Lexical Inhibition Effects in Time-compressed Speech

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Abstract

A recent study claimed that inhibitory processes in spoken language processing are relatively slow and may be strongly reduced in listening conditions that require extra processing resources. Time compression of a sentence context did not reduce facilitation of a congruent word target, but inhibition of word targets that were incongruent with the preceding sentence context was strongly reduced. The central question in this paper is whether lexical competition/inhibition effects due to word-initial overlap between primes and targets will be similarly affected by moderate time compression. The alternative option is that inhibition is not affected by time compression because lexical inhibition processes are qualitatively different from sentence-priming expectancy-based processes. The results of a prime-target experiment showed evidence for the latter option. Inhibition due to lateral competition seems to be a fast process that is not affected by increased processing load.

1. Introduction

During auditory word recognition, lexical word candidates compete and influence each other’s activation levels. Evidence for lateral suppression between competing word candidates comes from interference or inhibition effects found with high-similarity word-initial form-overlap between a prime and a following target [1,2]. When the prime is being processed, several word candidates compete. In the TRACE and Shortlist models of auditory word recognition, there are direct inhibitory connections between words. An increase in the level of activation of one candidate then automatically leads to a decrease in the activation level of others. McClelland & Elman [3] claim that this ‘winner-takes-all’ principle makes the recognition process more efficient. Once one of the candidates has been isolated and recognised, the other candidates are decreased in activation. When one of these once-activated candidates is subsequently presented as the next item, this item is inhibited, relative to unrelated (control) targets.

However, a recent study showed evidence that time compression may eliminate inhibitory effects found at a normal speech rate, without affecting the size of facilitatory effects. Aydelott & Bates [4] examined the effects of semantic facilitation of an auditory word target (by a biasing or congruent sentence context) and inhibition (by an incongruent context) in the presence of low-pass filtering and time compression of this preceding context. There was a 50 ms interstimulus interval between the onset of the word target and the offset of the preceding sentence context. Importantly, the two opposite priming effects (facilitation and inhibition) were differentially affected by the two types of acoustic distortion. Low-pass filtering made the preceding sentence context less intelligible and therefore reduced facilitation, and consequently inhibition as well. Time compression, on the other hand, primarily affects central language processing. As long as time compression is relatively moderate (not exceeding an acceleration factor of 2), intelligibility is unaffected, but speech processing in these distortion conditions requires extra processing resources. Time compression of the preceding sentence context was found to significantly reduce inhibition without affecting facilitation. This confirmed earlier results that facilitation occurs rapidly, whereas inhibition is a slower process that can be affected by attentional demand: the presentation of competing speech in the other ear significantly reduced the inhibitory effect of context on incongruent targets, without affecting facilitation of congruent targets [5].

Thus, the results of [4] show that inhibition and facilitation effects at sentence level have different time courses because the inhibition effects occur relatively late. Listeners presented with time-compressed sentences (compression to 50% of the original duration) have not had enough time or processing resources to inhibit incongruent targets. The central question in the present study is whether lexical-level inhibition effects will be eliminated by time compression, as was found for sentence-level inhibition in [4]. In order to get more insight into the effects of lexical activation and suppression and their time courses, it is important to know whether time compression of isolated words also reduces lexical inhibition effects at short prime-target intervals. If all inhibitory processes are particularly vulnerable to factors such as processing time or load, lexical inhibition effects, due to inter-word suppression, may also be strongly reduced if the prime word is time-compressed. On the other hand, inhibitory sentence priming effects may be slower than lexical-level suppression effects. Sentence priming may more closely reflect semantic integration processes and the generation of expectancies. These take time to build up during a sentence.

Generation of expectancies concerning the identity of the target also occurs in prime-target studies with relatively long interstimulus intervals. Low-similarity facilitation (prime and target sharing one or two initial phonemes) has been claimed to be mainly strategic: the facilitatory phonological priming effect actually entails a ‘cost’ for unrelated priming trials. In other words, the low-similarity condition does not show facilitation, but the unrelated condition shows inhibition. This inhibition should be attributed to the use of a bias: the target does not comply with the expectancies that the subject has generated [6,7]. When the experiment set-up minimises strategic response behaviour (by minimising the interstimulus interval and by reducing the number of phonologically related pairs), the facilitatory low-similarity effect disappears [8]. However, lexical inhibition effects have been found with short interstimulus intervals: inhibition effects have been
obtained with only 50 ms ISI in between offset of the prime and target onset [9]. This indicates that inhibition effects due to lexical competition are fast and are therefore qualitatively different from inhibitory expectancy-induced sentence priming effects which need time to accrue.

