Semantic Processing of Spoken Words under Cognitive Load in Older Listeners

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ABSTRACT

Processing of semantic information in language comprehension has been suggested to be modulated by attentional resources. Consequently, cognitive load would be expected to reduce semantic priming, but studies have yielded inconsistent results. This study investigated whether cognitive load affects semantic activation in speech processing in older adults, and whether this is modulated by individual differences in cognitive and hearing abilities. Older adults participated in an auditory continuous lexical decision task in a low-load and high-load condition. The group analysis showed only a marginally significant reduction of semantic priming in the high-load condition compared to the low-load condition. The individual differences analysis showed that semantic priming was significantly reduced under increased load in participants with poorer attention-switching control. Hence, a resource-demanding secondary task may affect the integration of spoken words into a coherent semantic representation for listeners with poorer attentional skills.

Keywords: speech comprehension, attention, cognitive load, individual differences

1. INTRODUCTION

In speech comprehension, listeners decode acoustic information in order to access semantic information for the interpretation of the message. Consequently, processing of (target) words that are preceded by a semantically related (prime) word is facilitated, or primed [4]. As such, semantic priming is evidence that the prime has activated the semantic system.

Processing of semantic information is suggested to be modulated by attention. There is some evidence that the size of the semantic priming effect may depend on whether listeners' attention is drawn to (or away from) the prime words [9]. This suggests that prime words are only processed deeply enough to elicit significant semantic priming if participants' attention is concentrated on the prime.

Given the evidence for the importance of attention on semantic priming, cognitive load (CL) would be expected to reduce semantic priming, particularly for those with poorer attentional abilities. However, results of previous studies, obtained with student participants, have been inconsistent in whether or not CL decreased semantic priming (cf. [7]), perhaps due to methodological differences. Individual differences in attentional abilities may particularly be found in a population of older adults, as attentional abilities generally decline with age [1, 8], but not affecting all individuals to the same extent.

Apart from attentional factors, speech signal clarity might influence semantic activation. Speech signal clarity has been shown to affect lexical processing and hence semantic priming [2, 15]. Processing of degraded input constitutes a perceptual load, which may occupy attentional resources that would otherwise be available for further processing of what has been heard [11, 12]. Particularly, the dampening of spectral information due to (age-related) hearing loss makes speech processing more effortful and may reduce semantic facilitation [2]. Prime words in the acoustically degraded condition were recognized in [2], but processing lagged behind, relative to the clear-speech condition, such that activation had not spread fully to semantic associates.

Given that older adults are expected to present a more heterogeneous sample with respect to hearing acuity and attentional abilities, both related to semantic activation, this study focuses on speech processing by older adults. We first addressed the question whether the presence of CL induced by a dual-task paradigm loading verbal working memory generally decreases semantic activation. Importantly, our design ensured that working memory was continuously taxed and both prime and target were processed. Secondly, we investigated whether individual auditory and cognitive abilities modify the priming effect and the load effect on semantic priming. In addition to attentional and working memory abilities, we also investigated the effect of processing speed as the latter may also play a role in lexical processing [6] and spreading of activation. We expected to find an effect of CL on semantic priming, particularly for participants with poorer auditory and/or poorer cognitive skills.

2. METHODS

2.1. Participants

Forty-six native Dutch older adults were recruited from the participant pool of the Max Planck Institute for Psycholinguistics in Nijmegen, The Netherlands. None of them wore hearing aids in daily life. Pure-tone (air conduction) thresholds were measured for both ears; the pure-tone average (PTA) of the better ear across 1 kHz, 2 kHz, and 4 kHz was used as an index of hearing acuity (M = 22.17 dB HL; SD = 10.94). Working memory capacity was defined as the percentage of correct sequences in a digit span task with backward recall [16] with visually displayed digit sequences consisting of two to seven digits (Mean accuracy = 47.12%; SD = 22.40). Processing speed was assessed by a pencil-and-paper digit/symbol coding test [16]. The higher the number of recoded symbols within 90 seconds, the faster the participant's processing (Mean number of recoded symbols = 46.46; SD = 9.59). The Trail-Making Test [13] was administered as a measure of attention control, and the quotient of time in seconds the participant needed to complete part B (alternatingly connecting digits and letters) was divided by the time the participant needed to complete part A (just connecting digits in ascending order). A higher quotient (TrailB/TrailA) indicated poorer attention-switching control (M = 1.90; SD = 0.42). Nine participants were excluded on the basis of their outlier performance on the Trail-Making Test. The final sample consisted of 37 older adults aged between 60 and 84 years (21 females; mean age: 67.1 years, SD = 6.1). Participants were paid for their participation.

