern of the word.)

Words	Beeps	Correct/Incorrect
Moeder ('mother')	Loud-soft	Correct
Kompas ('compass')	Loud-soft	Incorrect
Spiegel ('mirror')	Loud-soft	Correct
Ventiel ('valve')	Soft-loud	Correct
Ezel ('donkey')	Soft-loud	Incorrect
Monnik ('monk')	Soft-loud	Incorrect
Citroen ('lemon')	Soft-loud	Correct
Trommel ('drum')	Soft-loud	Incorrect
Matras ('mattress')	Loud-soft	Incorrect
Wagon ('wagon')	Soft-loud	Correct

B.3. Task 3

Dutch instruction (and English translation in brackets)

Bij deze laatste taak krijg je vier bisyllabische woorden gelijktijdig te zien. Drie van deze woorden hebben de klemtoon op dezelfde lettergreep. Eén van de vier woorden wijkt echter af. De bedoeling is dat je alleen dat woord hardop zegt, wat niet in het rijtje past. Dus bijvoorbeeld bij de volgende woorden:

GREPpel	KANker	PRIESTer	kaBAAL
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hoort het laatste woord kaBAAL niet in het rijtje thuis omdat dat het enige woord is waarbij de klemtoon op de tweede lettergreep ligt en niet op de eerste. In dit geval moet het woord kaBAAL dus hardop genoemd worden.

(In this last task, four bisyllabic words are presented together. Three of them have stress on the same syllable. One of the words is deviant however. Your task will be to name out loud this deviant word. For example with the words:

KITchen	GRAvel	CHICken	ciGAR
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The last word ciGAR is the only word with final stress whereas the other three words all have initial stress. In this case, the word ciGAR must thus be named out loud).

The targets (odd-man-out in italics)	
Lepel ('spoon')	Hamster ('hamster')
Reiger ('heron')	<i>Houweel</i> ('pickaxe')
Spijker ('nail')	Gieter ('watering-can')
<i>Tapijt</i> ('carpet')	Potlood ('pencil')
Tomaat ('tomato')	Fabriek ('factory')
Eekhoorn ('squirrel')	Bureau ('desk')

Appendix B. Pretest used to test participants' skills on metrical stress**B.1. Task 1**

Dutch instruction (and English translation in brackets).

"Bij deze eerste taak krijg je non-woorden aangeboden. Dit zijn niet bestaande, maar fictieve woorden. Het is de bedoeling dat je deze fictieve woorden hardop uitsprekt op zo'n manier, dat je de klemtoon ofwel op de eerste lettergreep legt, ofwel op de tweede lettergreep." (In this first task non-words are presented. These are not real words, but pseudo-words. Your task is to pronounce these non-words as if they have initial or final stress.)

Targets			
<i>Krabies</i>	(eerste, 'initial')	<i>Hompaat</i>	(tweede, 'final')
<i>griffop</i>	(eerste, 'initial')	<i>Stoebo</i>	(eerste, 'initial')
<i>Steloep</i>	(tweede, 'final')	<i>Schremier</i>	(tweede, 'final')
<i>Terkest</i>	(tweede, 'final')	<i>Lanko</i>	(tweede, 'final')
<i>Kanduul</i>	(eerste, 'initial')	<i>Wimpon</i>	(eerste, 'initial')

B.2. Task 2

Dutch instruction (and English translation in brackets).

"Bij deze tweede taak zie je een woord (2 lettergrepen). Gelijktijdig hoor je twee opeenvolgende tonen, waarbij één toon harder gepresenteerd wordt dan de ander. Wordt de

Haven ('harbor')	Pion ('paw')
Joker ('joker')	Pleister ('band aid')
Penseel ('brush')	Ober ('waiter')
Tractor ('tractor')	Kubus ('cube')
Trompet ('trumpet')	Servet ('napkin')
Dolfijn ('dolphin')	Bezem ('broom')
Monnik ('monk')	Lantaarn ('lantern')
Pistool ('pistol')	Harpoen ('harpoon')
Konijn ('rabbit')	Kano ('canoe')
Raket ('rocket')	Rivier ('river')

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