Thus, the assumption is that activation levels of competing candidates should be depressed immediately once one candidate receives a critical amount of bottom-up support. If this inhibitory effect is strong enough, it should immediately overrule any persisting sublexical activation. Given that lexical overlap inhibition effects have been found with short interstimulus intervals, and that moderate time compression does not interfere with intelligibility, the expectation is that a lexical inhibition effect will also be found when the overlap primes have been time-compressed.

A prime-target experiment was set up to test whether compression of isolated lexical primes would reduce or eliminate the inhibitory lexical priming effect without affecting facilitation. In other words, the question is whether lexical inhibition, like sentence priming of incongruent word targets, disappears in conditions with reduced processing time. If no inhibition is found after the presentation of time-compressed overlap primes, facilitation could arise due to two facilitatory effects: the first being persisting sublexical activation (phonemes or larger sublexical units are processed again), and the second being persisting lexical activation if processing resources have not been sufficient to deactivate the remaining word candidates. This potential facilitatory overlap effect can be compared with the size of a facilitatory repetition priming effect. The primary research question is whether time compression of lexical primes affects the target inhibition effect in a prime-target word-initial overlap condition. A secondary question is whether time compression of lexical primes affects the target facilitation effect when prime and target are the same word.

2. Method

A lexical decision experiment was set up with auditory pairwise presentation of primes and targets (all in Dutch).

2.1. Materials

The 30 prime-target pairs were polysyllabic because it is easier to obtain significant inhibition effects with greater amounts of initial overlap. The magnitude of the inhibitory priming effect is determined by the size of the competitor set: the longer a competitor competes with the target word, the fiercer the competition [9].

For each target, there were three types of primes. The first prime condition was an unrelated baseline condition: prime and target did not share phonemes and were not semantically related (e.g., routine – pyjama ‘routine – pyjamas’). The second prime condition was the initial-overlap condition in which primes and targets shared a number of initial phonemes (e.g., piano – pyjama ‘piano – pyjamas’). Mean number of overlapping initial phonemes in the overlap condition was 3.5 (mean number of phonemes in targets 5.7). The mean size of the cohort, evaluated before the isolation point, was 2.3. The third prime condition was the identity condition in which prime and target were the same word (e.g., pyjama – pyjama). Prime Type thus formed one factor in the experimental design. The second factor in the design was rate of presentation of the prime. Primes were presented either at normal rate or at a faster rate due to time compression (but note that targets were always presented at normal rate). The same amount of time compression was chosen as in [4]: prime words were compressed to 50% of their original duration. Earlier research on intelligibility of time-compressed polysyllabic words embedded in carrier phrases suggests that intelligibility is compromised only at higher rates of compression [10].

Apart from these 30 prime-target test pairs, there were 102 filler pairs. Filler pairs consisted of 30 polysyllabic word-nonword pairs, 36 monosyllabic word-word pairs, and 36 monosyllabic word-nonword pairs, so that the subjects would have to give a NO response equally often as a YES response during the lexical decision experiment. Furthermore, the relatively high number of fillers was mixed with the test material to lower the relatedness proportion (relatedness meaning phoneme overlap between prime and target). Half of the primes (of the test and filler material) were presented in the time-compressed condition, and half were presented at normal rate. Additionally, six practice item pairs were recorded to familiarise the subjects with the task of lexical decision on the second member of a word pair.

The materials were recorded by a male native speaker of standard Dutch with a clear speaking style. He read the words in isolation and at a normal speaking rate. The materials were recorded on digital audiotape with a Sennheiser microphone. They were fed as digital input into the computer and downsampled to 32 kHz. Time-scale modification of the primes was applied with the PSOLA technique, as implemented in the speech-editing program PRAAT. All words were stored as separate sound files.

2.2. Design and procedure

Because each target word was to be presented in six conditions (2 Prime Presentation Rates X 3 Prime Types), and to avoid multiple presentations of a target to the same subject, the 30 targets were distributed over six lists according to a Latin-square design. These six lists were presented to six different groups of listeners.