2.2. Material

2.2.1. Primary task

The primary task of the experiment consisted of an auditory lexical decision task. For this task, 72 semantically related word pairs consisting of Dutch nouns were selected. Each pair consisted of a prime and a target word of one to three syllables. Semantic-relatedness scores were retrieved from the Dutch Word Association Database (henceforth: semantic relatedness) [5]. We used log2-transformed scores from the "synonym search mode", which considers the distributional overlap of the association responses of two cue words such that both direct associates and near neighbors are included. Association strength between the members of our set of 72 word pairs varied on a continuum from mildly related (e.g., *snor-wenkbrauw* 'moustache-eyebrow', log2 value of .26) to highly related (e.g., *appel-peer* 'apple-pear', log2 value of .64). As reaction times (RTs) are influenced by word frequency, log-transformed word frequencies of the target words were retrieved [3] and were entered as a control variable in our statistical analyses.

As priming should be implicit, the words of a pair were presented consecutively for continuous lexical decision and were mixed with fillers to hide their associative relationship. More than twice as many one-to three-syllable filler items (96 Dutch words, 240 phonotactically legal pseudo words) were included. A total of 480 stimuli were split into 24 blocks, consisting of 20 trials each. These blocks were split over the two load conditions. The order of the load conditions and blocks was balanced over 2 different lists.

2.2.2. Secondary task

The secondary task consisted of either variant of a load-inducing digit recall task: a low-load and a high-load condition. The complexity of the load manipulation was varied rather than comparing a load to a no-load condition to ensure that the same strategies were used in both conditions. In the low-load condition, one one-digit number was presented auditorily for recall during lexical decision trials; in the high-load condition, two two-digit numbers were presented auditorily.

In order to investigate whether and how task performance in the secondary (digit recall) task affected performance in the primary task, the difference between recall performance in the high-load and low-load condition (Recall Difference) was calculated for each subject. If participants were less affected by the increased cognitive load, the difference scores should be closer to zero.

2.2.3. Recording

Stimuli for both the primary and secondary task were read out at a normal rate by a male native speaker of Dutch and recorded with a Sennheiser K6 microphone at a sampling rate of 16 bit/44.1 kHz in a sound-attenuated booth.

2.2. Procedure

Participants were tested in a sound-attenuated booth and stimuli were controlled by means of E-Prime 2.0 and presented via closed headphones (Sennheiser HD 215). The volume was kept at a constant level (approximately 70 dB SPL). Half of the participants were first presented with 12 blocks in the low-load condition followed by 12 blocks in the high-load condition; for the other half the order of load conditions was reversed. Participants were allowed a short break in between the two load conditions.

There were three consecutive phases for each block: digit presentation, auditory lexical decision and digit recall. First, after a blank screen (250 ms), participants heard either a one-digit number (low-load condition) or two two-digit numbers which were separated by a 50 ms pause (high-load condition). Following another blank screen (100 ms), the auditory lexical decision task started. On each trial, auditory presentation of each word was preceded by a fixation cross (500 ms) followed by a blank screen (100 ms). Participants had to decide whether the stimulus was a real Dutch word or not. They were instructed to make their choice as quickly and as accurately as possible using the keys 'M' (labeled 'yes') or 'Z' (labeled 'no') on the keyboard. Responses and RTs were measured from stimulus onset until key press. After the key press, the next stimulus was presented after a 1 second inter stimulus interval (ISI). If a participant did not respond within 4500 ms, a new trial started (cf. [15]) for similar timing parameters). Third, the participants were asked to recall the digits by entering them via the keyboard. After doing so, they proceeded to the next block.

Tests to assess hearing and cognitive skills were administered directly after the main task. The whole experiment session took approximately 60 minutes.

3. RESULTS

Only responses to correctly identified target words preceded by correctly identified primes were analyzed. Mean accuracy in the auditory lexical decision task was at ceiling in both the low-load (M = 95.5%, SD = 3.8) and high-load conditions (M = 95.1%, SD = 5.6), and did not differ significantly between the two load conditions; $t(36) = .36$, $p = .72$. In the digit recall task, mean accuracy in the low-load condition was high (M = 93.7%, SD = 12.9) and still reasonably high in the high-load condition (M = 73.2%, SD = 18.9). This difference in mean recall accuracy was significant; $t(36) = 6.12$, $p = .001$.

3.1. Lexical decision reaction time analysis

First, we investigated whether CL modifies semantic activation. Using linear mixed-effects regression modeling, log-transformed RTs (measured from auditory word onset) were entered as the dependent variable. Load condition (CL) and semantic relatedness (SemRel) were entered as fixed effects. Word frequency (per million words), word duration in ms (Duration $_{\text{target word}}$), RT on the previous trial, block number, and trial number (within a block) served as control variables. Crucially, we tested for an interaction between load condition and semantic relatedness. We also allowed for the possibility that the load effect might decrease over trials by including an interaction between load and trial. Continuous variables (such as SemRel) were centralized and the low-load condition was mapped on the intercept. As the effect of CL varied across participants, a random slope for load condition per participant was added to the best-fitting model.

The general model (Table 1) showed a significant effect for CL. Moreover, there was a significant effect for semantic relatedness: target responses were facilitated when they were preceded by more strongly associated primes. These two findings show that RTs were sensitive to our load and semantic relatedness manipulations. Importantly, the interaction between CL and SemRel just missed significance: target facilitation only tended to be decreased in the high-load condition.