Subjects were seated in a sound-insulated booth, wearing closed earphones. An experimental software programme was used to present the subjects with the materials. This program randomised the order of the item pairs and kept track of the subject’s lexical decision response times. Primes and targets were presented auditorily with a short intervening interstimulus (50 ms) interval to avoid strategic expectancy-based processing. Subjects were asked to give a lexical decision response to the second member of the pair by pressing either of two buttons on a response box. Subjects were instructed to respond with their dominant hand for a YES response, and with their non-preferred hand for a NO response. The experiment lasted about 11 minutes.

2.3. Subjects

Sixty subjects participated in the experiment: 10 listeners were assigned to each of 6 experimental lists. They were between 18 and 30 years of age and received €5 for their participation. They were all native speakers of Dutch, and they reported no hearing problems.
3. Results

Lexical decision times were measured from target onset. Only correct YES responses to the targets were analysed. Table 1 shows the mean RTs in the three prime conditions, broken down by Prime presentation rate. Additionally, accuracy rates are given (in parentheses).

Table 1: Lexical decision results: Mean response times (in ms) and accuracy rates (in %)

<table>
<thead>
<tr>
<th>Prime Type</th>
<th>Target following normal-rate prime</th>
<th>Target following compressed prime</th>
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<tbody>
<tr>
<td>Unrelated</td>
<td>904 (98%)</td>
<td>888 (97%)</td>
</tr>
<tr>
<td>Overlap</td>
<td>953 (99%)</td>
<td>939 (97%)</td>
</tr>
<tr>
<td>Identical</td>
<td>821 (98%)</td>
<td>846 (98%)</td>
</tr>
</tbody>
</table>

Figure 1 displays the size of the priming effects (relative to the baseline condition) for the two prime presentation rates.

Figure 1: Priming effects in identity condition (RT identical condition – RT unrelated condition) and overlap condition (RT overlap condition – RT unrelated condition), at two prime presentation rates.

Response times were transformed into inverse response times (1/RT) before statistical analysis. This was done to make the data distribution less skewed. The transformed data were analysed in Repeated Measures ANOVAs with either subjects or items as repeated measures to test the effects of Presentation Rate and Prime Type. In the subject analysis, subjects were nested under Experimental List. Missing values due to incorrect decisions were imputed by each subject’s mean in that condition in the subject analysis, and by each item’s mean in that condition in the item analysis. The analyses showed that there was no overall main effect of Presentation Rate ($F_1(1,54)<1$, n.s.; $F_2(1,29)<1$, n.s.); responses to targets were not affected by the presentation rate of the preceding prime. The effect of Prime Type was highly significant ($F_1(2,53)=89.4$, $p<0.001$; $F_2(2,28)=62.5$, $p<0.001$). A post-hoc analysis showed that all three prime conditions differed significantly from each other (collapsed over the two rates). The Rate by Prime Type interaction was significant in the subject analysis only ($F_1(2,54)=3.6$, $p=0.036$; $F_2(2,28)=2.3$, $p=0.1$). There was no main effect of Experimental List ($F_2(5,54)<1$, n.s.).

In order to further investigate the interaction between Rate and Prime Type, two subset analyses were run, each time leaving out one prime type condition (but note the increased risk of a Type I error in such subset analyses). If the identical prime condition is left out, a subset analysis can show whether the inhibition effect due to prime-target overlap is affected by presentation rate. The interaction between Rate and Prime Type was not significant ($F_1(1,54)<1$, n.s.; $F_2(1,29)<1$, n.s.), however. Thus, unlike the results of [4], the inhibition effect was not reduced in the time-compressed condition. As in the normal-rate condition (35 ms effect), a significant inhibition effect is found in the time-compressed condition (51 ms effect).

Figure 1 shows that the identity priming effect is smaller in the time-compressed condition (42 ms) than in the normal-rate condition (83 ms). A second subset analysis was run to test whether time compression of lexical primes affects the size of the identity effect (this time leaving out the overlap condition). The interaction between Rate and Prime Type was significant ($F_1(1,54)=7.1$, $p=0.01$; $F_2(1,29)=4.4$, $p=0.044$): the effect of identity priming is somewhat larger in the normal-rate condition than in the time-compressed condition. Thus, the Rate by Prime Type interaction that approached significance in the overall analysis should be attributed to the identity priming effect, rather than the inhibition effect, being modulated by rate. The decreased identity priming experiment in the time-compressed condition may be due to a smaller sublexical component: even though the same word is repeated, the acoustic form is different.

In sum, the results of the present experiment show that time compression of lexical primes does not affect the target inhibition effect due to lateral suppression.

4. Discussion and Conclusion

The central question in the present study was whether lexical inhibition effects would be eliminated by time compression. Moderate time compression does not reduce the speech signal’s intelligibility, but imposes an additional processing demand. Even though increased processing load was shown to interfere with sentence-level inhibition [4], the present results show that it does not modulate lexical-level inhibition.

The crucial point raised in sentence-priming studies such as [4, 5] is that facilitation and inhibition are qualitatively different: the first being a fast and automatic process of spreading of activation, whereas the second seems to be a later and more demanding process. Now, if inhibition due to lexical competition appears to be a fast process as well, does this mean that activation and inhibition, at the lexical level at least, are not so different after all? Evidence that these two processes are, nevertheless, qualitatively different comes from research with clinical populations and from studies that have claimed that anterior regions of the left hemisphere might be involved in initiation of (broad) lexical activation and posterior regions with inhibition or “focusing in” [11].

Studies with aphasic patients have shown that activation and suppression of word candidates can be impaired separately. In [12] lexical access was investigated by way of a mediated semantic priming study with three groups of participants: one group of fluent aphasic patients, one group of nonfluent aphasic patients, and a non-brain-damaged control group. Items such as cat, gat and wat were used as primes for a target item dog. The non-brain-damaged control group showed a decreasing degree of semantic facilitation for the target dog as a function of phonological distortion. Participants with fluent aphasia, however, showed priming in all phonological distortion conditions, relative to the unrelated baseline. The nonfluent group, on the other hand,
showed priming only in the undistorted related condition. Thus, whereas nonfluent or Broca’s aphasic participants seem to have reduced lexical activation levels, compared to an age-matched control group, fluent or Wernicke’s aphasic participants have increased lexical activation.

Similar results were found in another mediated priming study [13] in which priming effects for targets such as penny were compared by presenting either dime or t*ime as the prime word. When a control listener group was presented with an acoustically modified item t*ime (voice onset time altered [t], being closer to the voiced phonetic category boundary), a reduced but significant semantic priming effect was found for penny (through partial activation of the competitor dime). However, Broca’s aphasic participants did not show any mediated priming for targets preceded by altered primes. Wernicke’s aphasic participants, on the other hand, showed significant priming effects in the modified condition. Furthermore, the size of the priming effect did not differ from that in the unaltered (dime) condition. Importantly, post-test results confirmed that the modified prime stimuli were perceived as voiceless by all subject groups. So, whereas the Broca’s aphasic patients seem to have difficulty in activation of word candidates, suppression of inappropriate candidates seems to be the main problem for Wernicke’s aphasics. This was also found in an eye-tracking study [14] in which the effect of onset competitors was investigated for Wernicke’s patients. When presented with an auditory stimulus (e.g., camera), Wernicke’s patients fixated longer on onset-overlapping distractors (such as camel) than control adults. This implies that, even in the presence of negative bottom-up information, these patients are impaired in the suppression of once-activated word candidates.

This was confirmed in a study specifically designed to investigate lexical inhibition effects in aphasia [15] (and using the same materials as used in the present study but with list-wise presentation and a number of intervening items between prime and target). The results of [15] showed inhibition in the overlap condition for the control adults and Broca’s aphasic patients, but facilitation was found in the overlap condition for the Wernicke’s aphasic patients. Thus, even after several intervening items, co-activated word candidates showed persisting activation for the Wernicke’s aphasic patients, which is in stark contrast with the fast suppression of co-activated candidates found in the present study with unimpaired listeners. Although there is evidence that aphasic receptive deficits in syntax processing can be elicited in unimpaired subjects under stressful conditions [16], time compression did not elicit aphasic behaviour in the present study. Given that deactivation had not occurred even after several intervening items [15], it seems unlikely that deactivation in Wernicke’s aphasia is just delayed, relative to unimpaired processing.

In sum, even though the processes of lexical activation and inhibition can be impaired separately and reflect different underlying mechanisms, the present results show that both processes are fast in unimpaired auditory lexical processing and are not affected in conditions with increased processing load.

5. References