Table 1: General model of the linear mixed-effects regression RT analysis

Fixed effects	β	*t*
Intercept	6.99	310.30 ***
CL	0.04	3.29 **
SemRel	-0.25	-2.40 *
Block number	-0.01	-3.43 ***
Trial number	-0.00	-2.79 **
Previous RT	0.00	7.87 ***
Duration $_{\text{target word}}$	0.00	8.26 ***
CL × SemRel	0.14	1.68 $^{+}$

Notes: *** $p < .001$, ** $p < .01$, * $p < .05$, $^{+} < .1$

3.2 Individual differences

The second analysis investigated whether individual listener abilities modify lexical activation and the CL effect on lexical activation (Table 2). The set-up of this analysis was similar to that of the first analysis, but now individual differences measures were added as fixed effects (all mean-centered) to our initial model: hearing sensitivity (PTA), cognitive processing speed (digit/symbol coding), attention-switching control (Trail-making task, TMT), working memory capacity (digit span) and the individual load effect on digit recall (Recall Difference). We tested whether the individual measures interacted with the load effect on performance and whether they modified a possible interaction between load and semantic relatedness.

The best-fitting individual differences model replicated the effects of load and semantic relatedness and the marginally significant interaction between CL and semantic relatedness (CL × SemRel). The interaction between CL and Recall Difference was significant, i.e., older adults' lexical decision performance was more impacted by the increased load if they were also more affected by increased load in their digit recall. Second, in the low-load condition, those with poorer attention-switching control actually showed stronger semantic priming (SemRel × TMT) than those with better attention-switching skills. Importantly, however, under increased CL, participants with poorer attention-switching control showed significantly reduced semantic priming relative to the low-load condition (CL × SemRel × TMT).

Table 2: Individual differences model of the linear mixed-effects regression RT analysis

Fixed effects	β	*t*
Intercept	6.99	308.15 ***
CL	0.04	3.61 **
SemRel	-0.26	-2.42 *
Block number	-0.01	-3.47 ***
Trial number	-0.00	-2.85 **
Previous RT	0.00	7.85 ***
Duration $_{\text{target word}}$	0.00	8.26 ***
TMT	-0.01	-0.13
Recall Difference	-0.00	-1.16
CL × SemRel	0.14	1.67 $^{+}$
CL × TMT	-0.01	-0.46
SemRel × TMT	-0.28	-2.03 *
CL × Recall Difference	0.00	2.99 **
CL × SemRel × TMT	0.60	3.05 **

Notes: *** $p < .001$, ** $p < .01$, * $p < .05$, $^{+} < .1$

4. DISCUSSION

The question addressed in this study is whether the presence of a cognitive load (CL) modulates semantic priming, particularly for participants with poorer hearing or cognitive abilities. Our paradigm continuously taxed participants' working memory during the primary task, which is in contrast to earlier dual-tasking studies [10, 14] where two tasks had to be performed in succession. Furthermore, unlike [7], both our primary and secondary tasks taxed verbal working memory and were presented in the same auditory modality.

The results of our general analysis showed that significant semantic priming was found, as well as a clear effect of load on response times. Importantly, the hypothesized reduction of the priming effect in the high-load condition, compared to the low-load condition, did not reach significance. These results are similar to those of Mattys and Wiget [7], but differ from those of Otsuka and Kawaguchi [10], who found a significant reduction of the priming effect under divided attention, which they attributed to the cognitive load induced by their second task. This effect of cognitive load on semantic priming may, however, also be due to their experimental design. A prerequisite for semantic priming to occur is that prime words are actually processed (cf. [9]). However, participants in [10] only had to remember the pitch of the probe tone that was presented concurrently with the visual prime. Hence, participants may have opted to ignore the lexical content of the prime word, thereby cancelling the priming effect. In our set-up, ignoring the lexical content of the word was not an option, since participants had to decide on the lexical status of both the prime and the target (i.e., a continuous lexical decision task) which ensured processing of the prime. Nevertheless, no strong effect of cognitive load on semantic priming was found.

In a second analysis, we investigated effects of listener abilities, such as hearing sensitivity. Previous research has shown that perceptual load caused by degraded input, such as reduced [15] or low-pass filtered speech [2], may hamper semantic activation in younger adults. However, we did not find an effect of hearing sensitivity on semantic activation, nor did it interact with CL. This may be related to the fact that our participants still had reasonably good hearing so that the perceptual load was still manageable without employing additional resources.

Working memory and processing speed were not found to play a role for lexical activation while individuals with poorer attention-switching control showed relatively stronger semantic facilitation in the low-load condition. We can only speculate that participants with poorer attention-switching control may have spent extra effort on the low-load condition. However, in the high-load condition, these participants were overtaxed, such that they were less able to process the prime deeply and quickly enough. These results confirm the *attention modulation* hypothesis [14], i.e., semantic priming depends on attention allocated to primes.

In realistic listening conditions, two tasks that compete for attentional resources are frequently encountered. This study suggests that such a secondary task or distraction may affect the integration of words into a coherent semantic representation, but only for participants with poorer attentional skills.

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